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The site selection of wind energy power plant using GIS-multi-criteria evaluation from economic perspectives

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ABSTRACT

The use of wind turbines can help progress towards economic and technological development, lower rates of fossil fuel consumption, decreased greenhouse emissions, and reduced side-effects of climate change. A successful mechanism for developing renewable energy worldwide is the guaranteed purchase of electricity generated from renewable energy sources. Accordingly, this study aims to integrate Geographic Information System-based Multi-criteria Evaluation (GIS-MCE) models with economic frameworks to estimate the optimal purchasing price for electricity produced by wind turbines. A total of 13 criteria maps were used and integrated using Ordered Weighted Averaging (OWA) as a type of MCE model. The criteria were initially normalized based on the minimum, and maximum values and weights were assigned to each criterion, using the Best-Worst method. The OWA model identified optimal site locations at various decision risk levels. The economic efficiency of wind turbines and the potential purchasing price of electricity from turbines were also assessed in terms of Net Present Value (NPV). The results show that Ardabil and Southern Khorasan provinces had the most significant areas in the very-suitable class for wind turbine installation (small/large scale). The purchasing prices for wind-generated electricity ranged from 0.047 to 0.182 US$ for large wind farms and 0.074 to 0.384 US$ for small wind plants. The highest electricity produced from large wind farms was found in Maragheh.

1. Introduction

Renewable energy is a crucial element of sustainable development [1]. More than 80% of the world's energy production is driven by fossil fuels such as coal, oil, and natural gas [2,3]. However, the main oil reserves on earth have been distributed unevenly, which can shortly lead to severe political and economic contentions [4]. Increases in demand for energy and exhaustion of fossil fuels inevitably lead to higher prices. As a result, most countries have developed policies related to renewable energies to reduce costs and become self-sufficient [5]. Another incentive for using renewable energies to supply the energy demand is to be free of the environment's negative burden due to the consumption of fossil fuels [6].

The prospects of using renewable energies are considerably wide [7,8]. Some common renewable energy sources include solar, wind, geothermal, biomass, tidal power, hydrogen fuel, etc. Wind energy is one of the fastest-growing renewable energy sources worldwide [9]. Site selection is the first and most important step to establishing a wind power plant. The main environmental impacts of wind turbines include: visual impression [10], interactions with birds [10,11], noise production [12], electromagnetic interference [13], urban areas [14], land use [15], aviation facilities [16] and other safety issues [17]. Recently, Iran has incorporated a unique regulatory framework on renewable energy installations following precise land use and sustainable development plans (see http://www.satba.gov.ir/). However, besides accounting for the limitations posed by national laws and regulations, selecting and assessing sites for renewable energy farms must also be considered from various technical, economic, social, and environmental perspectives.

Fossil fuels lead most energy consumption in Iran; electricity alone is

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List of nomenclature

GIS	Geographic Information System
MCE	Multi-criteria Evaluation
OWA	Ordered Weighted Averaging
NPV	Net Present Value
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BWM	Best-Worst Method
WLC	Weighted Linear Combination
MW	megawatt
GW	gigawatt
NREL	National Renewable Energy Laboratory
DEM	Digital Elevation Model
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
D.F	Distance From

Table 1
Overview of the important criteria for selecting suitable sites for wind turbine installation.

	Tegou et al. [43]	Bennui et al. [44]	Baban and Parry. [13]	Gorsevski et al. [45]	Rodman and Meente-meyer. [46]	Georgiou et al. [47]	Latinopoulos and Kechagia. [48]	Watson and Hudson. [49]	Current study
Wind speed	A	A	B	A	B	A	A	A	A, B
Road	A	C	A	A	C	A	A	A	A, B
Power transfer lines	A	C	B	A	C	A	C	A	
Slope	A	B	A	C	A	A	A	B	A, B
Urban areas	A	A	A	B	B	B	B	A	A, B
Airport	B	A	C	B	C	B	B	C	C
Tourist attractions	A	A	A	C	C	C	A	A	C
Natural environments	B	B	A	C	B	B	A	A	A, B
Bird habitats	C	C	C	A	C	B	A	B	C
Water bodies	A	A	A	B	C	B	C	C	A, B
Marshlands	B	C	C	B	B	B	B	C	C
Land cover	A	C	B	A	A	B	A	C	C
Jungles and forests	A	C	A	A	A	B	A	C	A, B
Soil type	C	C	C	A	C	C	C	C	C
Elevation	C	A	B	C	C	A	C	C	A, B

A) Selected as a criterion; B) Selected as a constraint; C) Not selected as a criterion.

produced almost exclusively (94%) from fossil fuels, nearly 6% from hydroelectricity, and less than 1% from renewable energy sources [18]. On the other hand, greenhouse gas emissions in the country reached 850 million tons per year, making Iran one of the world's largest producers of greenhouse gasses [19]. These are compelling grounds for incorporating renewable energies in Iran to reduce greenhouse gas emissions significantly, provided such initiatives find their way into national plans and policies.

The guaranteed purchase of electricity generated from renewable energy sources has shown to be an efficient technique for expanding renewable energy globally, as private sector investors may anticipate the quantity of electricity sales and perform financial and economic feasibility analyses. Since the provinces of Iran are situated in diverse geographical, climatic, and topographical conditions (for example, the eastern and northwestern portions of the country have a cold and dry climate, as well as somewhat rugged terrain, while the western and southern regions have warm and humid surroundings and relatively flat terrain), policymakers and decision-makers must provide a flexible model for determining the most appropriate policies for each province.

The main objective of the present study was to provide a price estimation approach for wind energy-generated electricity using Geographic Information System-Multiplecriteria Evaluation (GIS- MCE) and economic models. The general purpose of GIS-MCE is to assist in spatial assessment by facilitating the selection of the most optimal choice among existing options. According to a predefined decision rule, these techniques operate on a combination of spatial data and user preferences [20]. The logic behind integrating GIS and MCE is that these two separate fields of study may act in synergy with one another [21–25]. On the one hand, GIS technology provides a comprehensive tool for storing, manipulating, analyzing, and representing geographical information, while MCE yields a rich array of structural methods and algorithms for decision making, design, evaluation, and prioritization of options [26–29].

2. Literature review

The combination of GIS and MCE has repeatedly been proven an efficient tool for selecting the optimal site for establishing a renewable energy farm [5,9,30–35]. The following is a brief outlook on scholarly sources related to using GIS- MCE models in site selection procedures to establish renewable energy farms. Sarpong and Baffoe [36] investigated the application of a combined GIS- MCE model for locating appropriate sites for wind turbine installation. The study used two data sets (constraints and criteria), and overlaying operations were done in a GIS environment to combine different criteria map layers. Weights were assigned to standards based on the pairwise comparison method. Suitable locations were selected from 5 regions. Finally, constraints and criteria sets were combined to obtain 142 appropriate locations.

Höfer et al. [37] proposed a comprehensive MCE approach, comprised of technical and economic indices and social, political, and environmental factors, for improving site evaluations at wind energy farms in Städteregion Aachen. The proposed framework operated on a combination of GIS and Analytic Hierarchy Process (AHP), which ultimately predicted 1.74% of an available 9.4% region as suitable sites for wind turbine establishment. Another study by Noorollahi et al. [38] employed a combination of GIS and AHP to evaluate wind energy potential in Markazi Province, Iran. For this purpose, a series of spatial criteria, including technical, environmental, economic, and geographical standards, were used. The final results indicated that only 28% of the region could establish large wind farms. Fuzzy-AHP was also

Table 2
Global wind power cumulative capacity (www.thewindpower.net).

Year	Capacity (GW)	Growth (GW)	Growth (percent)
1995	4.800	–	–
1996	6.100	1.300	27.1
1997	7.483	1.383	22.7
1998	9.671	2.188	29.3
1999	13.703	4.033	64.4
2000	18.043	4.341	31.7
2001	24.321	6.278	34.8
2002	31.187	6.866	28.3
2003	39.336	8.150	26.2
2004	47.664	8.329	21.2
2005	59.068	11.404	24.0
2006	74.180	15.112	25.6
2007	93.961	19.782	26.7
2008	121.263	27.302	29.1
2009	157.927	36.665	30.3
2010	194.626	36.699	23.3
2011	237.178	42.553	21.9
2012	283.009	45.832	19.4
2013	318.898	35.889	12.7
2014	371.205	52.308	16.5
2015	435.495	64.290	17.4
2016	487.135	51.641	11.9
2017	539.552	52.418	10.8
2018	589.675	50.123	9.3
2019	652.802	63.127	10.7
2020	741.255	88.453	13.5

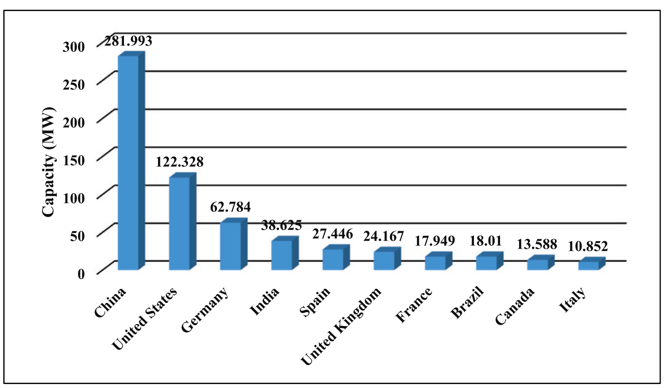

Fig. 1. The top ten countries in wind-turbine installation capacity for 2020 (www.ren21.net).

incorporated with GIS in an investigation by Ayodele et al. [39] for the process of site selection for wind turbines in Nigeria. The criteria, including economic (distance from road) and environmental factors (distance from rivers), were employed in the assessment process. As the findings suggested, the best sites for establishing wind turbines were in Nigeria's northern sectors. The territorial span identified as suitable for wind turbine establishment contributed to 125728.6 km^2 in area, with 2650.1 km^2 being the optimal size for a wind plant. Genç [40] used GIS and MCE tools to select suitable locations for wind farms in Develi city, Turkey. This study used a set of spatial criteria, including technical, environmental, and social. Their results showed two potential regions for establishing wind farms, including near the village of Havadan with a wind energy potential of 7.875 MW and the other near the town of Kalpak with a wind energy potential of 9.225 MW.

Ali et al. [41] integrated the GIS and AHP to evaluate different physiological, environmental, and economic criteria affecting wind and solar energy potential in Southern Thailand. The results were indicative of the high solar and wind power capacity of the southern regions, with 38.749% and 69.509% shares of the area identified as very suitable for wind plants and solar energy plants, respectively. Firozjaei et al. [42] investigated the effect of geographical, topographic, and climatic

Table 3
Wind power production capacity in Iran from 1997 to 2020 (MW) (www.thewindpower.net).

Year	Capacity (MW)	Growth (MW)	Growth (percent)
1997	11	–	–
1998	11	0	–
1999	11	0	–
2000	11	0	–
2001	11	0	–
2002	11	0	–
2003	11	0	–
2004	25	14	+127.3
2005	32	7	+28
2006	47	15	+46.9
2007	66	19	+40.5
2008	82	16	+24.3
2009	91	9	+11
2010	92	1	+1.1
2011	91	−1	−1
2012	91	0	–
2013	100	9	+9.9
2014	118	18	+18
2015	118	0	–
2016	118	0	–
2017	167	49	+41.6
2018	228	61	+36.6
2019	302	74	+32.5
2020	303	1	+0.4

conditions on feed-in tariff optimization for solar photovoltaic power generation in Iran using a combination of GIS and economic models. Also, Shorabeh et al. [5] and Firozjaei et al. [30], in their studies, have used the Ordered Weighted Averaging (OWA) model to prepare a potential solar map based on different risk levels in Iran.

Because of the mentioned investigations, the first step in this study involves the identification of the most significant criteria affecting the establishment of wind power plants. Table 1 lists the essential standards for selecting suitable sites for wind turbine establishment. Some of the mentioned criteria can, to certain degrees, be used in other regions worldwide, e.g., wind speed. In contrast, additional measures are specific to the national rules and regulations and can differ significantly from one part to another (e.g., distance from urban areas).

A quick review of the literature reveals that each study utilized various criteria to find optimal locations. However, establishing the ideal price of electricity provided by these power plants might be just as important as determining the best sites for wind farms. This aspect of the research has not been examined in earlier studies. Accordingly, the present study uses a combination of GIS-MCE and economic models to determine the optimal electricity prices produced from wind plants. Various weighting models have been used in previous studies. However, the Best-Worst Method (BWM) has two main advantages over these methods: First, it uses fewer pairwise comparisons, and second, it has a higher consistency ratio [50–53]. Also, different methods have been used to combine the criteria maps, none of which has considered the concept of risk in the site selection process. This study used the GIS-based OWA model to eliminate this gap. The study differs from previous studies in aspects of (1) combining MCE and NPV (Net Present Value) for estimation of optimal prices; (2) the use of GIS-based analysis as well as BWM and OWA methods for identifying suitable sites of wind turbine installation; (3) estimation of the wind energy potential of regions for small and large scale plans and comparison of optimal prices. Small wind farms are utilized to deliver electricity to the nearby residential area. However, electricity generated by huge wind farms can be diverted to provide power to more remote places.

3. Wind energy: throughout the world and Iran

As stated in the previous sections, fossil fuels are limited in supply and exert hazardous impacts on the environment when combusted and

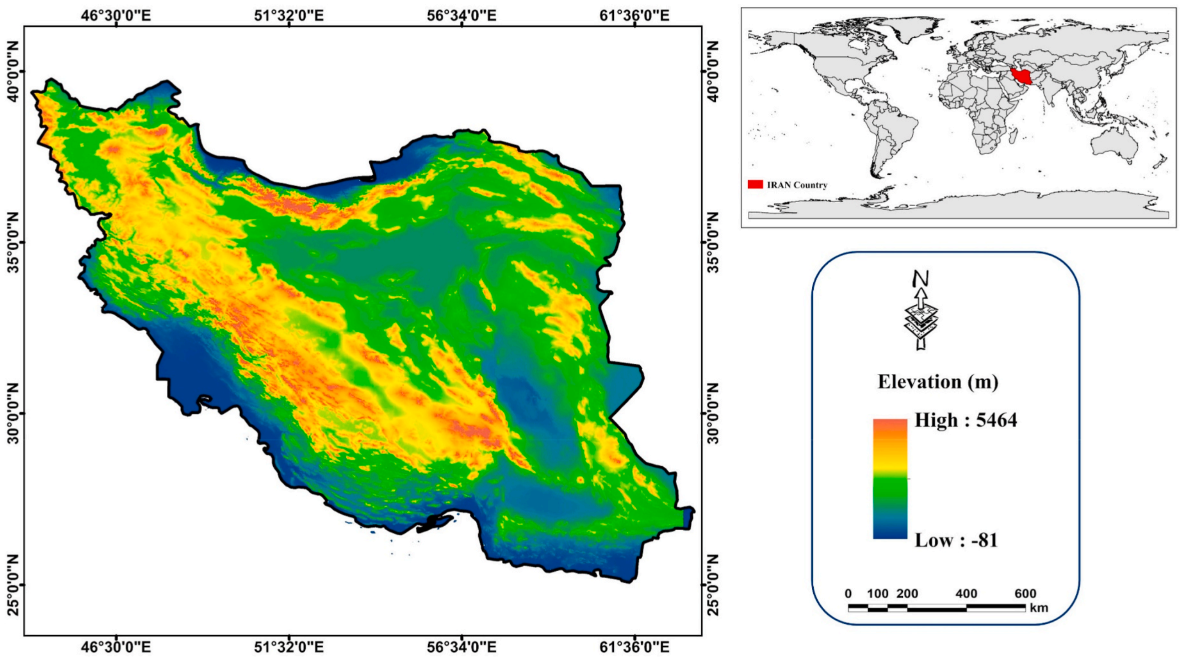

Fig. 2. Geographical location and digital elevation model of the study area.

consumed. This is further aggravated as the global population grows, resulting in higher energy demand. As a result, numerous countries around the globe are seeking alternative sources of renewable energies to replace fossil fuels [54]. Among the available alternatives, wind-power capacity has multiplied during the past few decades (Table 2); i.e., the global capacity for wind-power production has risen by 15343%, from 4.800 GW in 1995 to 741.255 GW in 2020 (see www.thewindpower.net). For the most part, this significant increase has resulted from good governmental policies in countries such as China, Countries of the European Union, and the United States. The top-ranking countries by wind-power production capacity until 2020 consist of China, the United States, Germany, India, and Spain. Fig. 1 shows the top ten countries installing wind power facilities for 2020.

The concentration of windy areas in Iran incited the construction of windmills dating back to 200 BC. Even now, the windy areas remain active, creating the appropriate conditions for the exploitation of wind turbines. Most windy areas in Iran are located in arid and extremely arid regions of the country (East of Iran), which are relatively underdeveloped and subject to high electricity costs due to a lack of access to electrical energy resources. The total electricity load in the regions is highest during the summer when temperatures are very high. Still, winds are also the strongest [32], which is indicative of the essentiality of installing wind turbines. The earliest installations were made in 1994, with the establishment of the Manjil and the Rudbar wind farm with capacities of 500 kW, totaling 1.8 million kilowatts of energy per year [54]. The farms are located 250 km from the country's capital (Tehran), in northern Iran. Iran's wind power production capacity has changed from 11 MW in 1997 to 303 MW in 2020, an approximate 2655% increase (Table 3).

4. Materials and methods

4.1. Study area

Iran covers an area of 1,648,195 km^2 and has a population of over 80 million, making it the 16th largest country in the world and the second-largest country in the Middle East. The country is situated within a temperate zone in the northern hemisphere, at 25–40 ° latitude north of the Equator and 44–63.5 ° longitude east of the Prime Meridian (Greenwich). Overall, the country lacks the cold climates often found at higher latitudes and is only cold in some areas of higher elevation. The country has access to open waters and seas in the south (the Persian Gulf and the Gulf of Oman) and the north (Caspian Sea). From a climate perspective, coastal provinces adjoining the Caspian Sea, such as Gilan, Mazandaran, and Golestan—located between the Alborz Ranges and the Caspian Sea— are highly influenced by humid air flows stemming from the sea, which in turn help vegetation growth and formation of forests, mainly due to the ensuing high rate of moisture and rainfall during the summer. The Persian Gulf and the Gulf of Oman act as primary routes for access to open waters, which facilitate communication with other countries of the world. The overall climate around these regions is warm and highly humid during the summer: Armenia, Azerbaijan, and the Caspian Sea border Iran in the north. At the same time, from the east, the country reaches Afghanistan and Pakistan, and from the west to Turkey and Iraq, and finally bordered by the Persian Gulf and the Gulf of Oman in the south. Fig. 2 shows the map of the study area's geographical location and digital elevation model.

4.2. Data

The data used in this study involves raster and vector map layers. The raster layers included elevation, slope, vegetation, and temperature. Elevation and slope maps were derived from the DEM (Digital Elevation Model) of the Aster Satellite with a spatial resolution of 30 m (https://earthexplorer.usgs.gov), and vegetation and temperature were procured from the MODIS sensor products with spatial resolutions of 250 and 1000 m (https://modis.gsfc.nasa.gov). Vector layers consisted of maps of road networks, railway lines, and cities obtained from the Iranian National Cartographic Center (https://www.ncc.gov.ir/en), along with maps of water bodies and protected areas procured from the Forests, Range, and Watershed Management Organization (https://www.frw.ir), as well as fault maps gathered from the Geological Survey and Mineral Explorations of Iran (https://gsi.ir).

4.3. The processing steps of the GIS-Economic model

In the first step, the effective spatial criteria for determining optimal wind power plant locations are based on the relevant literature, and

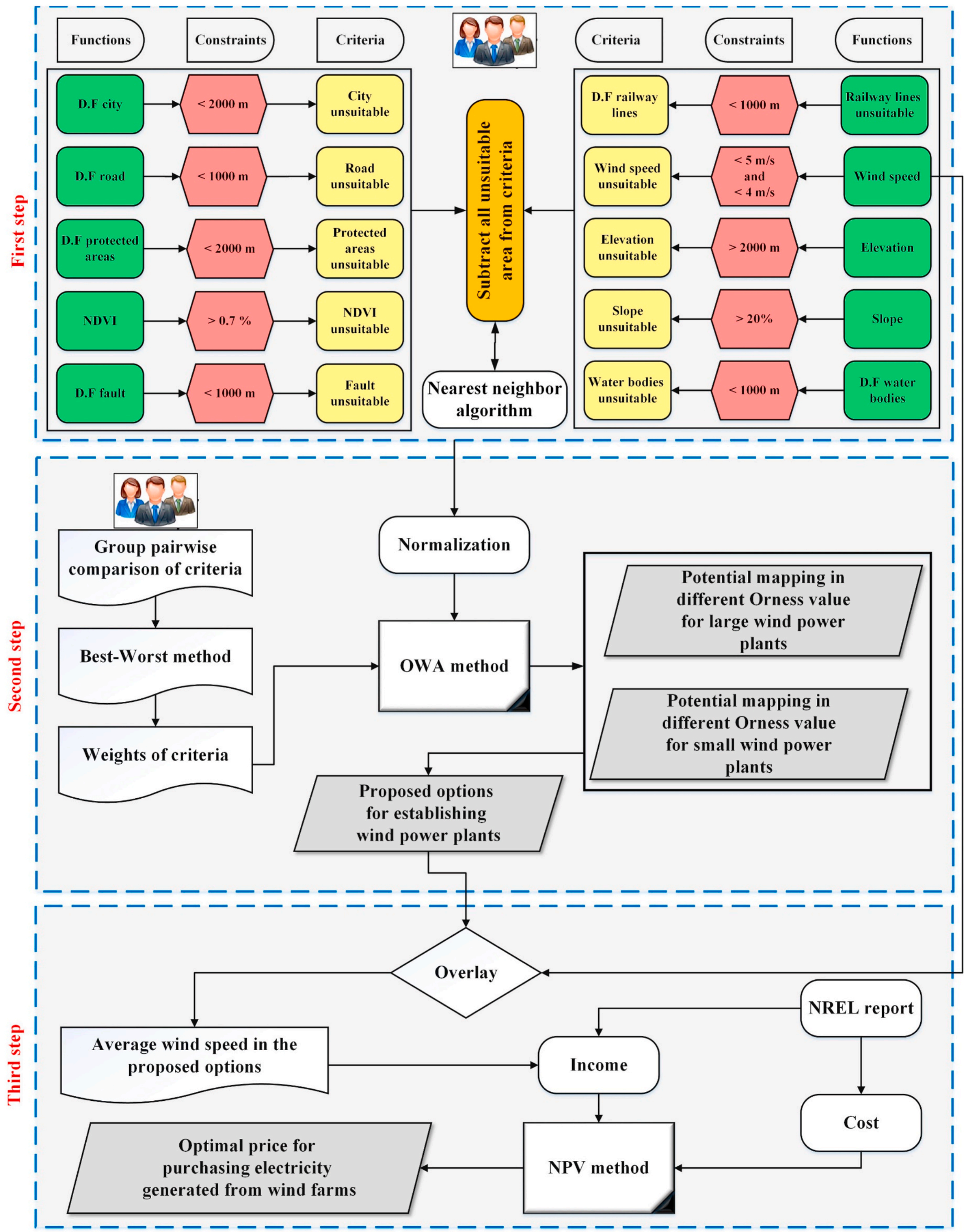

Fig. 3. Flowchart of the proposed framework.

expert opinions were selected. Then, the nearest neighbor algorithm was used to obtain values of different pixels and create criteria maps. In the second step, criteria were normalized based on the minimum and maximum approaches. Then, criteria weights were calculated using the BWM and expert opinions. The normalized criteria were combined and weighted using OWA to obtain potential wind maps at different degrees of risk. In the third step, the mean wind speed of each possible site for wind turbine installations was calculated. Finally, NPV was used to obtain the optimal purchasing price for electricity produced from small and large wind power plants. Fig. 3 depicts the conceptual framework of the present study.

4.3.1. *Identification of criteria*

The criteria in this study were selected based on relevance and significance to locating optimal sites for wind turbine installations, previous relevant studies, and expert opinions. The opinions of 73 experts (25 wind energy experts, 20 economics experts, 18 GIS experts, and 10 environmental experts) have been used. Finally, the set of criteria

Table 4
Consistency index values in order of best to worst criteria.

a_{BW}	1	2	3	4	5	6	7	8	9
CI (maxξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

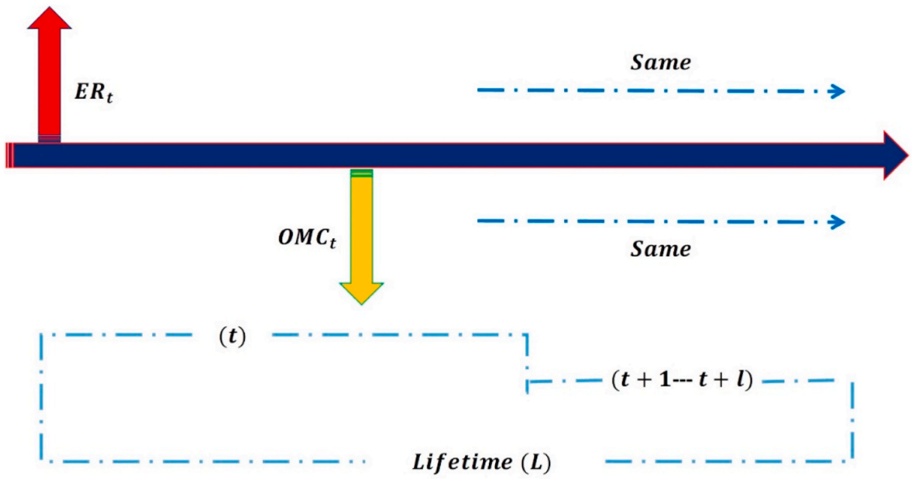

Fig. 4. Cash flow diagram for a wind power project [42,69].

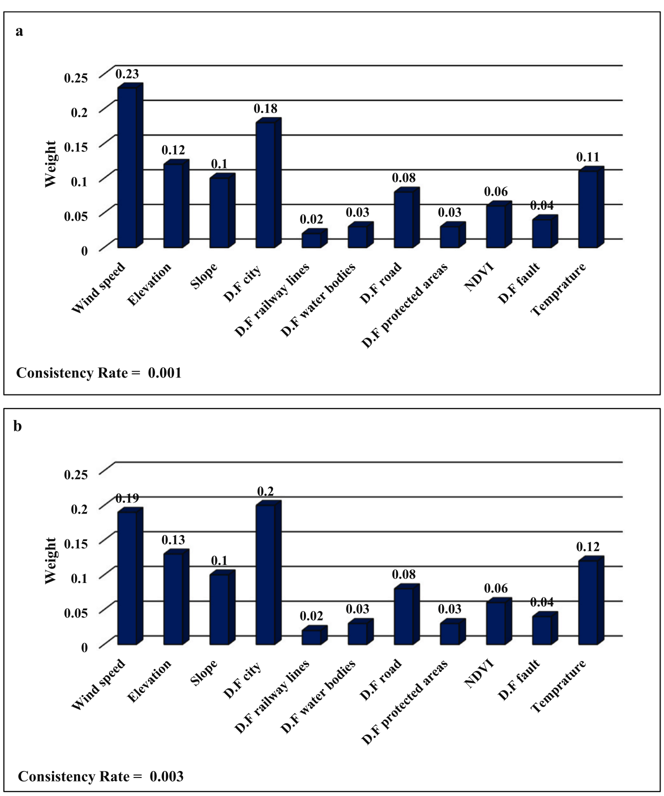

Fig. 5. The criteria weights are large (a) and small (b) wind power plants.

related to geographical, economic, ecological, and climatic conditions was selected as follows:

Wind speed: wind speed is commonly considered the most critical criterion in relevant studies due to its determinant role in assessing the economic capacity of a wind turbine [37,39]. The minimum required wind speed for a wind farm often differs among various studies. For instance, Ayodele et al. [39] consider the minimum wind speed as 4.4 m/s, while the figure proposed by Höfer et al. [37] is 5.5 m/s. The minimum wind speed used in the present study was 5 m/s for large wind plants [55] and less than 4 m/s (limited potential areas) for small wind plants [56].

Elevation and slope: as elevation and slope increase, potential regions for wind turbine installations become less. This is primarily explained because increases in slope and elevation bring higher construction costs, energy transfer, and equipment transportation [57]. In the case of this study, areas higher than 2000 m [58] in elevation and slope values greater than 20% were considered limited-potential areas.

Distance from city: two perspectives were considered on distance from cities in this study. The presumption for small wind-power plants was that a lesser distance from cities corresponded to a higher potential for establishment. However, for large and medium wind plants, which create noise and destroy the landscape for residents, the greater the distance, the better the potential [39]. Regions with less than 2000 m [38] distance from cities were considered limited-potential areas.

Temperature: Temperature reductions are beneficial to wind turbines' performance and service life. Therefore, areas with lower temperatures are more suitable for wind turbine installation [59]. Accordingly, the present study considered areas with higher temperatures as lower potential regions and vice versa.

Distance from the road and railway lines: areas closer to road and railway lines are often more suitable for construction purposes and reduce the costs and environmental damages of establishing wind power plants [43]. Nevertheless, regions with less than 1000 m [61] distance from the road and railway lines are considered limited-potential locations to lessen the aesthetic burden and ensure electrical safety standards are met.

Distance from water bodies: closeness to water bodies can threaten the state of wind turbines in the case of water overflows, the economic burdens of which are very high [19]. For this reason, the more significant the distance from water bodies corresponded to a higher potential. In this study, areas located at distances of less than 1000 m [60] from water bodies were categorized as limited-potential regions.

Distance from protected areas: wind turbines should insofar as possible be distanced from protected areas such as national parks, tourist attractions, ancient and historical sites, and bird and wildlife habitats. Interaction with birds is fatal for birds and damages the turbine as well

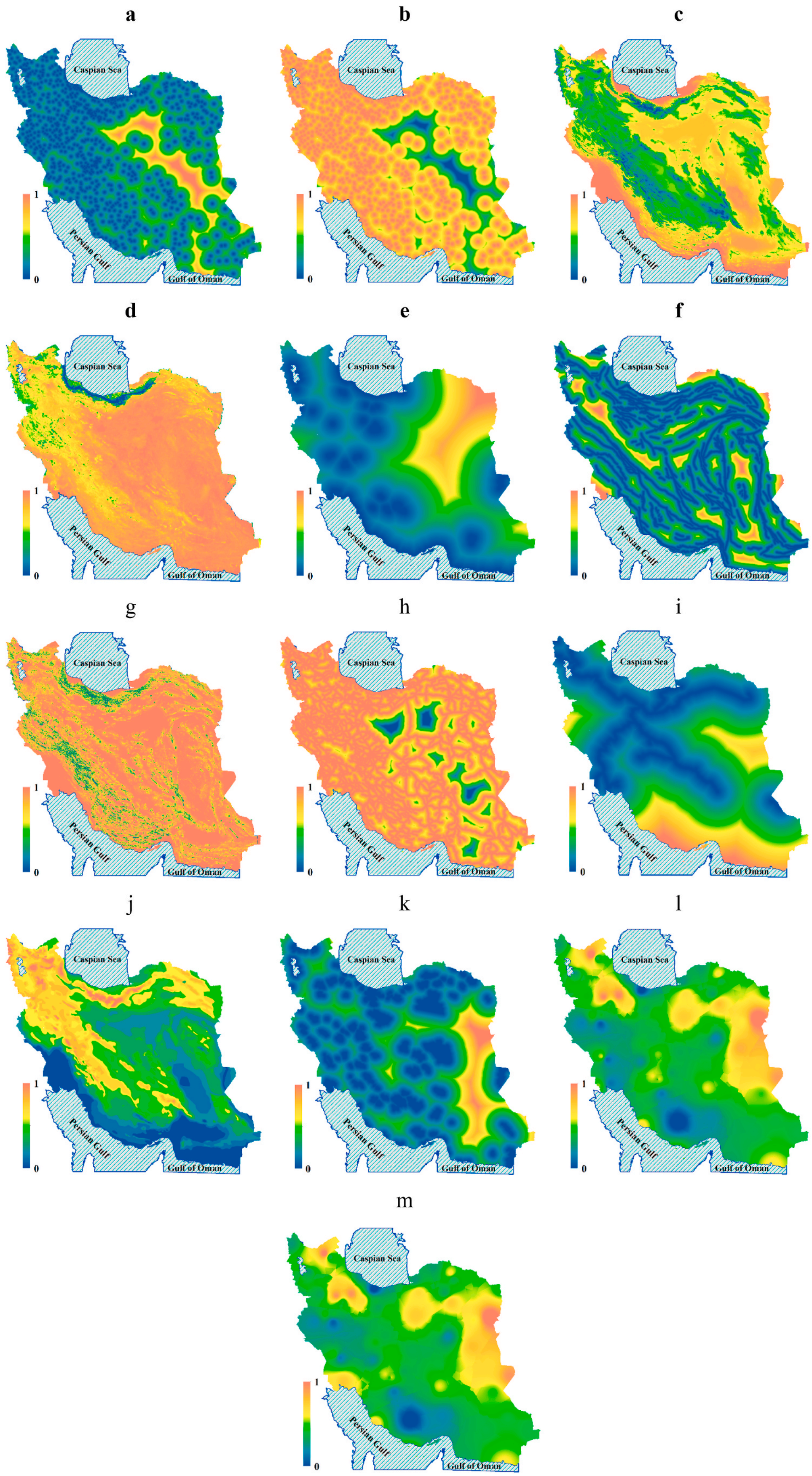

Fig. 6. Map of practical criteria for determining suitable locations for the establishment of small and large wind power plants; a) distance from cities (large power plant), b) distance from cities (small power plant), c) elevation, d) vegetation, e) distance from water bodies, f) distance from the fault, g) slope, h) distance from the road network, i) distance from railway lines, j) temperature, k) distance from protected areas, l) wind speed at the height of 30 m (small power plant), m) wind speed at the height of 80 m (large power plant).

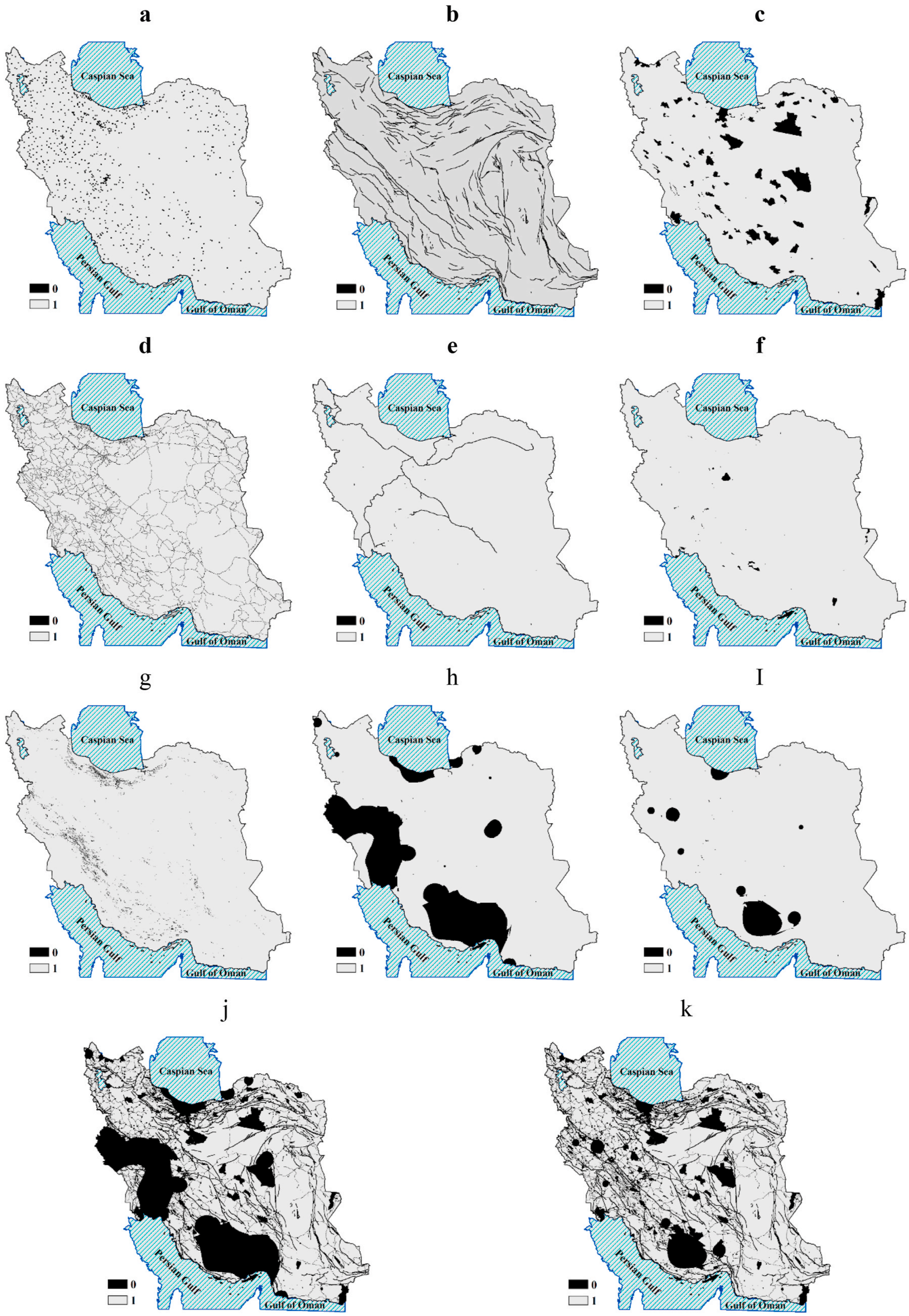

Fig. 7. Map of restrictions on suitable locations for the establishment of small and large wind power plants; a) distance of 2000 m from the city, b) distance of 2000 m from the fault, c) protected areas and distance of 1000 m from it, d) distance of 1000 m from the road network, e) distance of 1000 m from the railway lines, f) water bodies and distance of 1000 m from it, g) slope above 20%, h) wind speed less than 4 m/s for small wind power plants, i) wind speed less than 5 m/s for large wind power plants, j) total restrictions for optimal locations for small wind power plants, k) total restrictions for optimal locations for large wind power plants.

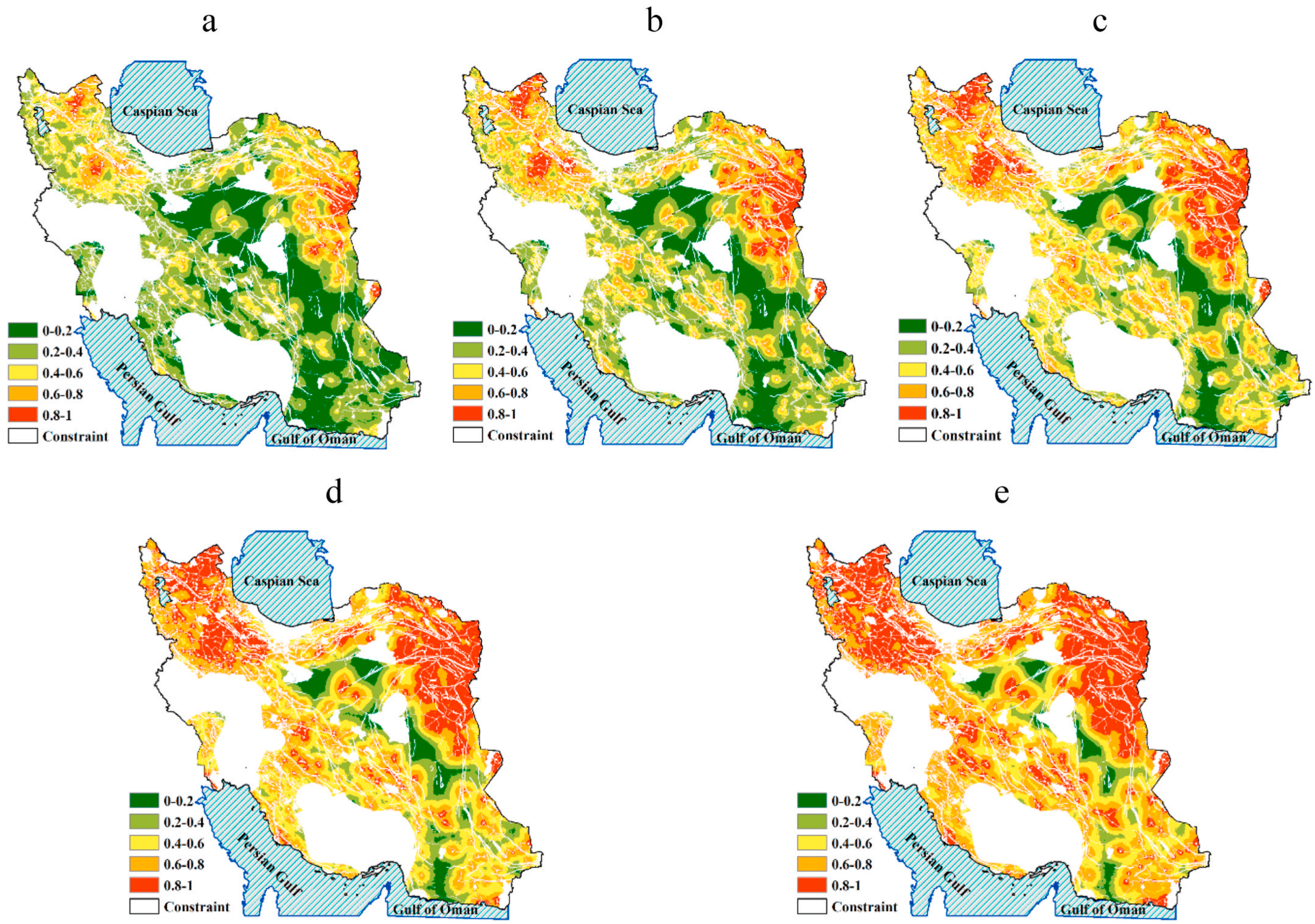

Fig. 8. The potential maps for the establishment of a small wind power plant for different ORness: (a) ORness = 0, (b) ORness = 0.2, (c) ORness = 0.5, (d) ORness = 0.8, and (e) ORness = 1.

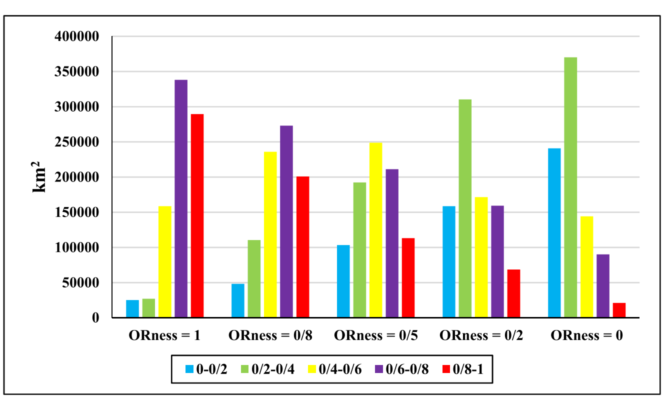

Fig. 9. Area of different suitability classes in Iran for different degrees of risk in decision making (small wind power plant).

[5]. Given these reasons, greater distance from protected areas is commensurate with higher site potential. The minimum distance for suitable sites in this study was 2000 m [58], below which the locations were categorized as limited-potential.

Normalized Difference Vegetation Index (NDVI): vegetation is often described in terms of NDVI, representing the green coverage in a region. Below-zero values of this index indicate water bodies, while values from 0 to 0.2 represent dry soil, between 0.2 and 0.7 indicate low vegetation, and values above 0.7 correspond to high vegetation [61]. The relevance of vegetation to wind turbine installations lies in the fact that woodlands and jungles can inhibit wind flows and are therefore not suitable for establishing wind power plants. Accordingly, this study categorized areas with NDVI values above 0.7 as limited-potential regions.

Distance from fault: this factor is relevant to the objectives of wind power installation from the perspective that closeness to faults can incur costly damages to wind turbines in the case of landslides [58]. Therefore, the present study considered regions located at distances of less than 1000 m [5] from faults as limited potential regions.

4.3.2. Determination of suitable locations for wind turbine installations

- **Criteria rescaling**

The criteria affecting the selection of suitable locations for wind turbine establishment were rescaled and divided into two categories of costs (distance from roads, temperature, distance from railway lines, slope, elevation, and NDVI) and benefits (distance from protected areas, wind speed, distance from water bodies, distance from fault). Low values for the cost criterion and higher values for the benefits criterion indicate more suitable regions for establishing wind plants. The distance from city criterion appeared in both categories of costs and benefits, as explained above. Equations (1) and (2) formulate the cost and benefit criteria, respectively [29]:

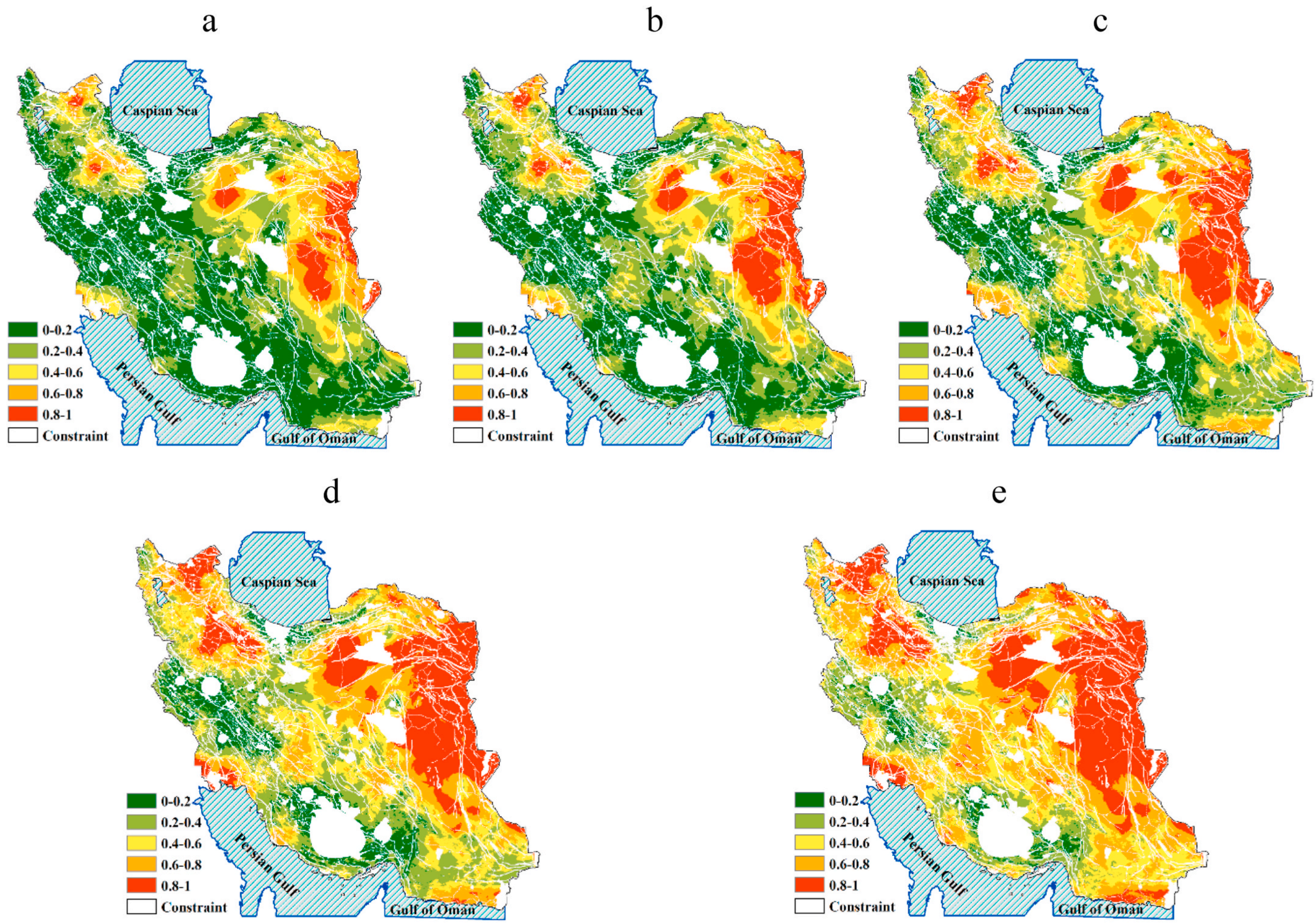

Fig. 10. Potential maps for the establishment of large wind power plants for different ORness (risk) levels: (a) ORness = 0, (b) ORness = 0.2, (c) ORness = 0.5, (d) ORness = 0.8, and (e) ORness = 1.

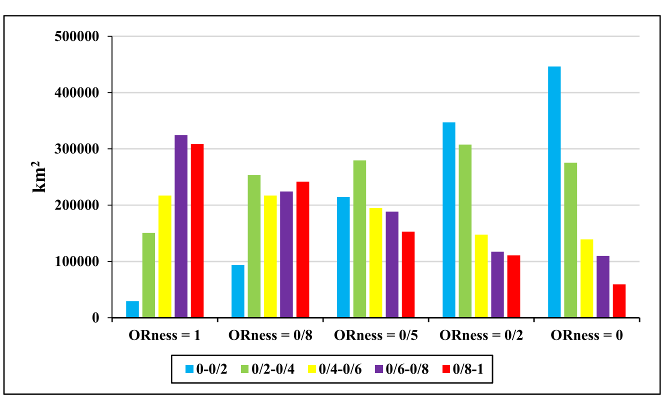

Fig. 11. Area of different classes of suitability in Iran for different degrees of risk in decision making (large wind power plant).

$$a(ij) = \frac{T_j^{max} - T_{ij}}{T_j^{max} - T_j^{min}} \tag{1}$$

$$b(ij) = \frac{T_{ij} - T_j^{min}}{T_j^{max} - T_j^{min}} \tag{2}$$

where a(ij) and b(ij) show standardized or rescaled values for the *i*th location and the *j*th criterion. T_j^{min} and T_j^{max} represent the lowest and highest values for the *i*th location and the *j*th criterion, and T_{ij} Shows the value of the *i*th location in relation to the *j*th criterion.

- **The Best-Worst method**

The BWM for multicriteria evaluation was first proposed by Rezayi [52]. The method works by first identifying the decision maker's best and worst criteria preferences. A pairwise comparison was also made between these criteria (best and worst) and the remaining criteria. The corresponding weights were then formulated and obtained using solving a maximum-minimum problem. One of the primary advantages of this weighting method is the relatively low number of pairwise comparisons required, which also reduces the processing time and leads to more accurate results. Similar to the AHP method, this approach uses a 9-item scale for stating preferences and judgments. The process involves the initial calculation of the best (or the most significant) and the worst (the least significant) criteria. In the next step, the relative significance of the best criteria is obtained concerning the remainder of the criteria, along

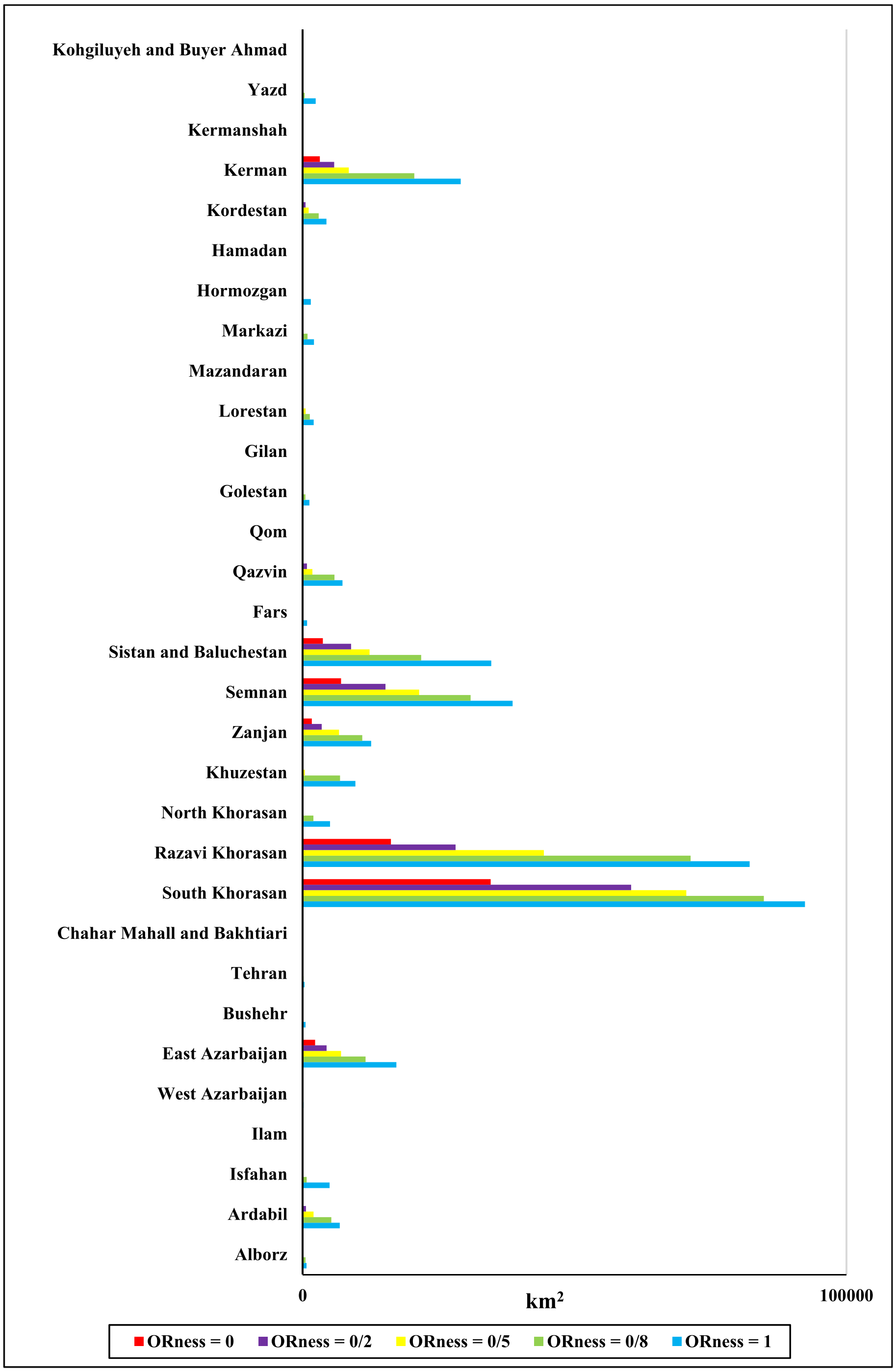

Fig. 12. Very suitable class area in Iran provinces for establishing large solar power plants.

with the relative significance of each, proportionate to the worst criteria. Equation (3) gives the criteria weights and ξ value.

$$\min_j^{\max} \left\{ \left| \frac{\omega_B}{\omega_j} - a_{Bj} \right| . \left| \frac{\omega_j}{\omega_W} - a_{jW} \right| \right\}$$

$$s \cdot t$$

$$\sum_{j=1}^{n} w_j = 1 \tag{3}$$

$$w_j \geq 0. \ for \ all \ j$$

The consistency ratio for the Best-Worst method can be obtained using the ξ value and the consistency index, as formulated in Equation (4).

$$Consistency\ Ratio = \frac{\xi}{Consistency\ index} \tag{4}$$

Different values for the consistency index are given in Table 4.

Values for the consistency ratio range from 0 to 1. Values closer to 1 indicate lower consistency and stability of comparisons, while values near zero represent higher consistency and stability of comparisons. The individual weights were then combined using geometric and arithmetic means.

- **OWA method**

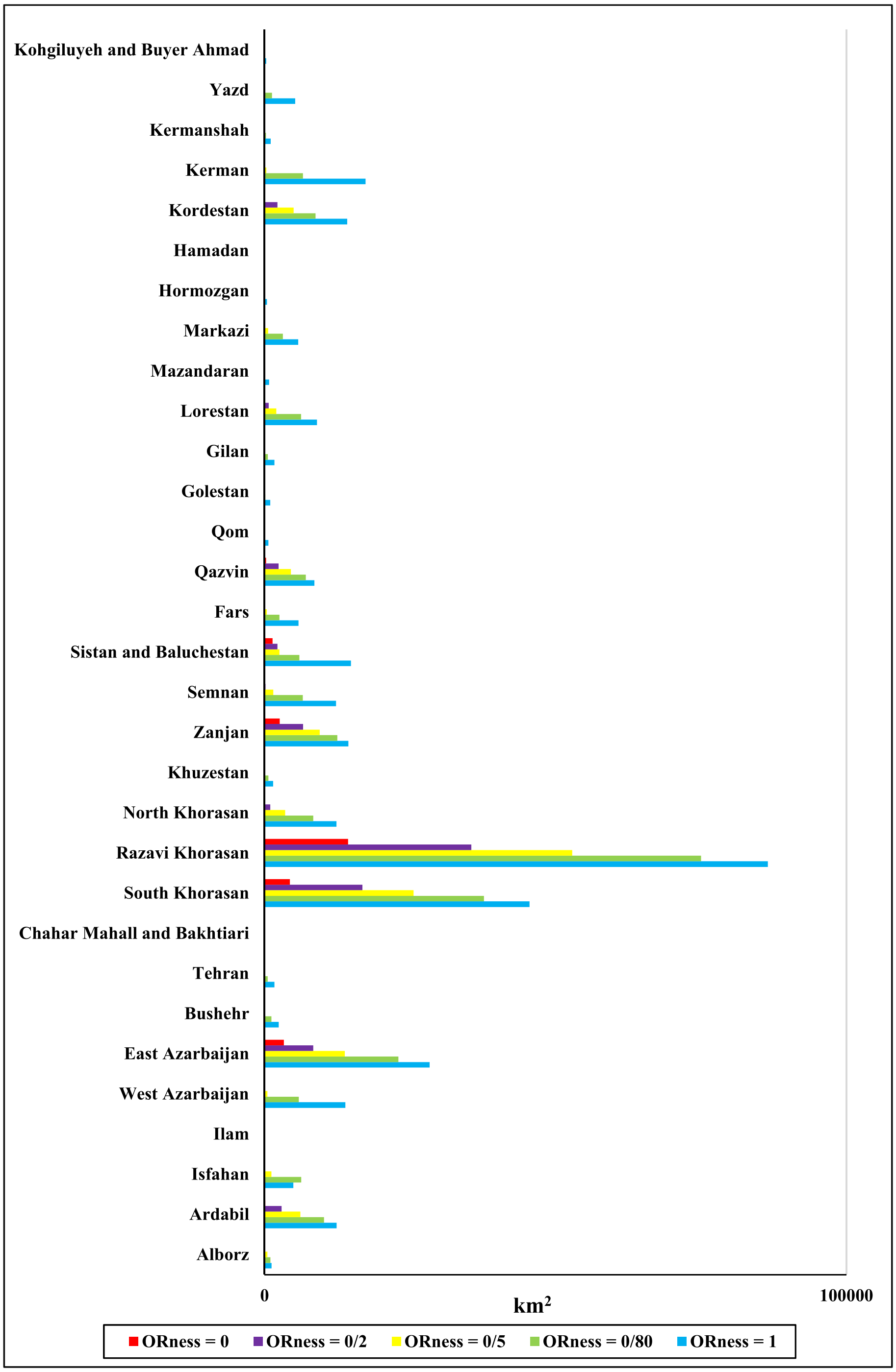

Fig. 13. Very suitable class area in Iran's provinces for establishing small solar power plants.

Often, specific criteria, mainly qualitative decision-making criteria, are measured in a state of risk due to a lack of accurate predictions of future values or access to precise and specific information and an absence of a correct estimate of criteria [21,62]. Under such conditions, the outcome is influenced by the decision maker's degree of risk-taking and risk aversion. The OWA is introduced as a decision-making technique that considers decision-makers priorities and mental evaluations. The decision maker's level makes the ultimate decision of risk-taking/aversion [63]. Various studies in the field of renewable energy have used the OWA model [5,30,64]. For instance, in their studies, Shorabeh et al. [5] and Firozjaei et al. [30] have used the OWA model to prepare a potential solar map based on different risk levels in Iran.

Two weights are employed in the OWA method: criteria and ordered weight. The criteria weight represents the relative significance of each evaluation criterion (layers and maps). The ordered weights are assigned based on the location of cells in criteria layers; i.e., cells located at one location for various criteria are assigned different weights [65]. All cells in a specific criterion map have similar criterion weights but different ordered weights [64]. The OWA formula can be expressed as follows (Equation (5)):

$$OWA_i = \sum_{i=1}^{n} \left(\frac{u_j \, v_j}{\sum_{j=1}^{n} u_j \, v_j} \right) z_{ij} \tag{5}$$

where, z_{ij} is the value of the ith cell corresponding to criteria j; u_j is the jth criteria weight, which is obtained in relation to the jth criteria, the

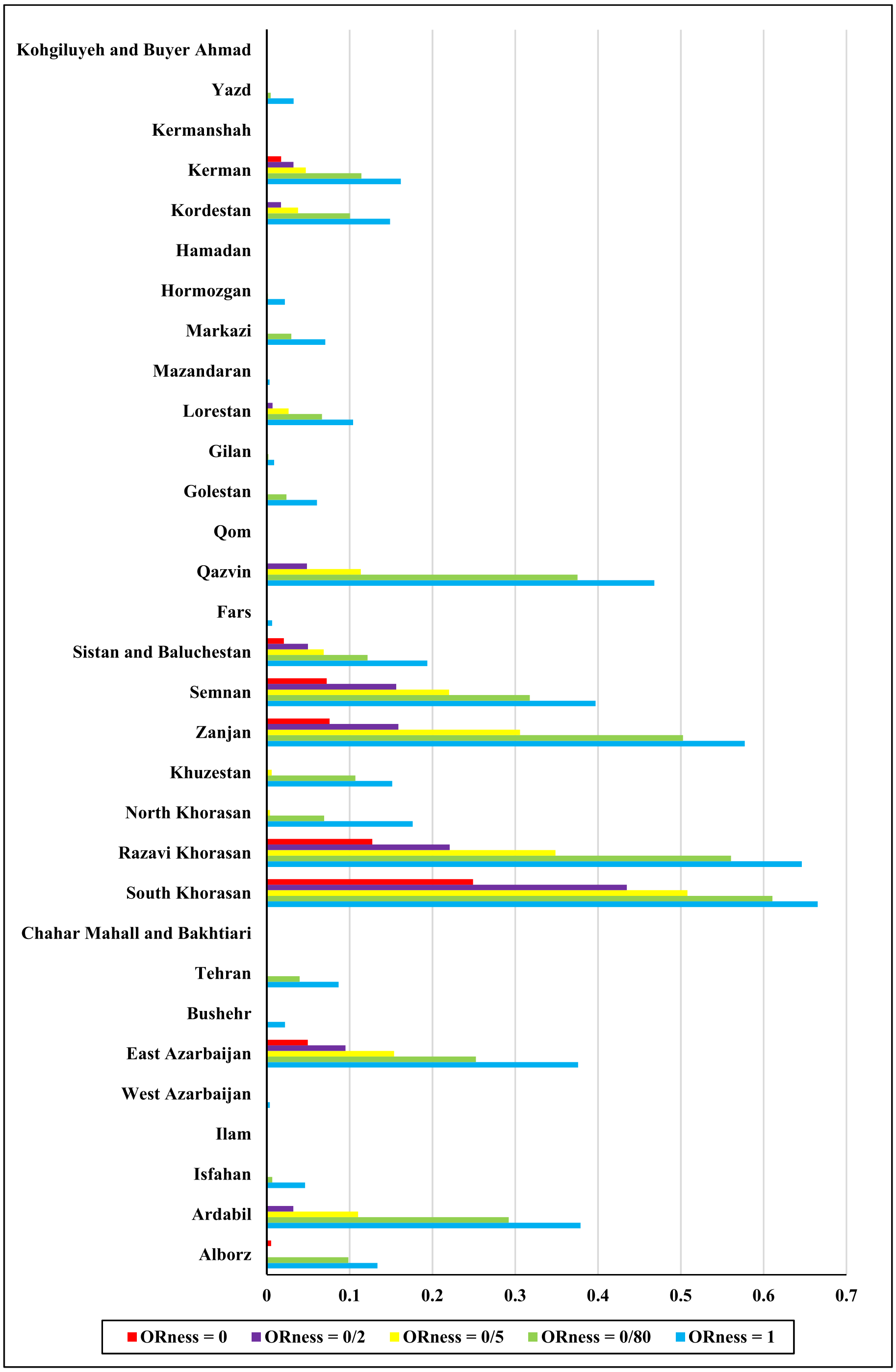

Fig. 14. The ratio of very-suitable class area for establishing large wind power plants to the province area.

user preferences, and the ordered weight v_j.

The OWA model operates on two main components: ORness or risk-taking degree and trade-off or the degree of compromise between indices [66]. Risk-taking in OWA is formulated in AND and OR relations and represents the user's (decision maker's) emphasis on better or worse values for a set of criteria, i.e., risk-taking/aversion behavior [67]. Conversely, the trade-off reflects the amount of interaction or influence between indices [21]. ORness is obtained as follows (Equation (6)):

$$ORness = \sum_{j=1}^{n} \left(\frac{n-j}{n-1}\right) \lambda_j, \quad 1 \leq ORness \ \leq 0 \tag{6}$$

Low (0) and high (1) values of ORness represent risk-aversion and risk-taking behavior of investors. Several scenarios can thus be simulated for investors consisting of shallow risk to very high-risk maps, which can be used to select highly suitable locations for wind turbine installations [5].

4.3.3. *Estimation of the optimal purchasing price for electricity produced by wind turbines*

- **Turbine nominal production capacity**

The electricity generation process by wind turbines initially starts with the transformation of kinetic energy to mechanical energy, which is then used to produce electricity. The nominal production capacity of

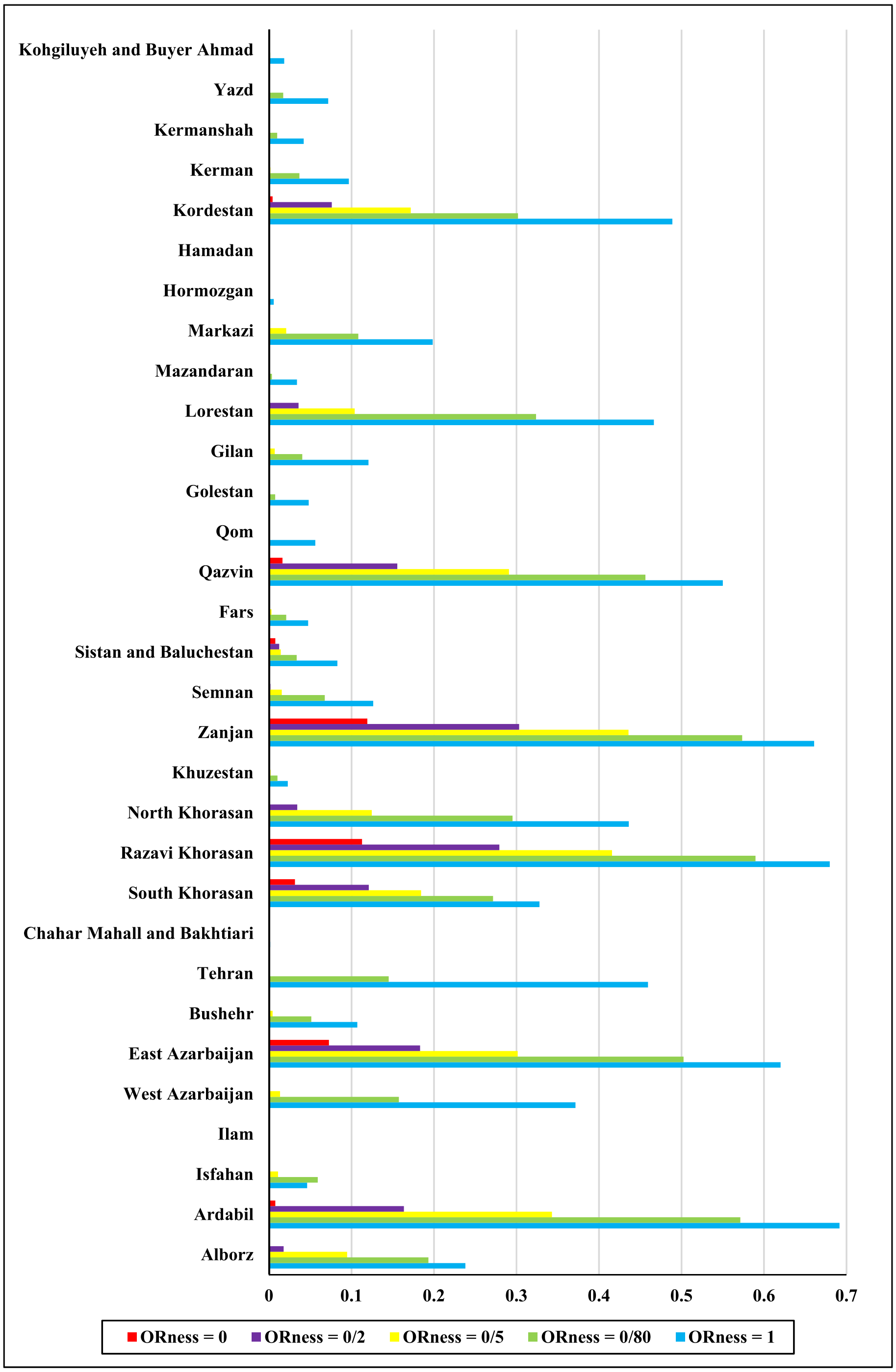

Fig. 15. The ratio of very-suitable class area for establishing small wind power plants to the province area.

wind turbines is highly dependent on windspeed, and other factors, including air density and turbine surface area, are affected by the length of turbines [68]. Equation (7) formulates the nominal production capacity for a wind turbine [69].

$$P = \frac{1}{2}\rho A V^3 \tag{7}$$

where ρ is the air density, A is the surface area, and V represents wind speed.

- **Costs and benefits of wind power production**

The overall income for a wind plant is subject to the duration of electricity generation and the purchasing price. Nevertheless, wind speed is the most significant factor affecting a wind plant's production rate. The annual nominal production capacity was obtained in this study using the mean wind speed in Equation (7). However, the actual amount of electricity produced is contingent upon the system's overall performance, which is hindered by mechanical and technical depreciation. Underperformance causes reductions in the amount of electricity produced by wind turbines in forthcoming years and must therefore be considered in estimating prospects for electricity production [70]. Equations (8) and (9) can be used to estimate income for wind power [71].

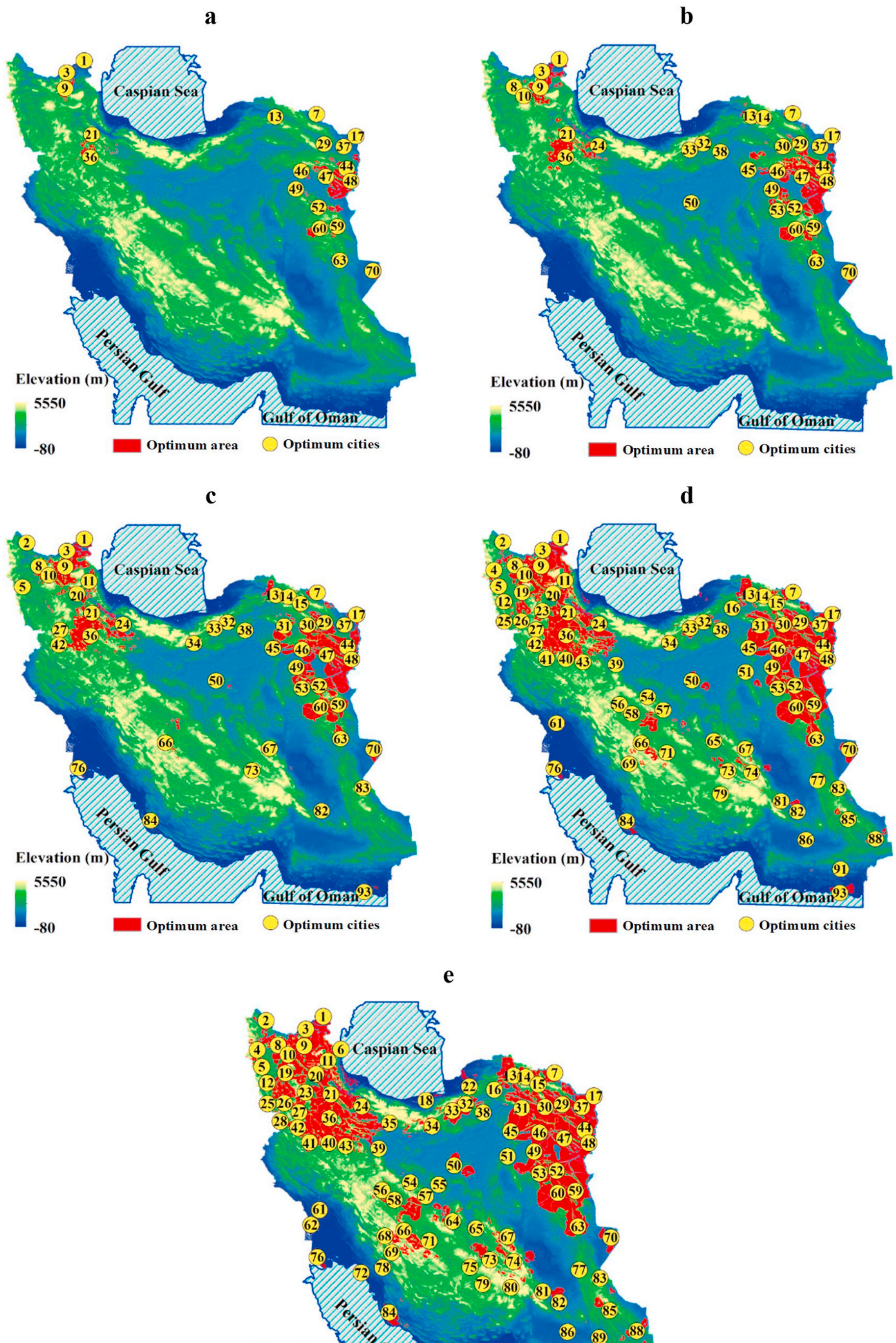

Fig. 16. The optimum cities maps for the installation of a small wind power plant for different ORness levels: (a) ORness = 0, (b) ORness = 0.2, (c) ORness = 0.5, (d) ORness = 0.8, and (e) ORness = 1.

$$ER_t = \overline{P} \times IC \times Ge_t \times FIT_t \tag{8}$$

$$Ge_{t+1} = Ge_t \times (1 - Rr) \tag{9}$$

where IC is the installation capacity, $\overline{P}$ shows the mean production per year, Ge_t represents system performance, Rr shows the amount of reduction in system performance, and FIT_t is the feed-in tariff for wind power.

The costs of establishing a power plant can be determined with respect to factors of capacity and structure of wind plant, type and price of equipment, costs of installation, and other involved expenditures. The majority share of wind power plants costs includes purchasing, establishing, and maintaining the system. Further details on these factors can be found in the NREL report [72].

- **Net present value for wind turbines**

Firozjaei et al. [42] stated that the NPV is an effective model for

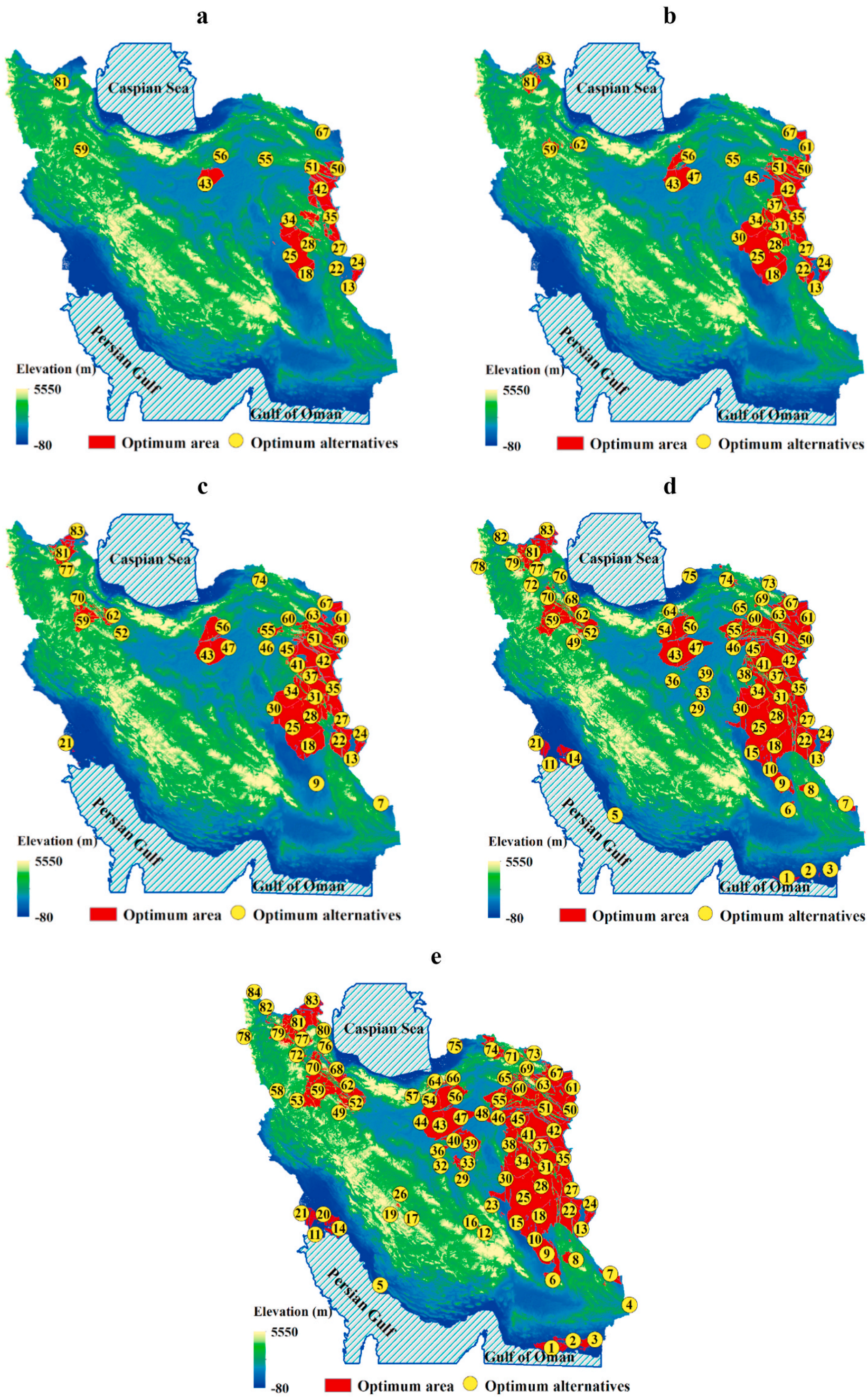

Fig. 17. The optimum alternative maps for the installation of a large wind power plant for different ORness levels: (a) ORness = 0, (b) ORness = 0.2, (c) ORness = 0.5, (d) ORness = 0.8, and (e) ORness = 1.

calculating the optimal price of renewable energy. Assuming a wind-power project with a service life of L (25 years in this study) and investment time of t, expected to be operational by the first year [73], the NPV approach proceeds with the discounting of potential earnings to the present time. A positive value for NPV, as formulated in Equation (10), indicates that the project is economically feasible; otherwise not. NPV can be obtained as follows [74]:

$$V_t = E\left[\sum_{i=t}^{t+l}\frac{YCF_i}{(1+r)^{i-t}} - I_t\right] \quad 0 \le t \le t_v \tag{10}$$

where r is the discounting (reduction) ratio, YCF represents annual cash flow, t_v is the last period of operation, and I_t relates to initial investments and can be formulated as (Equation (11)):

$$I_t = UI \times IC \tag{11}$$

Table 5
Optimal purchase price of electricity generated by small power plants based on the geographical location of cities.

Id	Name	Wind speed (m.s^{-1})	Optimal price (US$)	Id	Name	Wind speed (m.s^{-1})	Optimal price (US$)
1	Parsabad	5.49	0.154	**48**	Taybad	6.84	0.081
2	Poldasht	4.35	0.311	**49**	Bajestan	5.27	0.175
3	Meshginshahr	6.08	0.113	**50**	Jandaq	5.11	0.192
4	Salmas	4.69	0.248	**51**	Eshqabad	4.43	0.294
5	Urmia	4.71	0.245	**52**	Qaen	5.76	0.134
6	Astara	4.81	0.231	**53**	Seh Qaleh	5.34	0.168
7	Lotfabad	4.54	0.274	**54**	Ardestan	4.22	0.341
8	Marand	5.14	0.189	**55**	Anarak	4.51	0.281
9	Ahar	7.01	0.074	**56**	Alavijeh	4.32	0.317
10	Tabriz	5.16	0.186	**57**	Naein	4.57	0.268
11	Varzaqan	4.84	0.226	**58**	Isfahan	4.3	0.321
12	Naqadeh	4.53	0.276	**59**	Asadiyeh	6.15	0.111
13	Bojnord	5.36	0.167	**60**	Birjand	6.09	0.113
14	Shirvan	4.72	0.243	**61**	Shush	4.95	0.211
15	Quchan	4.62	0.261	**62**	Rofayyeh	4.21	0.342
16	Jajarm	4.43	0.293	**63**	Nehbandan	5.68	0.141
17	Sarakhs	4.64	0.257	**64**	Yazd	4.25	0.333
18	Sari	4.12	0.365	**65**	Bafq	4.38	0.305
19	Maragheh	4.05	0.384	**66**	Izad Khast	4.86	0.223
20	Mianeh	5.02	0.203	**67**	Ravar	4.62	0.259
21	Zanjan	5.89	0.125	**68**	Mal-e Khalifeh	4.41	0.298
22	Azadshahr	4.21	0.343	**69**	Yasuj	4.71	0.246
23	Tarom	4.95	0.211	**70**	Zabol	6.41	0.097
24	Qazvin	5.61	0.145	**71**	Abarkuh	4.42	0.295
25	Sardasht	4.36	0.309	**72**	Razi	4.12	0.366
26	Saqqez	4.65	0.255	**73**	Rafsanjan	5.04	0.211
27	Marivan	4.48	0.285	**74**	Kerman	4.76	0.237
28	Sanandaj	4.54	0.273	**75**	Shahr-e Babak	4.17	0.353
29	Mashhad	5.04	0.199	**76**	Abadan	4.91	0.216
30	Neyshabur	5.02	0.203	**77**	Nosratabad	4.85	0.225
31	Sabzevar	4.89	0.219	**78**	Manujan	4.45	0.291
32	Shahroud	5.25	0.177	**79**	Sirjan	4.18	0.351
33	Damghan	5.26	0.176	**80**	Rabor	4.09	0.374
34	Semnan	4.91	0.217	**81**	Bam	4.36	0.308
35	Tehran	4.35	0.311	**82**	Mohammadabad	4.35	0.311
36	Zarrin Rood	5.82	0.131	**83**	Zahedan	5.03	0.201
37	Nahavand	4.87	0.222	**84**	Kaki	4.92	0.215
38	Tuyserkan	4.85	0.224	**85**	Khash	4.33	0.314
39	Qom	4.41	0.298	**86**	Galmurti	4.14	0.359
40	Hamadan	4.27	0.328	**87**	Bandar Lengeh	4.35	0.311
41	Sonqor	4.71	0.247	**88**	Saravan	4.29	0.324
42	Harat	4.61	0.261	**89**	Iranshahr	4.39	0.303
43	Arak	4.07	0.378	**90**	Sarbaz	4.06	0.382
44	Torbat-e Jam	6.14	0.111	**91**	Qasr-e-qand	4.76	0.237
45	Gonabad	5.71	0.138	**92**	Pishin	4.62	0.259
46	Kashmar	5.47	0.156	**93**	Chabahar	5.29	0.172
47	Roshtkhar	6.29	0.103				

where *UI* is the cost for each unit investment, and *IC* represents investment capacity.

Fig. 4 illustrates the cash flow chart for a typical wind power project. Equation (12) formulates the annual net cash flow as YCF_t, which is calculated concerning earnings and costs; ER_t represents earnings from electricity sales in year t; OMC_t represents costs of wind-power project in the t*th* year, including workforce costs, insurance, and maintenance and repair work [75].

$$YCF_t = ER_t - OMC_t \tag{12}$$

5. Results

The proposed method proceeded with integrating GIS with expert knowledge on renewable energies to weigh different criteria affecting the establishment of wind power plants using the Best-Worst method. The best criteria show the highest relative significance to the decision-making process, while the minor relative significance is assigned to the worst criteria. The criteria were weighted using a geometric mean followed by a final potential mapping of the study region. Wind speed was selected as the best criteria (highest weight and significance) for both small and large wind plants. At the same time, distance from railway lines was adopted as the worst criterion (lowest weight and significance) (Fig. 5).

As the findings suggest, the consistency ratio for allocating weights to criteria based on expert knowledge was measured at less than 0.1, which shows relatively good consistency among expert opinions. Fig. 6 illustrates different criteria maps used for selecting suitable sites for establishing wind power plants. The criteria values range from 0 to 1, with values closer to one indicating a higher potential for wind turbine installation. However, as the figure shows, potential areas obtained from each criterion differ. For example, the eastern areas of the study region have the highest suitability in terms of wind speed, while the north-eastern sections are more suitable in terms of temperature. This shows that each location is potentially suitable, albeit the optimal regions are selected as ones that have the highest value in all criteria.

Restrictions and constraints were also recruited to abide by the national and international rules and standards for establishing power plants (Fig. 7). Limited areas included regions within 2000 m distance from cities, 2000 m distance from faults, 1000 m distance from protected areas, 1000 m distance from road networks, 1000 m distance from railway lines, 1000 m from water bodies, and slope higher than 20%, less than 5 m/s wind speed for large wind plants, and finally, less than 4 m/s wind speed for small wind plants. The constraint criteria were also

Table 6
Optimal purchase price of electricity generated by large power plants with respect to the geographical location of alternatives.

Id	Wind speed ($m.s^{-1}$)	Optimal price (US$)	Id	Wind speed ($m.s^{-1}$)	Optimal price (US$)
1	5.87	0.125	**43**	7.19	0.069
2	6.33	0.101	**44**	6.33	0.101
3	6.16	0.109	**45**	6.72	0.085
4	5.47	0.156	**46**	6.35	0.099
5	6.72	0.084	**47**	6.73	0.084
6	5.47	0.156	**48**	6.25	0.104
7	5.74	0.135	**49**	5.99	0.119
8	5.96	0.121	**50**	7.78	0.0545
9	6.12	0.112	**51**	7.53	0.061
10	6.39	0.098	**52**	6.84	0.081
11	6.78	0.082	**53**	5.74	0.135
12	6.29	0.102	**54**	6.47	0.094
13	7.34	0.064	**55**	7.27	0.066
14	7.03	0.073	**56**	6.69	0.088
15	6.42	0.096	**57**	5.97	0.121
16	5.97	0.121	**58**	5.39	0.163
17	6.02	0.117	**59**	8.12	0.047
18	6.88	0.078	**60**	6.23	0.106
19	6.25	0.104	**61**	5.92	0.123
20	6.68	0.085	**62**	7.88	0.052
21	6.34	0.102	**63**	6.38	0.098
22	7.24	0.067	**64**	6.27	0.1041
23	5.74	0.135	**65**	5.81	0.131
24	7.86	0.052	**66**	6.31	0.101
25	6.62	0.088	**67**	6.08	0.114
26	5.91	0.124	**68**	6.95	0.0765
27	7.23	0.067	**69**	5.89	0.125
28	7.16	0.069	**70**	6.82	0.083
29	5.31	0.172	**71**	5.82	0.131
30	5.99	0.119	**72**	6.08	0.113
31	7.27	0.066	**73**	5.77	0.133
32	5.42	0.161	**74**	6.28	0.103
33	5.35	0.167	**75**	5.21	0.182
34	7.11	0.071	**76**	6.14	0.112
35	7.72	0.055	**77**	6.55	0.091
36	5.89	0.125	**78**	5.82	0.131
37	7.22	0.068	**79**	6.47	0.094
38	5.72	0.137	**80**	5.93	0.123
39	5.61	0.145	**81**	8.53	0.041
40	6.12	0.111	**82**	5.71	0.138
41	6.58	0.09	**83**	6.81	0.081
42	8.87	0.036	**84**	5.31	0.171

mapped for both small and large power plants. Values shown in the maps range from 0 to 1, with values near zero representing unsuitable locations for wind turbine establishments, while a value of 1 indicates a suitable location.

The GIS-OWA method was employed to obtain potential maps of the region in terms of suitability for wind turbine establishment. Normalized maps, ORness values, and criteria weights were also obtained accordingly. Criteria weights were considered fixed, and ORness as a variable, ranging from 0 (risk aversive or pessimistic) to 1 (risk-taking or optimistic). ORness maps were categorized into 5 classes of very unsuitable (0–0.2), unsuitable (0.2–0.4), moderately suitable (0.4–0.6), suitable (0.6–0.8) and very suitable (0.8–1). Fig. 8 illustrates the potential maps obtained for a small wind plant using OWA operands and different ORness values. The potential maps showed different risk-taking/risk-aversive qualities. ORness is directly correlated with the degree of investment risk, such that higher ORness values correspond to higher investment risk and vice versa.

The chart in Fig. 9 illustrates the area of different classes of site suitability for a small wind plant in Iran for different degrees of risk. As evident, increases in ORness value correspond to the increased area of higher potential (very suitable) regions for establishing small wind power plants. In comparison, areas of lower potential (e.g., very unsuitable) regions decrease. There are two crucial cases when working with ORness values; ORness = 0 indicates the highest risk category, where investors show risk-aversive behavior. Under such conditions, a suitable region is identified as one with the highest value for all criteria. However, as other restrictions are also incorporated in this strategy for identifying potential locations, the area size of evaluated regions in the suitable class is reduced. This state is often used to identify high potential regions with high sensitivity and specific economic restrictions on financial budgets.

On the other hand, ORness = 1 corresponds to shallow investment risk, wherein having the highest value in at least one criterion is sufficient for categorizing the region as very suitable. As a result, a more significant portion of areas is selected as very suitable. ORness = 1 can be used when sensitivity is low, and restrictions are few.

Fig. 10 shows potential maps for establishing large wind power plants using OWA and different ORness levels. The maps show the region's overall potentiality for large-scale wind turbine establishments while accounting for various scenarios of risk-taking/risk-aversion. ORness values are directly correlated with the degree of investment risk; i.e., increased ORness corresponds to higher risk, and vice versa.

Fig. 11 depicts areas of different classes of site suitability by different degrees of decision-making risk for establishing a large wind power plant. As the results show, reductions in ORness correlate with reductions in the suitable classes (suitable and very suitable) area, while areas in the unsuitable classes (unsuitable and very unsuitable) increase. Stated differently, since optimal locations, in the case of lower ORness value, corresponding to the highest values in all criteria, the overall area size for the suitable classes (suitable and very suitable) decreases. This may also be understood as a very low-risk investment and is convenient for risk-aversive behaviors (or individuals). Conversely, when ORness is high (maximum = 1), regions showing high values in even one criterion are selected as optimal locations, indicating a high-risk investment.

Figs. 12 and 13 show areas of the very suitable class of regions in the province for establishing large and small solar power plants by different ORness values. It can be inferred from Fig. 12 that the most significant proportion of the suitable area is found in provinces located to the east of the country, with South Khorasan, Razavi Khorasan, and Sistan and Baluchestan having the highest share of areas in the very suitable class. On the other hand, provinces such as Kohgiluyeh and Boyer-Ahmad, Tehran, Hamedan, Qom, Mazandaran, Bushehr, Ilam, and Chaharmahal and Bakhtiari had no shares in the very suitable class.

Fig. 13 indicates that the two provinces, Khorasan Razavi and South Khorasan, have the highest proportion of areas categorized as very suitable for establishing small wind plants, while Ilam and Hamedan showed the lowest potential and the lowest share of areas in the very suitable class.

Considering that areas depicted in Figs. 12 and 13 were measured per class, Fig. 14 shows the share of areas in the very suitable class for establishing large wind plants. As can be observed from this figure, in addition to Southern Khorasan and Razavi Khorasan having the largest surface area labeled as very suitable for large wind plants, Zanjan, Semnan, Western Azerbaijan, and Ardebil also held a considerable share of very suitable regions relative to the remainder of provinces.

The relative proportion of areas in the very suitable class to the total area of the province is given in percent in Fig. 15 for small wind power plants. In addition to the eastern provinces (South Khorasan and Razavi Khorasan), which hold a considerably large share of areas in the very suitable classes, provinces of Lorestan, Kurdistan, Qazvin, West Azerbaijan, East Azerbaijan, and Ardabil also hold significant shares of very suitable areas.

Fig. 16 illustrates the locations of adjacent cities to suitable regions for establishing wind power plants for different scenarios of risk. Since small wind-power plants are better positioned near cities, the optimum cities are selected with respect to the very suitable class. The greatest concentration of suitable cities for small wind turbine establishments was located in the country's eastern and north eastern regions, which drop in number as ORness decreases. For example, at ORness = 1, a total of 93 options were found, while for ORness = 0, the options are limited to 21 cities as suitable for small wind turbine establishments. Alternatively, cities selected from the ORness = 1 map are commensurate with a risky decision, while ORness = 0 maps indicate low to no risk of investment.

Maps in Fig. 17 also show the location of suggested regions and cities for establishing large wind power plants for various degrees of risk. Based on the illustrated figures, in addition to the country's eastern and northeastern regions, the central parts also include the considerable potential for large wind turbine establishments. The country's central regions are particularly suitable for large wind turbine installations, given their extended plains, intense winds, and distance from residential areas. The maps further suggest that reductions in ORness correlate with decreases in potential cities for establishing large wind plants; 84 very suitable options (cities) for ORness = 1, and 18 for ORness = 0. In other words, working on ORness = 1 concludes a risky decision, while ORness = 0 can be used for identifying low-risk investments.

Table 5 lists the optimal purchasing price for small and large power plants with respect to the geographical location of cities. As the figures suggest, the overall price range for electricity varies from 0.074 to 0.384 US$, with Ahar, Taibad, Rashtkhar, Torbat-e Jam, and Asadiyeh contributing to the lowest prices in order of magnitude, while Maragheh, Sarbaz, Arak, Rabor, and Galmurti corresponded to the highest prices, respectively. In other words, cities with lower wind speed conditions charge higher prices for electricity generated by wind power plants since investors tend to choose economically affordable locations.

Table 6 shows the optimal purchasing price for electricity obtained from large power plants, with respect to different alternatives. Evidently, 84 options were categorized as very suitable for large wind turbine establishments, with the lowest price estimated at 0.047, and the highest price at 0.182 US$. These prices appear to drop as wind speed increases in a region and vice versa.

6. Discussion

This study can be divided into two parts (*i*) determining the optimal locations for the construction of wind farms and (*ii*) determining the optimal purchase price of electricity generated by wind farms in these areas. In several studies, different dimensions of determining the optimal locations for the construction of wind farms were investigated [76–80]. The focus of these studies is on the use of MCE to determine optimal locations. The accuracy of the results of multi-criteria spatial decision-making systems depends on (*i*) the comprehensiveness of the effective criteria, (*ii*) the weight accuracy determined for the effective criteria, and (*ii*) the model used to combine the values and weight of the effective criteria.

Based on our knowledge of previous studies and the opinion of experts, a comprehensive set of criteria, including environmental and economic, was considered in assessing the suitability of areas for the construction of wind farms. The BWM was used to determine the weight of the criteria. This weighting method was used for the first time in determining suitable areas for constructing renewable power plants. In previous studies, AHP, ANP, and Fuzzy methods were used. The BWM has notable advantages over other methods. First, it uses fewer pairwise comparisons, and second, it has a higher consistency ratio [50,52,81]. In previous years, this model was used to determine the weight of effective criteria in the field of waste disposal [82–84], bicycle stations [85,86], hospitals [87], and emergency facility planning [88]. Also, in these studies, various models based on MCE, including WLC, AHP, and fuzzy, have been used to determine the optimal locations. Each of these models has advantages and disadvantages. One of the most important limitations of these models is not considering the concept of risk in decision-making. Therefore, in this study, for the first time, OWA has been used to determine suitable locations for the construction of wind farms. OWA output is the mapping of optimal wind farm locations in various risk-based decision scenarios. In recent years, the efficiency of this model has been confirmed in a number of studies in the fields of landfill [89–91], parking [92–94], and ecotourism [95–97].

Several previous studies have used economic models to determine the optimal price of electricity generated by wind and solar power plants [91,98,99]. In this study, the multi-criteria spatial decision-making system and economic model are combined to achieve a more accurate model. The proposed method calculates the optimal price of electricity generated for power plants in optimal areas. The optimal feature of the very suitable locations ensures the highest benefit for the investor and consequently overpayment on the government's part for purchasing electricity from wind-power plants in these locations. Also, this study evaluated suitable areas for construction of large and small wind power plants separately. In previous studies, in determining suitable areas for the construction of wind farms, the power plant size was not considered.

The limitations of the present study are: (i) the lack of accessibility to appropriate data for mapping some of the criteria such as bird habitats and marshlands, (ii) uncertainty in the expert opinions, and (iii) determination of optimal values of the parameters used in the NPV model in different geographical areas. Finally, it is worth noting that the primary concern in developing and applying renewable energy resources is centered on the higher amount of initial investment required compared to fossil fuels. A promising solution incorporates the role of the government in creating opportunities for international agreements and partnerships and further support from private investors. Therefore, it is suggested that fossil fuel subsidies be gradually eliminated so that the acquired investments can be directed towards funding renewable energy projects. Furtherance of private investments and international cooperation can also prove significantly helpful.

7. Conclusions

The global energy scarcity, in conjunction with environmental degradation, has seriously raised concerns around the world to search for alternative resources of renewable energies to replace non-renewable resources. Applying renewable energies would allow for better safety measures and stability in energy production, exempt from the adverse climatic effects of using renewable energies. Renewable energies are recognized as one of the suitable primary alternatives to fossil fuels. Nonetheless, the high rate of investments required for such applications has transformed renewable energies into one of the most expensive energy sources. This, however, was alleviated through new endorsement policies, causing a raise from 11 MW worth of capacity in 1997, to over 303 MW in 2020. This significant increase is indicative of the supportive actions and rather well reception of power plants, particularly wind-power projects. Still, the present installation capacity has not reached its full potential, with plans proceeding toward actions to increase the global installed wind-generation capacity. Present policies in Iran also support investments in wind-power projects and the purchase of electricity at an ensured price for all wind power plants throughout provinces of the country. Accordingly, the present study proposed an integrated model of GIS-MCE for locating optimal sites for establishing small and large wind power plants and NPV for estimating the optimal purchasing price of electricity generated by wind turbines. The best and worst assessment criteria, based on expert opinion and our findings, were wind speed and the distance from the fault. The findings also revealed two scenarios, where reductions in ORness values for both small and large wind power plants resulted in deductions from the proportion of areas in the very suitable and suitable classes while adding to the area of the unsuitable and very unsuitable classes. Our further assessments indicated that the highest share of areas in the very suitable class for large wind power plants exists in Razavi Khorasan, South Khorasan, and Zanjan provinces. However, for small wind turbine establishments, the most significant share of very suitable regions is distributed in Ardabil, Razavi Khorasan, and Zanjan provinces. The highest optimal price was found for Maraghe based on estimates of purchasing price for electricity from large wind-power plants in cities of the very suitable category. The optimal feature of the very suitable locations ensures the highest benefit for the investor and consequently overpayment on the government's part for purchasing electricity from wind-power plants in these locations.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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