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Selection of biogas, solar, and wind power plants' locations: An MCDA approach

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Abstract – This study discusses a multi-criteria approach to locating biogas, solar and wind power plants that significantly addresses the challenge of global warming caused by power generation. Because the utility of locations to build renewable energy power plants depends on economic, social and environmental dimensions, after reviewing literature, the sustainable frameworks of criteria affecting the location of biogas, solar and wind power plants were examined in this paper. The offered frameworks are applied to determining the site of biogas, solar, and wind power plants in Iran. The provinces of Iran are assessed as alternatives in this paper. To compute the weight of criteria in the offered framework, data from a sample of experts in Iran are used via an online survey form designed based on the best-worst method (BWM). Using the results of the BWM and the performance data, the overall score are calculated for the various provinces of Iran. The results of this study indicate that *energy saving*, *effect on resources and natural reserves* and *wind flow*, respectively, are the most effective factors for determining the place of biogas, solar and wind power plants, and South Khorasan, Khuzestan, and Khuzestan show the best result for establishing biogas, solar, and wind power plants in Iran respectively.

Keywords: Biogas; solar and wind power plant location; sustainability; utility of places; best-worst method (BWM)

1. Introduction

The reduction in fossil fuel resources and the increase in global warming as a result of carbon dioxide emissions are considered to be important issues for the near future. The energy sector, which largely depends on fossil fuels, is the major cause of environmental pollutants (Perera 2017). Coal and oil, and their use by fossil fuel power plants generate the emission of CO2, SO2, and other pollutants (Gouw et al. 2014). These issues are far more noticeable in developing countries, for instance in Iran, a developing country, where approximately 80% of the generated power comes from fossil fuels (Shahsavari and Akbari 2018) and is in charge of approximately 28% of the overall CO2 emission in Iran (Shahsavari et al. 2018).

Using renewable energies, not only controls the air pollution caused by the energy sector, it also significantly improves the socio-economic aspects of that sector (Treyer et al. 2014). Choosing a location is the main step in development of renewable energy projects. The utility of each potential location should be examined based on the socio-economic and environmental sustainability (Ghaderi et al. 2016), because choosing the wrong location increases the direct and indirect costs, while creating social and environmental problems which can prevent the development of renewable energy (Fleischer and Felsenstein 2000).

Biogas, solar and wind are the three types of renewable energy that not only are used to meet the challenge of global warming (Panwar et al. 2011) but are also identified as the three main renewable resources in the world. Each type of renewable energy has its own socio-economic and environmental impact, which may make it problematic to use them simultaneously. Identifying the right criteria to choose

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a power plant’s location and calculating the utility of locations based on those criteria are two essential steps that help policy-makers design a comprehensive plan to optimize existing potentials.

The literature review reveals that there are only a few sustainable frameworks none of which covers all the main criteria which affect the location selection of biogas, solar and wind power plants. In this regard, as a first contribution of this paper, we present a sustainable framework which includes all the criteria for biogas, solar and wind power plants location selection. The criteria divided into the three dimensions of sustainability, are identified through a comprehensive literature review. The offered framework not only provides an appropriate reference to assess the location of biogas, solar and wind power plants, it also provides an overview of the criteria that play a role in in different evaluations, like the cost-benefit analysis of the three power plants and the location selection of other renewable facilities.

From an application point of view, as a second contribution of this paper, all the criteria included in the sustainable framework are applied to a real large-scale problem involving the selection of biogas, solar and wind power using a multi-criteria decision analysis (MCDA) approach. In this regard we employ the offered framework in Iran, a country that has a great potential when it comes to renewable energy. For example, it is estimated that 17 to 20% of Iranian crops are waste products (Najafi et al. 2009), the main source of biogas production. Iran also has a great potential when it comes to generating solar and wind power. There are approximately 300 sunny days annually in Iran which can generate at least 9 million MWh of energy each day(Najafi et al. 2015). The nominal capacity of Iran, with a system efficiency of 33%, is about 6500 MWh from wind power generation (Mostafaeipour and Jadidi 2015a).

To determine the suitability of potential locations using an MCDA approach, calculating the weights of the indicators in the offered framework is one of the main steps, for which the best-worst method (BWM) is used, which provides more reliable results than the alternative weighting methods used in other studies (Rezaei 2015).

In brief, the objectives of this research are:

- Identifying the criteria contributing to the biogas, solar and wind facilities location selection.
- Categorizing the identified criteria into economic, social and environmental dimensions.
- Calculating the weight of the criteria categorized into the three dimensions of sustainability.
- Determining the best location of biogas, solar and wind facilities in Iran.

The remainder of the paper is organized as follows: In Section 2, studies focusing on the location of biogas, solar and wind facilities are reviewed to develop a comprehensive framework of criteria. We discuss the methodology applied in this paper in Section 3. In Section 4, the results of the study involving the locations of renewable energy production in Iran are analyzed. In the end, conclusion and suggestions for future research are presented in Section 5.

2. Literature Review

The literature reviewed involving the locations of biogas, solar and wind power plants in this study. The result of that review, the framework of sustainable criteria is presented in Table 1. The identified criteria were divided into the three dimensions of sustainability (economic, environmental, and social). Since the MCDA (multi criteria decision analysis) papers on the locations of biogas, solar and wind power plants are associated with this study, we discuss them below.

2.1. Biogas

Kigozi et al. (2014) used simple multi-attribute rating technique (SMART) and analytic hierarchy process (AHP) to select the suitable bio-digester technology and site in South Africa. Based on the result of that research, “current and future expected land use” was identified as the main criterion with regard to the location of the biogas plant. Höhn et al. (2014) used geographic information system (GIS) and road network analysis for determining the location of biogas plants in Finland. “Natural gas grid availability”, “biomass resource availability”, “material supply and transport”, “closeness to demand point” are the factors utilized in that research. Silva et al. (2014) also determined the location of a biogas plant using GIS and the Elimination et Choice in Translating to Reality (ELECTRE) in Portugal. They used 13 criteria organized into “environmental”, “economic” and “social and safety”. Franco et al. (2015) proposed GAF (GIS-AHP-FWOD) for the location of biogas plants in Denmark. They first measured the attributes of alternatives using GIS and then identified the most suitable location for the biogas power plant via the AHP and fuzzy weighted overlap dominance (FWOD). The results revealed that the weight of “distance to transport economic optimal zones “is greater than that of other criteria in selecting a location for the biogas plant. Galves et al. (2015) suggested a mixed-integer linear programming (MILP) model for designing the chain of biogas reverse logistics in France. The proposed model minimizes the overall costs of reverse logistic. In addition, Akther et al. (2018) proposed GIS and AHP for a biogas digester plant’s location in Bangladesh. They examined locations based on 11 criteria, divided into environmental, social-safety and economic dimensions. Based on the results of AHP, “distance from sensitive areas”, “land use “and “agricultural land “emerged as the three main criteria in that research.

Yücenur et al. (2020) used step-wise weight assessment ratio analysis (SWARA) and complex proportional Assessment (COPRAS) methods to select the best location of biogas power plants in Turkey. They used 12 criteria divided into " location", "cost", "risk" and "raw material" categories. According to the result of this work "distance to raw material" is identified as the main factor. Taraszkiewicz (2019) made use of a hybrid methodology (i.e. AHP and TOPSIS) to determine the best place for biogas power plant in Miastkowo, Poland. "Distance to residential areas", "distance to energy crops", distance to protected habitats", "distance from roads" and "cost of land" are among the criteria utilized in this work.

2.2. Solar

Azadeh et al. (2008) by using data envelopment analysis (DEA) determined the sites of solar plants in Iran. Places in this research were evaluated based on “social”, “geographical” and “technical” criteria. Principal component analysis (PCA) and numerical taxonomy (NT) methods were applied for validation of the results. Azadeh et al. (2011) applied an artificial neural network (ANN) and fuzzy DEA to rank 125 solar plant units in Iran, using criteria categorized into “technical”, “geographical” and “social” dimensions. Kengpol et al. (2013) applied a hybrid methodology including fuzzy AHP and the technique for order of preference by similarity to ideal solution (TOPSIS) to select the appropriate location of solar power plant in Thailand. Candidate locations were assessed on the basis of 19 criteria divided into the five dimensions of “climate”, “geography”, “transportation”, “environment” and “costs”. The results of AHP method in that study showed that “diffuse radiation”, “seismic belt”, “distance from the roadway”, “land use” and “installation cost” have the maximum effect on the location selection of solar power plant in the five dimensions. Sánchez-Lozano et al. (2013) selected solar farm locations using GIS and AHP–TOPSIS in Southeastern Spain, on the basis of “environmental”, “geomorphological”, “locational” and “climatic” criteria. In that study, “distance to power lines”, “solar radiation potential”, “land slope” and “distance to substation “emerged as the main criteria.

Khan and Rathi (2014) proposed GIS for the identification of the best place for a photovoltaic power plant in India. They used 10 criteria for this purpose such as “solar radiation”, “availability of land”, “accessibility from national highways”, “distance from transmission line”, “local climate” and “topography of site”. Effat (2013) looked at meteorological, terrestrial and economic criteria for the selection of solar farm sites in Egypt, using shuttle radar topography mission (SRTM), spatial multi-criteria evaluation (SMCE) model and AHP as a hybrid methodology for site selection. Potential locations were assessed based on give criteria, including “solar radiation”, “topography features”, “proximity to transmission lines”, “proximity to main roads” and “proximity to residences”. Uyan (2013) determined the best location of solar farms in Turkey using AHP and GIS. The locations were rated on “environmental” and “economic “indicators. The results of that research indicated that “land use” and “distance to power lines” were the most important indicators in the environmental and economic categories, respectively. Chen et al. (2014) selected the location of solar farms in Taiwan by applying decision-making trial and evaluation laboratory (DEMATEL), analytic network process (ANP), and GIS as a hybrid methodology. Locations were evaluated on the basis of factors involving “environment”, “orography”, “location” and “climatology”. The results of DANP method showed that “solar radiation”, “temperature” and “distance to residence” are the main factors in the solar farms location selection problem. Vafaeipour et al. (2014) looked at criteria from “economic”, “technical”, “environmental”, “social” and “risk” aspects in identifying suitable regions to build solar power plants in Iran, applying GIS, step-wise weight assessment ratio analysis (SWARA), weighted aggregates sum product assessment (WASPAS), and Delphi as a hybrid methodology. The results indicated that the weight of "investment cost", "transmission grid accessibility", "demand" and "economic risk" is greater than that of other criteria in the solar power plant location in Iran. Mondino et al. (2014) also used a multi-layer perceptron ANN to select the place of a large photovoltaic plant in Italy, using two types of criteria, exclusion/inclusion and quantification. Lee et al. (2015) conducted a study to identify the location of solar plant in Taiwan, and used a hybrid fuzzy AHP assurance region DEA to evaluate the efficiency of candidate places. The sites were evaluated based on 12 criteria, divided into three categories: "policies", "costs" and "environmental conditions". The results of fuzzy AHP indicated that "service life", "operation and maintenance cost", "wildlife and habitat", are the main criteria in the three dimensions.

Tahri et al. (2015) determined the location of a solar farm with AHP-GIS in Sothern Morocco based on criteria involving "orography", "location" and "climate", identifying "solar radiation", "temperature" and "slope" as the three main criteria. Singh et al. (2016) applied a modified digital logic approach and fuzzy AHP to help India improve the use of its available solar resources, using six criteria. Based on the research results, "solar radiation", "energy demand" and "land availability "emerged as the most important criteria. Sánchez-Lozano et al. (2016) also applied GIS, AHP, TOPSIS and ELECTRRE TRI to identify the appropriate places for solar photovoltaic power plants in Spain, first determining the weights of the 10 criteria via AHP, and then evaluating the locations via TOPSIS and ELECTERE TRI. Liu et al. (2017) used grey cumulative prospect theory as a methodology to choose the best sites for photovoltaic power plants in China, using "environmental", "geographical" and "economic" dimensions. The results of that research indicated that, of the eight criteria that were applied, "initial investment", "total revenue" and "carbon dioxide emission saving" were identified as the main factors. Sindhu et al. (2017) selected the best location of solar farms using AHP and TOPSIS in India, based on "political", "environmental", "social", "technical" and "economic" criteria. Their research showed that "land acquisition", "road and rail accessibility" and "solar radiation data availability" have the greatest weight in the solar farms' location selection problem. Azizkhani et al. (2017) used AHP to choose photovoltaic power plants location in Iran, based on "global horizontal irradiance", "economic", "technical" and "land use" criteria. Their research indicated that the criteria in the "global horizontal irradiance dimension" have the greatest weight in selecting the location of photovoltaic power plants. Lee et al. (2017), finally, selected the most appropriate place for a photovoltaic plant in Taiwan using fuzzy ANP, interpretive structural modeling (ISM) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). Places in this paper were evaluated based on 10 criteria categorized into four dimensions of "costs", "biological environment, physical environment", and "economic development".

Ozdemir and Sahin (2018) selected solar PV power plant location in Turkey, by using the AHP on the basis of "potential energy production", "environmental factors", "safety", "distance from existing transmission line" and "topographical properties" criteria. Finally, the results demonstrated that "topographical properties" was weighted as the main factor. Wang et al. (2018) applied a hybrid methodology including fuzzy AHP, DEA and TOPSIS to select the appropriate location of solar power plant in Vietnam. Candidate locations were assessed on the basis of 15 criteria divided into the five dimensions of "social", "environment", "technological", "economic" and "site characteristics". The results of AHP method in that study showed that "sunshine hours" has the maximum effect on the location selection problem.

2.3. Wind

Aras et al. (2004) employed AHP to identify wind observation station place in Turkey, using 12 criteria categorized into 5 dimensions involving, "infrastructure", "costs", "transportation", "topography" and "security". The outcome of their research showed that the criteria included in the topography and security dimensions have the main impact on the wind station location selection problem. Chatterjee and Bose (2012) proposed the complex proportional assessment-fuzzy technique in a group decision-making environment to identify wind farms site in India. "Average wind speed", "average air density", "grid connection cost" and "payback period" were identified as the main factors. Gamboa and Munda (2007) suggested a mathematical model to specify wind farm sites in Spain. To that end they employed a framework of criteria which includes "socio-economic", "socio-ecological" and "technical" dimensions. "Number of jobs", "construction tax", "visual impact", "avoided CO2 emissions" and "installed capacity" are among the criteria considered in that research. Azadeh et al. (2011) employed DEA to select wind farms places in Iran, using "technical", "geographical" and "social" criteria, validating the results of the proposed method using PCA and numerical taxonomy methods. Azadeh et al. (2014) also applied fuzzy DEA to specify wind farm site in Iran, validating the results with PCA and numerical taxonomy methods. Wu et al.

(2014) using a hybrid methodology i.e. fuzzy Choquet and fuzzy ordered geometric averaging, identified wind farm site in in China, looking at criteria including “quality”, “economy”, “risk”, “environment” and “contribution”. Satkin et al. (2014) employed ArcGIS software to determine appropriate locations for wind-compressed zone in Iran. “Resource of wind”, “availability of grid connection”, “possibility for energy storage” and “environmental-economical suitability “were the criteria that were applied in that paper. Samiei and Arvan (2015) determined the most appropriate location a wind farm in 24 nominal locations in Iran, using a hybrid methodology including discrete event simulation and DEA. The performance of candidate locations was determined through “access to the workforce”, “number of geological places”, “severity of natural disasters” and “the situation of topography” which were used as indicators in that study.

Mostafaeipour and Jadidi (2015b) also ranked five cities of Sistan and Baluchistan (south-east province of Iran) for a wind turbine, using DEA to determine its optimal location and validating the results via the simple additive weighting (SAW) method. The potential locations were evaluated using five criteria from “economic”, “social” and “environmental” aspects. Latinopoulos and Kechagia (2015) using a hybrid methodology including GIS and a MCDA method selected the best location of wind farms in Greece. Criteria in this study were categorized into “economic”, “social”, “technical” and “environmental” dimensions. Wu et al. (2016) selected the suitable location for an offshore wind farm in China using 22 sub-criteria, divided into six dimensions and fuzzy ELECTRE III employed as methodology. Villacreses et al. (2017), finally, analyzed candidate places in Ecuador for wind power plants, using AHP and ordered weighted averaging to determine the weight of 9 indicators, divided into “meteorological”, “relief-related”, “locational” and “environmental” criteria, ranking potential locations using VIKOR and TOPSIS. Wind speed, slope, air density and distance to electrical substations were identified as the main criteria in that research.

Toklu and Uygun (2018) utilized FAHP and fuzzy axiomatic design (FAD) methods to identify wind power plant location in Turkey, using five criteria including "wind speed", "wind power density", "capacity factor", "distance to power grid" and "land roughness value." The outcome of their research showed that “wind speed " has the main impact on the wind station location selection problem. Moradi et al. (2020) using a hybrid methodology including ArcGIS and AHP method selected the best location of wind farms in Alborz, Iran. Criteria in this study were "wind speed", "slope", "power line", "power station", "urban area" and "roads". "Wind speed" was identified as the main criteria in that research.

Based on a comprehensive review of existing literature, we have compiled a list of criteria for the three dimensions of sustainability used to select the best places for biogas, solar and wind power plants (see Table 1).

It is worth mention that to categorize the criteria into the three dimensions of sustainability the following approach is used in this research:

- All criteria which are related to environmental protection are categorized into environmental dimension.
- People, government and social rules and regulations are categorized as social factors.
- In the economic dimension we are dealing with cost and income indicators.

As the literature review shows, AHP is a popular method to calculate the weight of indicators affecting the selection of the location for biogas, solar and wind power plants. However, the BWM performs better than AHP in a number of aspects. BWM that determines the weight of criteria based on pairwise comparison helps decision-makers conduct a very systematic evaluation. Since BWM involves fewer comparisons than AHP, the consistency rate of BWM is considerably better than that of AHP (Rezaei 2015). BWM is easy to use, because it uses integers, and the number of pairwise comparisons is efficient, because it uses two vectors of pairwise comparisons, which, compared to a matrix-based MCDA method like AHP, uses fewer comparisons, which is particularly useful when there are multiple criteria and the number of knowledgeable respondents willing to take part is limited (Rezaei 2020).

3. Methodology

As discussed earlier, selecting a power plant’s optimal location is a multi-criteria decision-making problem (Nie et al. 2017), because there are a number of alternative locations to be evaluated along a set of criteria, which leads us to propose a MCDA method to formulate and solve the problem. In this study, we used a newly developed MCDA method called the best worst method (BWM), a pairwise comparison-based weighting method (Rezaei 2015 and 2016). The method has been applied successfully in many real-world cases, including information system

Table 1. Effective criteria on the utility of biogas, solar and wind power plants' location

Category	Criteria	Sub-criteria
Social	Policy and legal support (S, W)	
	Availability of labor (W)	
	Work force (W)	
	Acceptance (B, S, W)	
	Quality of life (S)	Public security (S, W) Education (W)
	Impact on Society (S, W)	Society benefits (W) Improvement of life quality (S, W) Jobs generated (W) Infrastructure and industrial development (S, W) Distance to the residential area (S, W) Economic disadvantage (S, W) Effect on agriculture (S, W) Effect on tourism (S, W)
Environmental	Ecologically sensitive areas (S, W)	Tropical forest (S, W) Biosphere reserve (S, W) Important lake (S, W) Coastal areas and rich in coral formation (S, W)
	Effect on protected areas (S, W)	
	Effect on resources and natural reserves (S, W)	
	Energy-saving (B, W)	
	Distance from historical-tourist areas (S, W)	
Economic	Investment costs (B, S, W)	Topographical features (S, W) Field cost (B, S, W) Infrastructure cost (S, W) Provincial finance subsidies (S, W)
	Production and operation costs (B, S, W)	Maintenance cost (B, S, W) Intensity of natural disasters (W) Volcanic hazard (B, S, W) Earthquake (B, S, W) Storm (B, S, W) Thunderbolt Access to expert (W) Access to equipment (W) Climate condition (B, S) Moisture (B, S) Pressure (B, S) Temperature (B, S)
	Stability in supply (B, S, W)	Resources (B, S, W) Area potential (B, S, W) Land availability (B, S) Soil quality (S, W)
	Demand (B, S, W)	
	Transportation accessibility (B, S, W)	Proximity to rail way (B, S, W) Proximity to airport (B, S, W) Proximity to highway/ road (B, S, W)
	Safety and security cost (S)	
	NPV (S, W)	
	Payback period (S, W)	

The letters B, S, and W next to each criterion indicate that that factor was taken from biogas, solar and wind facility location' paper(s), respectively management (Kheybari et al. 2020), location selection (Kheybari et al. 2020, Pamučar et al. 2017, Kheybari et al. 2019, Stević et al. 2018) sustainability (Kheybari et al. 2019, Amoozad Mahdiraji et al. 2018, Liu et al. 2019), technology selection (van de Kaa et al. 2017, Yang et al. 2018, Kheybari et al. 2019), emergency decision making (Ding and Liu 2019), reliability engineering(Liu et al., 2018), customer requirements(Huang et al. 2019) and supply chain management (Rezaei, et al. 2017, Ahmad. et al. 2017, Ahmad et al. 2016). The steps of BWM for determining the weights of criteria $\left(w_{1,}^{*} w_{2}^{*}, \ldots, w_{n}^{*}\right)$ are as follows:

Step 1. Determine a set of decision criteria $\{c_1,\ c_2, \ldots, c_n\}$.
Step 2. Determine the best (*B*) and the worst (*W*) criteria.
Step 3. Determine the preference of the best criterion (*B*) over all the other criteria, using a number from 1 to 9 (where 1 is equally important and 9 is extremely more important). The result of “Best-to-Others” comparisons is the vector $A_B = \left(a_{B1},\ a_{B2}, \ldots, a_{Bj}, \ldots., \ a_{Bn}\right)$, where a_{Bj} indicates the preference of criterion *B* over criterion *j* .
Step 4. Determine the preference of all the criteria over the worst. The result of “Others-to-Worst” comparisons is the vector $A_w = \left(a_{1W},\ a_{2W}, \ldots, a_{jW}, \ldots., \ a_{nW}\right)$, where a_{jW} denotes the preference of criterion *j* over criterion *W*.
Step 5. Calculate the optimal weights $\left(w_{1,}^{*} w_{2}^{*}, \ldots, w_{n}^{*}\right)$.

The optimal weights are calculated by minimizing the maximum absolute difference of $\left\{\left|w_B - a_{Bj} w_j\right|, \left|w_j - a_{jW} w_W\right|\right\}$ for all *j*, which is translated into the following optimization model:

$$\begin{aligned} &\min max_j \left\{\left|w_B - a_{Bj} w_j\right|, \left|w_j - a_{jW} w_w\right|\right\} \\ &\quad \text{subject to} \\ &\quad \textstyle\sum_j w_j = 1 \\ &\quad w_j \geq 0, \text{for all } j \end{aligned} \tag{1}$$

Model (1) can be transferred into:

$$\begin{aligned} &\min \xi \\ &\quad \text{subject to} \\ &\quad \left|w_B - a_{Bj} w_j\right| \leq \xi, \text{for all } j \\ &\quad \left|w_j - a_{jW} w_W\right| \leq \xi, \text{for all } j \\ &\quad \textstyle\sum_j w_j = 1 \\ &\quad w_j \geq 0, \text{for all} \end{aligned} \tag{2}$$

The optimal weight for the criteria $\left(w_{1,}^{*} w_{2}^{*}, \ldots, w_{n}^{*}\right)$ is calculated by solving Model (2). The minimum value of the objective function in Model (2) (ξ^*) indicates the consistency of the final results, which means that it shows the level of the veracity between the provided pairwise comparisons provided by the decision-maker (respondent) and the optimal weights obtained from the model. If its value is close to zero, that implies a high level of consistency in the pairwise comparisons provided by the respondent.

When there is an MCDA problem with more than one level, the local weights for each level are first calculated by following BWM steps, after which the global weights are determined thorough multiplying the local weights of the sub-criteria by the weight of the associated main criterion. After determining the global weights of all the criteria, the overall score (utility) of each place is determined by Equation (3):

$$V_i = \sum_{j=1}^{n} w_j u_{ij} \quad \text{for all } i \tag{3}$$

Where u_{ij} is the normalized value of option *i* in indicator *j*, and u_{ij} are computed by Equations 4 and 5 for positive and negative criteria, respectively.

$$u_{ij} = \frac{x_{ij} - \min\limits_{i}(x_{ij})}{\max\limits_{i}(x_{ij}) - \min\limits_{i}(x_{ij})} \qquad \text{for all } i \text{ and benefit criteria} \tag{4}$$

$$u_{ij} = \frac{\max\limits_{i}(x_{ij}) - x_{ij}}{\max\limits_{i}(x_{ij}) - \min\limits_{i}(x_{ij})} \qquad \text{for all } i \text{ and cost criteria} \tag{5}$$

3.1. Data Collection

To apply the proposed methodology, we first screened the criteria affecting the utility of solar and wind power plant location presented in Section 2 (see Table 1). By increasing the number of criteria, the decision-maker's discrimination power is reduced (Wanke et al. 2016) and the reliability of comparing criteria decreases (Rezaei 2015). For screening criteria, the opinion of experts who work and study in these areas was collected using an online questionnaire scored on a five-point Likert scale. After collecting the questionnaires and aggregating the expert opinions, and after testing several values, the scores of 2.3 and 2.9 (out of 5) were considered for the selection of appropriate criteria applied to calculate the utility of places where solar and wind power plants are established, respectively. We selected these values such that the number of sub-criteria in the three dimensions of the offered framework is balanced (having a meaningful and similar number of criteria per dimensions and per main criteria (Pfeffer 2003). The results of the screening process are shown in Figure 1. Please note that since criteria contributed to biogas facility location selection is less than 9 in each dimension, we did not screen them.

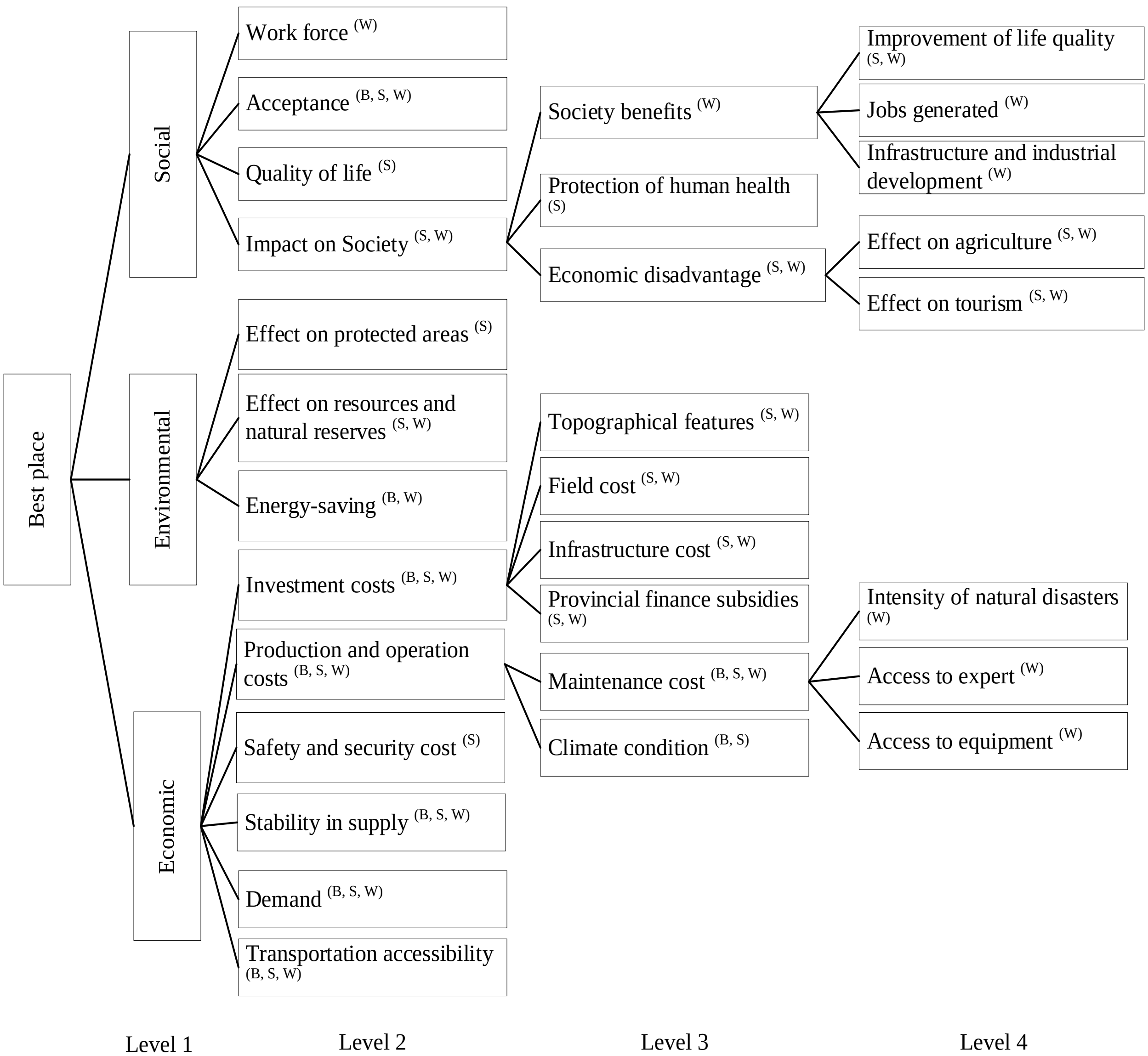

Figure 1. Hierarchical tree for criteria

To compute the weight of the criteria in Figure 1, we designed a BWM-based online questionnaire. The specifications for the experts involved in answering the questionnaire are summarized in Table 2. All experts that have been identified have conducted extensive studies, as well as having practical experience with biogas, solar or wind facilities. Because renewable energies are a new industry in Iran, researchers at universities and related research institutes were also included as respondents in this research, based on their online profile. The data collection process for screening and weighting the criteria took 39 and 80 days, respectively.

Table 2. Specifications of experts

Power plant	Respondents	For screening criteria	Average years of work experience	For weighting criteria	Average years of work experience
Solar	Faculty members (Ph.D.)	4	9.25	4	3.5
	Ph.D. candidate	-	-	2	3.5
	Ministry of energy	-	-	19	7.16
	Renewable Energy and Energy Efficiency Organization	-	-	8	4.25
Wind	Faculty members (Ph.D.)	4	9.25	4	3.5
	Ph.D. candidate	-	-	2	3.5
	Ministry of energy	-	-	21	7.48
	Renewable Energy and Energy Efficiency Organization	-	-	6	5.7
Biogas	Faculty members (Ph.D.)	-	-	12	12.83
	Ph.D. candidates	-	-	7	4.43
	Research Institute of Petroleum Industry	-	-	2	7.5
	Renewable Energy and Energy Efficiency Organization	-	-	3	7.7
	Niroo Research Institute	-	-	7	7.6

The quantitative data for alternatives, i.e. the provinces of Iran, were collected from the websites of the Statistical Center of Iran, Ministry of Science, Research and Technology, Institute for Research and Planning in Higher Education, Ministry of Culture and Islamic Guidance, Ministry of Housing and Urban Development, Law Enforcement Force of the Islamic Republic of Iran, Ministry of Health and Medical Education, Ministry of Energy, Iran Meteorological Organization, and the Ministry of Petroleum. The performance of alternatives in qualitative criteria, including provincial subsidies and climate conditions, was determined by experts in the final part of BWM survey using a ten-point Likert scale. It should be mentioned that to aggregate the expert opinion for both BWM and alternative evaluation, we used arithmetic mean.

4. Results and Discussion

We assessed alternatives based on the categories of "*economic", "social"* and "*environmental"* sustainability. Their effect on the location of biogas, solar and wind power plants is shown in Figure 2.

According to the experts, "economic", "environmental" and social "dimensions" are the three main dimensions for determining the utility of locations (see Figure 2). Low cost of fossil fuels in Iran (Payam and Taheri 2018) and the instability of Iran's economy (Hoolari et al. 2014) are the main reasons which justify the high weight of economic dimension. Below, the weights of sub-criteria in the three dimensions for each facility are discussed separately.

4.1. Biogas

The results of local weight for the sub-criteria affecting the utility of biogas power plant's location are presented in Figures 3 and 4. Since there is just one sub-criterion affecting the utility of the location of a biogas power plant in the "environmental" and "social" dimensions, the weight of sub-criteria in the "economic" dimension is analyzed in this section. "Investment costs" was selected as the main factor by experts in the "economic" dimension, possibly due to unsustainable economic conditions and high investment risks due to economic

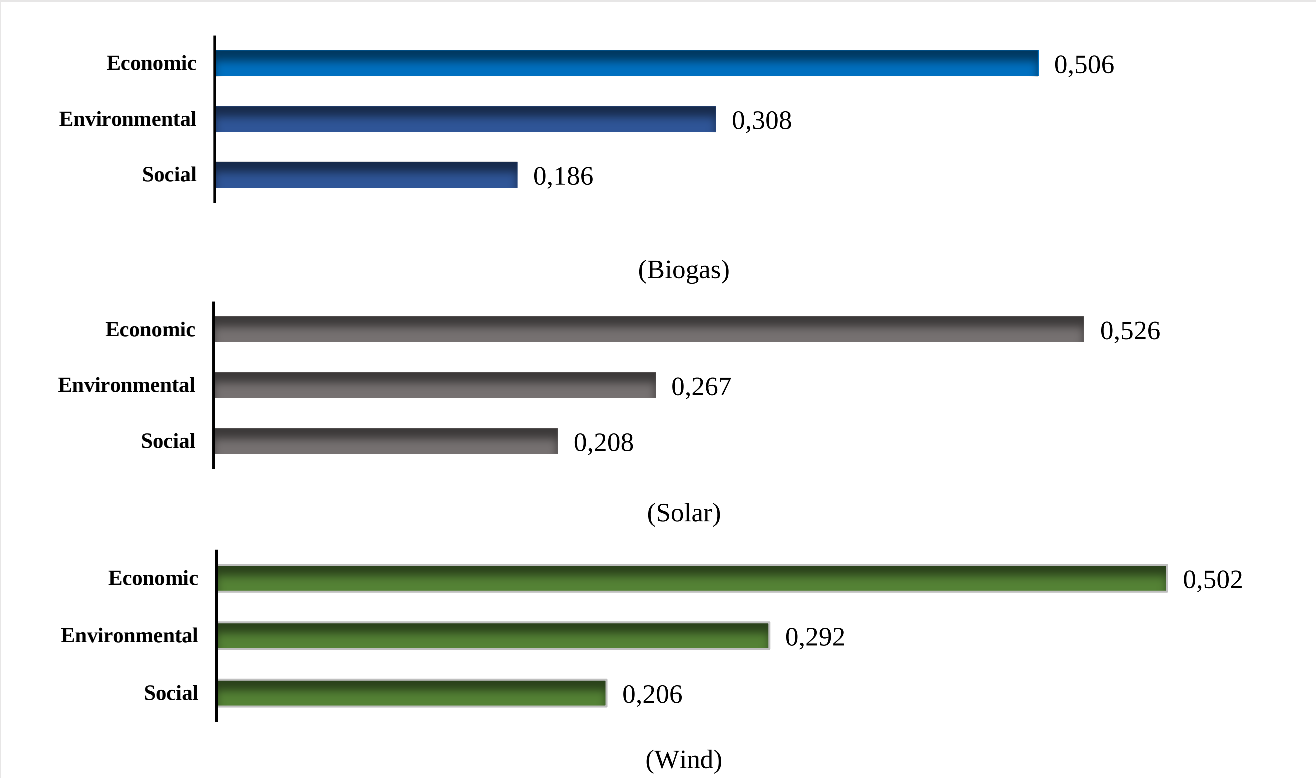

Figure 2. Weight of the criteria in level 1

sanctions (Esfahani and Pesaran 2009). “Production and operation costs”, “stability in supply and demand”, and “transportation accessibility” are other important criteria in this dimension (see Figure 3).

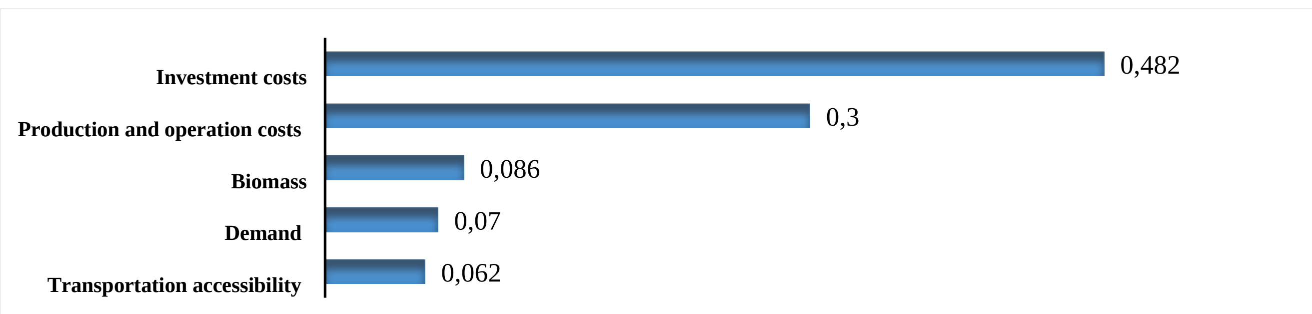

Figure 3. Weight of the criteria in level 2 (Biogas)

Experts also indicated “maintenance cost”, divided into “production and operating costs”, as the most important factor in comparison to “climatic conditions” (see Figure 4). Economic sanctions of Iran have culminated in the lack of specialists and equipment, which in turn, increases the production costs (Sabouhi et al. 2016), this would explain this type of weighting.

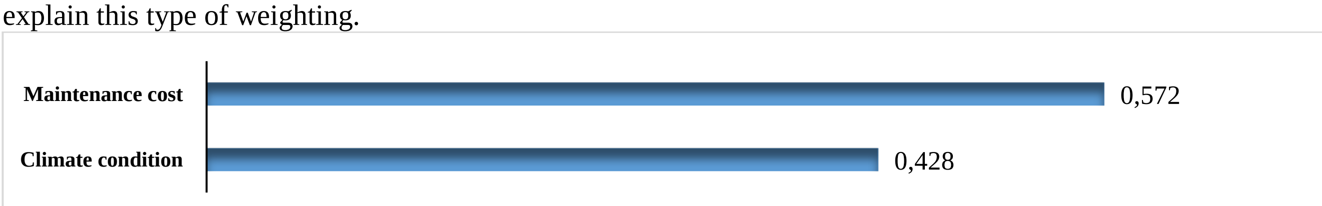

Figure 4. Weight of the criteria in level 3 (Biogas)

4.2. Solar

The results with regard to the location of solar power plants are shown in Figures 5, 6 and 7. Similar to the results of the studies conducted by Boran et al. (2010), Xiao et al. (2013), Chen et al. (2014) and Tahri et al. (2015), the “solar radiation” is considered the most important factor. For this type of weighting, the fact that there are variety of climatic conditions in Iran (Ahmadi et al. 2018) is the most important reason, because the efficiency of solar power plants depends on solar radiation (Wagh and Walke 2017, Zhou and Sun 2014). “Investment costs”, “production and operation costs”, “demand”, “safety and security”, and “transportation accessibility” are other important “economic” criteria (see Figure 5-A). Between the two criteria of the “environmental” dimension, expert selected the “effect on resources and natural reserves” as the most important criterion, because various resources, including water, forests and soil are faced with considerable challenge in recent years in Iran (Saeid 2017) and the establishment of solar power plants, which would require a lot of land (Boudaoud et al. 2015) could exacerbate the situation (see Figure 5-B). According to the experts, the “quality of life” is the main factor in the “social” dimension. Building solar power plants creates several problems, like increasing the temperature (Singh et al. 2016). Therefore, it is necessary that the location where the solar power plant is established have a high level of welfare. Because renewable energy is a new industry in Iran (Mollahosseini et al. 2017), building solar power plants may increase social dissatisfaction and disapproval among residents. “Impact on society” and “acceptance” were weighted as other two indicators in the “social” dimension (see Figure 5-C).

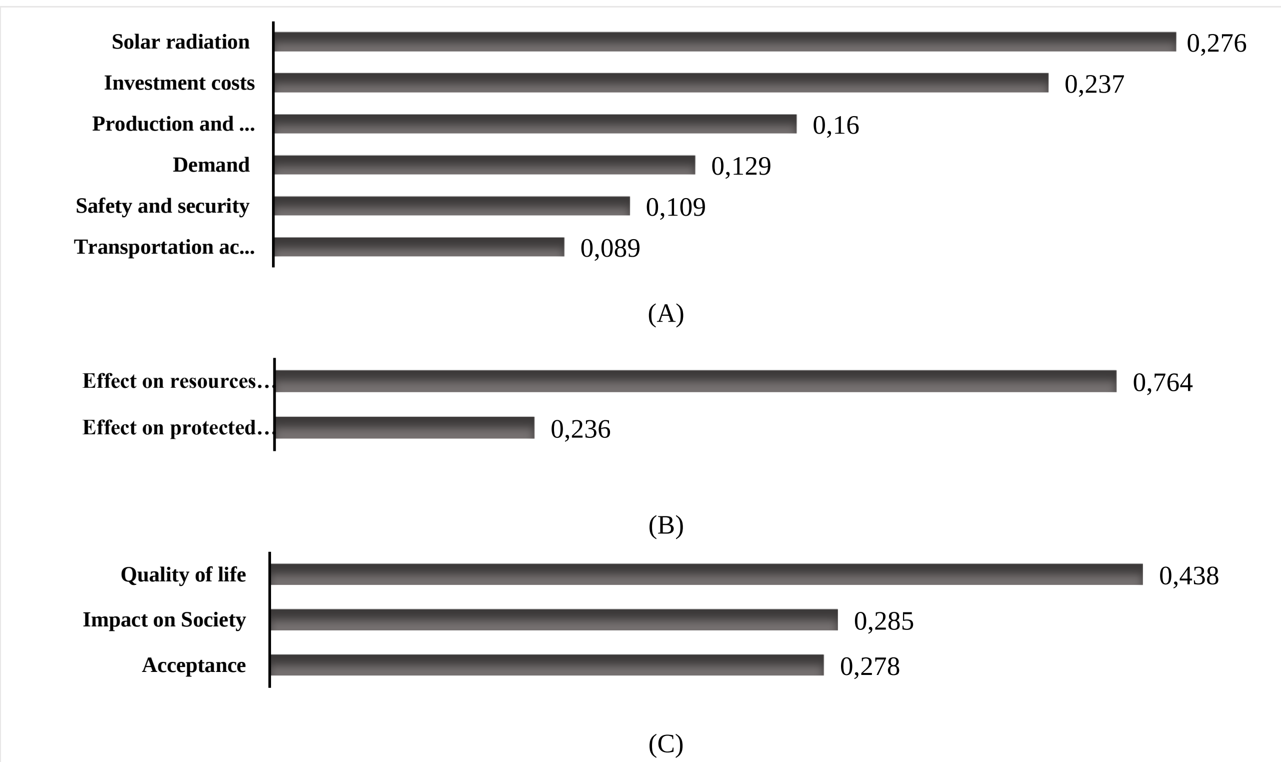

Figure 5. Weight of the criteria in level 2 (Solar)

Of the two sub-criteria in the category of “production and operating costs”, “maintenance costs” is more important than “climate condition” (see Figure 6-A), for reasons which we explained in the Biogas section. The experts considered “provincial subsidies” the most essential sub-criterion in the category of “investment costs”, due to the high cost of starting up solar power plants, added to the shaky economic conditions of Iran (Enevoldsen and Sovacool 2016, Esfahani and Pesaran 2009). “Infrastructure cost”, “topographical features” and “fields cost” are other criteria that affect the choice of location for solar power plants in this category (see Figure 6-B). Distance to the residential area”, with a slight difference with the “improvement of the quality of life”, was chosen as the main sub-criterion in the “impact on society” category; possibly due to the air pollution problems caused by solar power generation facilities in Iran (Qureshi et al. 2014). Since some of the materials used in solar cells generate greenhouse gases (Poindexter et al. 2017), locations that have less air pollution are considered to be more suitable solar power plants (see Figure 6-C).

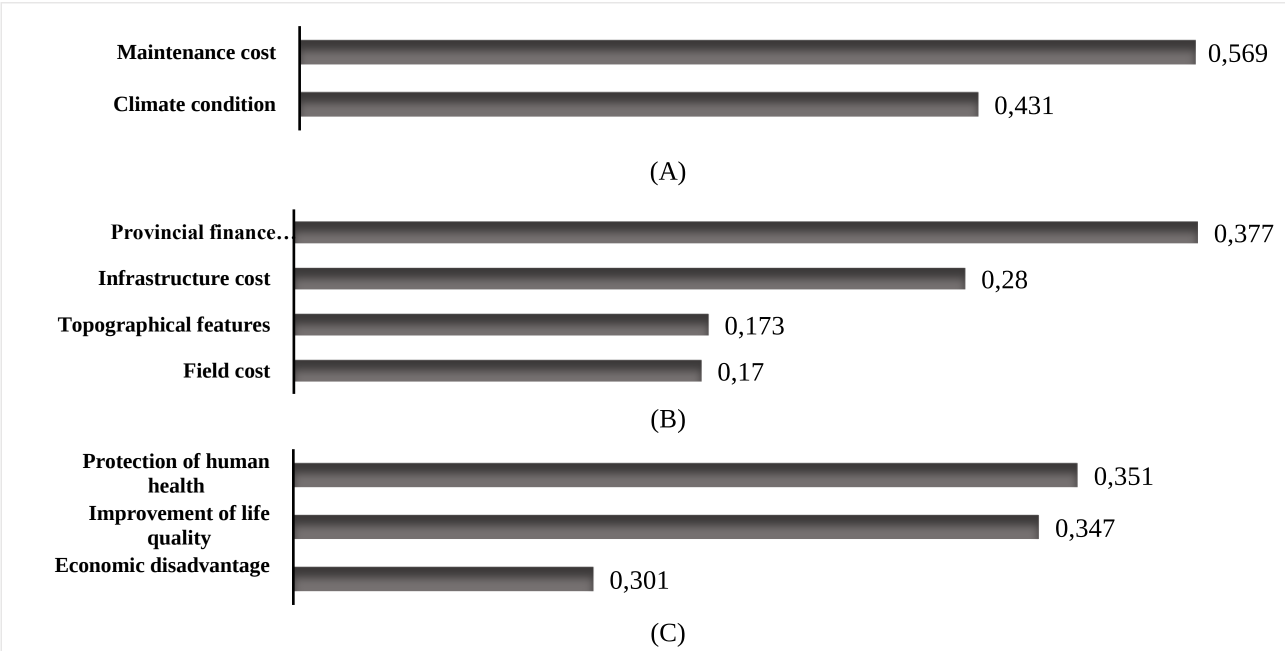

Figure 6. Weight of the criteria in level 3 (Solar)

The "effect on agriculture" was chosen as the primary criterion in the "economic disadvantage" category, followed at a great distance by the "effect on tourism" (see Figure 7), because temperature changes by solar power plants may have devastating effects on agricultural production, which plays a crucial role in the country's economy.

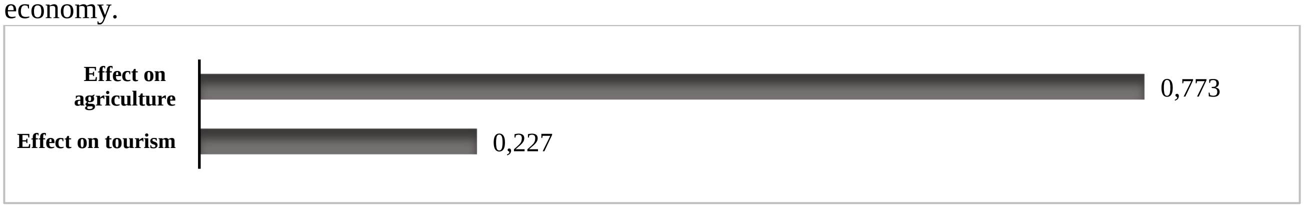

Figure 7. Weight of the criteria in level 4 (Solar)

4.3. Wind

The results for the wind power plant location are shown in Figures 8, 9, and 10. As indicated in Figure 8-A, "wind flow" (stability in supply) was considered to be the main sub-criterion in the "economic" dimension. For a country like Iran, with four seasons (Ahmadi et al. 2018), it is difficult to find a location with a stable and strong wind flow. This finding is consistent with the results of Wu et al. (2014), Azizi et al. (2014), and Nasehi et al. (2016). "Investment cost", "production and operation cost", "demand" and "transportation accessibility "are other important criteria in this category (see Figure 8-A).

According to the experts, the "effect on resources and natural reserves" is a more important criterion than "energy saving" in determining how suitable a location is for the wind power plant (see Figure 8-B), because a big land area is required to build wind farms. Of the three criteria in the "social" category, "workforce" was chosen as the primary factor by the experts. Because renewable energy is a new industry in Iran, there are few specialists in this country, while their presence is essential for the exploitation of wind farms (Sabouhi et al. 2016). "Impact on society" and "acceptance" are the other two major criteria in this category with a small difference (see Figure 8-C).

"Field cost" was chosen by the experts as the most important sub-criterion in the "investment cost" category, perhaps due to rising land prices and the fact that a lot of land is needed for wind farms (Enevoldsen and Sovacool 2016). "Provincial subsidies", "infrastructure cost", and "topographical features" are the other important factors in this category (see Figure 9-A). In the “maintenance cost” category, the “intensity of natural disasters” was indicated as the main factor, probably due to the large number of natural disasters in Iran (Amiri et al. 2013). “Access to experts” and “equipment” are the other two important factors in this category (see Figure 9-B). As far as the “impact on society” is concerned, “economic disadvantage” was considered to be more important than “social benefits” (see Figure 9-C), which may be due to the shaky economic conditions of Iran (Esfahani and Pesaran 2009).

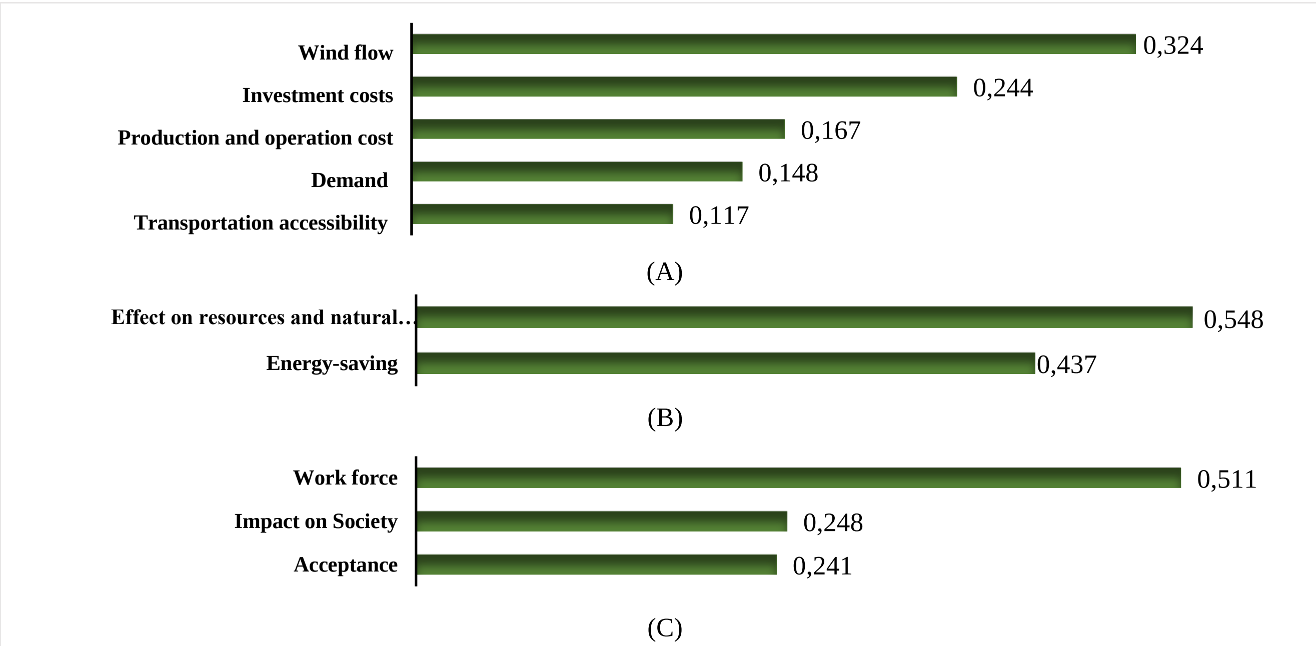

Figure 8. Weight of the criteria in level 2 (Wind)

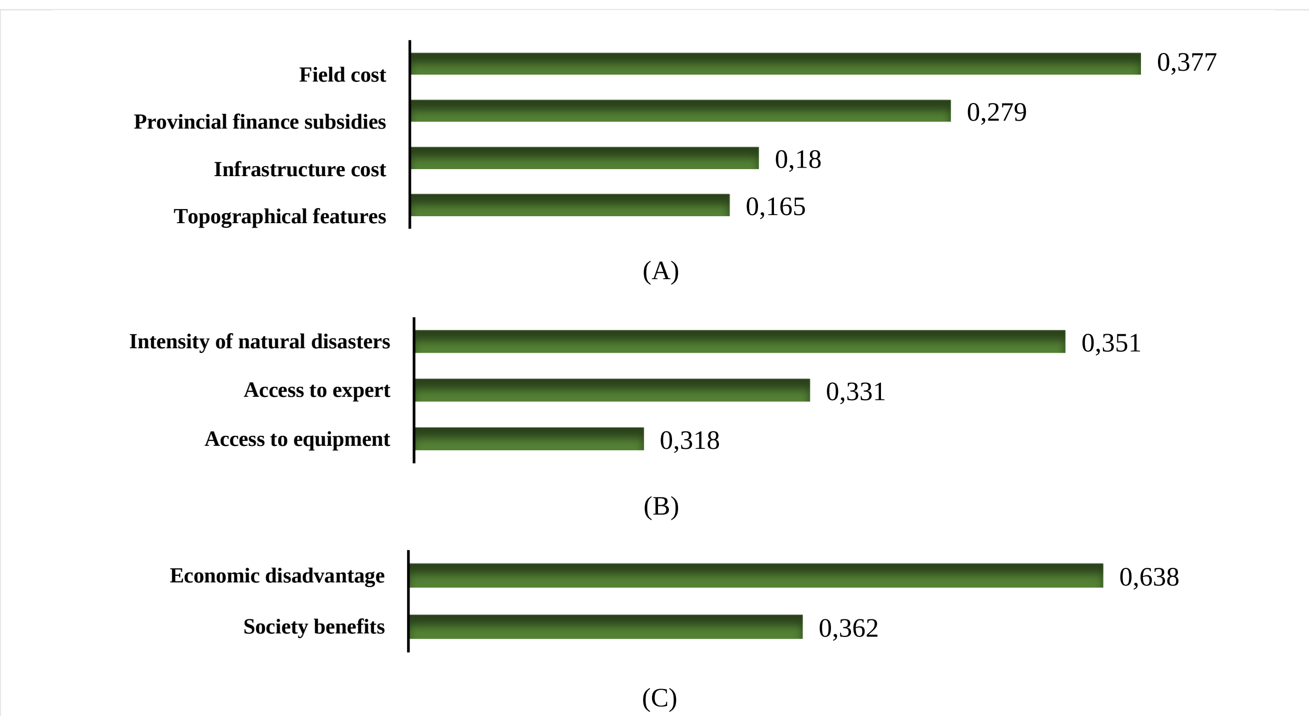

Figure 9. Weight of the criteria in level 3 (Wind)

Experts also chose “jobs generated” as the most important criterion among the three criteria in the “social benefits” category, because of the high unemployment figures in Iran. “Improvement of the quality of life” and “infrastructure and industrial development” are other major criteria in this category (see Figure 10-A). Of the two criteria into the “economic disadvantage” category, the “effect on agriculture” was considered to be more important than the “effect on tourism” (see Figure 10-B), for the same reason as the one outlined earlier.

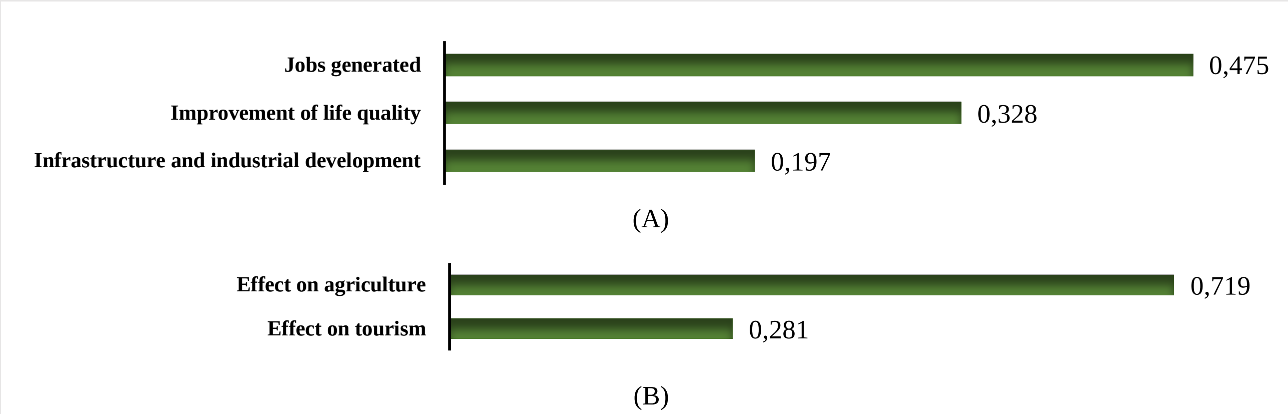

Figure 10. Weight of the criteria in level 4 (Wind)

As mentioned before, using the weights of the main criteria and the local weights of the sub-criteria, by multiplying the weights of the sub-criteria by the weight of their associated main criteria, allowed us to identify the global weights of all the criteria, which are shown in Table 3.

4.4. Utility of Places

To calculate the suitability of the different Iranian provinces for building biogas, solar and wind power plants, V_i in Equation 3 was calculated. The weight of criteria (w_j) and provinces' score in criteria (u_{ij}) are two factors for calculating V_i. The global weight of criteria presented in Figures 11, 12, and 13 for w_j and the normalized data from Equations 4 or 5 for u_{ij} (see Tables A, B, and C in Appendix) were utilized.

According to the results of V_i presented in Table 4, from among 31 provinces of Iran, South Khorasan, Khuzestan, and Khuzestan are the most suitable for building biogas, solar and wind power plants, respectively. Province of South Khorasan is located in the northeast of Iran, with a population of approximately 768,898. The performance of South Khorasan in social and environmental dimensions, compared to the other provinces, is the main reason that it is the most suitable for building a biogas and wind power plant. Khuzestan is a province in the south of the country, with a population of over 4.7 million. The effect on resources and natural reserves, infrastructure cost, and provincial finance subsidies are reasons for selecting Khuzestan as the first alternative for building solar and wind power plants. Based on the research outcomes, Tehran, Semnan and Tehran provinces are the least suitable for building establishing biogas, solar and wind power plants, respectively (see Table 4).

5. Conclusion and Future Research

The aim of this study was to determine the locations of biogas, solar, and wind power plants in Iran. To calculate the suitability of different locations, we started by identifying relevant criteria, and dividing them into three sustainability dimensions, namely economic, social and environmental. Finally, BWM was used to determine the suitability of the different provinces of Iran for building biogas, solar and wind power plants.

According to the results of the BWM, energy saving, solar radiation and wind flow are the most effective criteria on the utility of places for establishing biogas, solar, and wind facilities, respectively. The provinces of South Khorasan, Khuzestan and Khuzestan turned out to be the most suitable candidates for building biogas, solar, and wind facilities, respectively. The lack of qualified experts in Iran to complete the questionnaires was the main limitation of this study.

This study has a number of managerial implications. Firstly, the offered framework provides an overview for decision-makers with regard to the aspects of establishing renewable energy facilities. Secondly, the results of the BWM regarding the impact of each criterion on the suitability of locations can help policy-makers prioritize their decisions. Finally, the results of this study can help the Iranian government to arrive at the optimal number of biogas, solar, and wind facilities in the country.

Table 3. Global weight of criteria biogas, solar and wind

	Criteria	Weight	Rank
Biogas	Energy saving	0.3084	1
	Investment cost	0.244	2
	Acceptance	0.1855	3
	Maintenance cost	0.087	4
	Climate condition	0.065	5
	Biomass	0.0434	6
	Demand	0.0353	7
	Transportation accessibility	0.0313	8
Solar	Effect on resources and natural reserves	0.2037	1
	Sun radiation	0.1449	2
	Quality of life	0.091	3
	Demand	0.0681	4
	Effect on protected areas	0.0629	5
	Acceptance	0.0577	6
	Safety and security cost	0.0575	7
	Maintenance cost	0.0477	8
	Provincial finance subsidies	0.047	9
	Transportation accessibility	0.0466	10
	Climate condition	0.0362	11
	Infrastructure cost	0.0349	12
	Topographical features	0.0216	13
	Field cost	0.0211	14
	Distance to the residential area	0.0208	15
	Improvement of life quality	0.0206	16
	Effect on agriculture	0.0138	17
	Effect on tourism	0.0041	18
Wind	Wind flow	0.1564	1
	Effect on resources and natural reserves	0.1562	2
	Energy saving	0.1371	3
	Work force	0.1102	4
	Demand	0.0763	5
	Transportation accessibility	0.0605	6
	Field cost	0.0458	7
	Acceptance	0.0453	8
	Provincial finance subsidies	0.0337	9
	Intensity of natural disasters	0.0282	10
	Access to equipment	0.0272	11
	Access to expert	0.0265	12
	Effect on agriculture	0.0263	13
	Infrastructure cost	0.0241	14
	Topographical features	0.0196	15
	Jobs generated	0.0087	16
	Effect on tourism	0.0075	17
	Improvement of life quality	0.0065	18
	Infrastructure and industrial development	0.0040	19

Table 4. Utility of provinces for establishing biogas, solar and wind power plants

Alternatives	Biogas		Solar		Wind	
	Overall value	Rank	Overall value	Rank	Overall value	Rank
East Azarbaijan (A_1)	0.654	12	0.594	4	0.6137	2
West Azarbaijan (A_2)	0.5543	24	0.5371	11	0.4706	23
Ardabil (A_3)	0.5382	26	0.406	26	0.5508	8
Isfahan (A_4)	0.5327	27	0.5514	9	0.571	7
Alborz (A_5)	0.635	13	0.4179	25	0.4288	29
Ilam (A_6)	0.6605	10	0.5209	13	0.4632	26
Bushehr (A_7)	0.6999	5	0.5773	6	0.536	11
Tehran (A_8)	0.3895	31	0.4883	19	0.4013	31
Chaharmahal and Bakhtiari (A_9)	0.6801	7	0.4674	22	0.5044	16
South Khorasan (A_{10})	0.7444	1	0.4669	23	0.4518	28
Razavi Khorasan (A_{11})	0.5111	28	0.6305	3	0.6081	4
North Khorasan (A_{12})	0.7422	2	0.3989	28	0.4671	25
Khuzestan (A_{13})	0.424	30	0.7893	1	0.6542	1
Zanjan (A_{14})	0.6038	16	0.4424	24	0.4826	20
Semnan (A_{15})	0.6672	9	0.3432	31	0.4789	22
Sistan and Baluchestan (A_{16})	0.5937	18	0.4929	18	0.425	30
Fars (A_{17})	0.5695	22	0.669	2	0.5384	10
Qazvin (A_{18})	0.6025	17	0.3952	29	0.5013	17
Qom (A_{19})	0.6593	11	0.3811	30	0.4629	27
Kordestan (A_{20})	0.6142	14	0.5449	10	0.491	18
Kerman (A_{21})	0.6717	8	0.5297	12	0.5237	13
Kermanshah (A_{22})	0.6117	15	0.5633	8	0.59	5
Kohgeluyeh and Boyer-Ahmad (A_{23})	0.7166	3	0.5139	16	0.4825	21
Golestan (A_{24})	0.589	19	0.5785	5	0.5083	15
Gilan (A_{25})	0.562	23	0.5203	14	0.6109	3
Lorestan (A_{26})	0.6874	6	0.574	7	0.5153	14
Mazandaran (A_{27})	0.5495	25	0.4786	20	0.5423	9
Markazi (A_{28})	0.4661	29	0.4749	21	0.5846	6
Hormozgan (A_{29})	0.7051	4	0.5182	15	0.5345	12
Hamadan (A_{30})	0.571	21	0.5029	17	0.4858	19
Yazd (A_{31})	0.5764	20	0.4055	27	0.4672	24

There are different nodes in biogas supply chains that are needed for energy production, such places to store raw materials and dispose of waste materials. Developing a mathematical model that includes those nodes is suggested as a future research avenue. Furthermore, developing a multi-objective model, using the result of this paper, which maximizes the utility of the power plants' location and minimizes the cost of the power being transferred to customers is another avenue of future research.

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Appendix

Table A. Data and overall value for biogas power plant

Alternatives	Criteria								
	Investment cost	Energy saving	Acceptance	Biogas	Demand	Transportation accessibility	Maintenance cost	Climate condition	Overall value
East Azarbaijan (A_1)	0.319	26905052170	0.084	0.380	3909652	0.531	0.083	0.616	0.654
West Azarbaijan (A_2)	0.516	22470257590	0.096	0.286	3265219	0.468	0.085	0.915	0.5543
Ardabil (A_3)	0.797	8742649314	0.272	0.200	1270420	0.252	0.316	0.675	0.5382
Isfahan (A_4)	0.591	35240153450	0.085	0.338	5120850	0.753	0.138	0.591	0.5327
Alborz (A_5)	0.449	18665923080	0.306	0.057	2712400	0.115	0.439	0.547	0.635
Ilam (A_6)	0.844	3992473309	0.609	0.070	580158	0.184	0.107	0.578	0.6605
Bushehr (A_7)	0.546	8006169780	0.310	0.114	1163400	0.205	0.042	0.372	0.6999
Tehran (A_8)	0.457	91303897540	0.049	0.403	13267637	0.487	0.146	0.568	0.3895
Chaharmahal and Bakhtiari (A_9)	0.569	6522220637	0.398	0.068	947763	0.180	0.125	0.638	0.6801
South Khorasan (A_{10})	0.547	5291325367	0.571	0.084	768898	0.174	0.182	0.610	0.7444
Razavi Khorasan (A_{11})	0.562	44280305530	0.049	0.492	6434501	0.658	0.158	0.558	0.5111
North Khorasan (A_{12})	0.382	5939540216	0.378	0.122	863092	0.145	0.268	0.561	0.7422
Khuzestan (A_{13})	0.976	32416309790	0.077	0.384	4710509	0.703	0.023	0.452	0.424
Zanjan (A_{14})	0.646	7277129364	0.373	0.243	1057461	0.177	0.643	0.627	0.6038
Semnan (A_{15})	0.762	4833430812	0.520	0.091	702360	0.196	0.089	0.553	0.6672
Sistan and Baluchestan (A_{16})	0.537	19096813840	0.125	0.191	2775014	0.378	0.059	0.615	0.5937
Fars (A_{17})	0.548	33385012290	0.068	0.394	4851274	0.783	0.024	0.553	0.5695
Qazvin (A_{18})	0.640	8765641074	0.276	0.144	1273761	0.187	0.336	0.563	0.6025
Qom (A_{19})	0.612	8893103921	0.629	0.040	1292283	0.137	0.932	0.537	0.6593
Kordestan (A_{20})	0.565	11031440800	0.224	0.292	1603011	0.356	0.423	0.577	0.6142
Kerman (A_{21})	0.416	21778639860	0.115	0.738	3164718	0.564	0.024	0.628	0.6717
Kermanshah (A_{22})	0.572	13436065060	0.184	0.191	1952434	0.330	0.138	0.575	0.6117
Kohgeluyeh and Boyer-Ahmad (A_{23})	0.691	4907009948	0.622	0.077	713052	0.151	0.098	0.592	0.7166
Golestan (A_{24})	0.662	12860651710	0.168	0.167	1868819	0.266	0.107	0.444	0.589
Gilan (A_{25})	0.668	17415490660	0.129	0.112	2530696	0.348	0.097	0.442	0.562
Lorestan (A_{26})	0.416	12116258220	0.193	0.217	1760649	0.309	0.080	0.535	0.6874

Alternatives	Criteria								
	Investment cost	Energy saving	Acceptance	Biogas	Demand	Transportation accessibility	Maintenance cost	Climate condition	Overall value
Mazandaran (A_{27})	0.676	22596626250	0.108	0.206	3283582	0.511	0.115	0.430	0.5495
Markazi (A_{28})	0.976	9837218108	0.238	0.209	1429475	0.262	0.329	0.602	0.4661
Hormozgan (A_{29})	0.416	12224755110	0.210	0.081	1776415	0.284	0.058	0.363	0.7051
Hamadan (A_{30})	0.524	11962004920	0.032	0.251	1738234	0.333	0.294	0.616	0.571
Yazd (A_{31})	0.594	7835042546	0.037	0.286	1138533	0.239	0.085	0.623	0.5764

Table B. Data and overall value for solar power plant

Alternatives	Criteria									
	Acceptance	Quality of life	Demand	Sun radiation	Safety and security cost	Effect on resources and natural reserves	Effect on protected areas	Transportation accessibility	Improvement of life quality	Protection of human health
East Azarbaijan (A_1)	0.084	0.295	3909652	4.659	3296	0.561	484668	0.531	2019	0.343
West Azarbaijan (A_2)	0.096	0.233	3265219	5.027	6089	0.442	116250	0.468	1098	0.210
Ardabil (A_3)	0.272	0.154	1270420	4.045	4934	0.407	129108	0.252	1368	0.109
Isfahan (A_4)	0.085	0.360	5120850	5.277	8227	0.192	300529	0.753	2944	0.438
Alborz (A_5)	0.306	0.091	2712400	4.845	7412	0.215	72617	0.115	2019	0.154
Ilam (A_6)	0.609	0.306	580158	4.997	30	0.299	146695	0.184	1439	0.080
Bushehr (A_7)	0.310	0.328	1163400	5.392	236	0.224	151555	0.205	16581	0.107
Tehran (A_8)	0.049	0.387	13267637	4.845	55152	0.190	374940	0.487	2547	0.889
Chaharmahal and Bakhtiari (A_9)	0.398	0.104	947763	5.002	12915	0.382	153063	0.180	1172	0.088
South Khorasan (A_{10})	0.571	0.143	768898	5.247	2245	0.113	94280	0.174	1380	0.117
Razavi Khorasan (A_{11})	0.049	0.397	6434501	4.867	4638	0.600	786988	0.658	1422	0.486
North Khorasan (A_{12})	0.378	0.102	863092	4.55	4335	0.266	270717	0.145	1629	0.076
Khuzestan (A_{13})	0.077	0.417	4710509	5.172	186	0.806	345385	0.703	4788	0.365
Zanjan (A_{14})	0.373	0.120	1057461	4.695	2995	0.443	214842	0.177	1523	0.103
Semnan (A_{15})	0.520	0.139	702360	4.735	7507	0.114	1110164	0.196	1915	0.107
Sistan and Baluchestan (A_{16})	0.125	0.292	2775014	5.461	10812	0.157	592757	0.378	1321	0.279

Alternatives	Criteria									
	Acceptance	Quality of life	Demand	Sun radiation	Safety and security cost	Effect on resources and natural reserves	Effect on protected areas	Transportation accessibility	Improvement of life quality	Protection of human health
Fars (A_{17})	0.068	0.513	4851274	5.422	10649	0.459	764802	0.783	2150	0.481
Qazvin (A_{18})	0.276	0.126	1273761	4.295	333	0.273	25344	0.187	2033	0.111
Qom (A_{19})	0.629	0.074	1292283	4.99	11424	0.093	30945	0.137	1436	0.091
Kordestan (A_{20})	0.224	0.185	1603011	4.908	908	0.589	176164	0.356	1402	0.101
Kerman (A_{21})	0.115	0.353	3164718	5.396	2605	0.217	824219	0.564	2963	0.236
Kermanshah (A_{22})	0.184	0.241	1952434	5.027	89	0.482	120992	0.330	1939	0.142
Kohgeluyeh and Boyer-Ahmad (A_{23})	0.622	0.155	713052	5	121	0.416	182860	0.151	1751	0.072
Golestan (A_{24})	0.168	0.168	1868819	4.99	700	0.440	49420	0.266	1181	0.146
Gilan (A_{25})	0.129	0.187	2530696	3.813	1415	0.556	124814	0.348	1092	0.190
Lorestan (A_{26})	0.193	0.176	1760649	5.284	387	0.554	169069	0.309	1081	0.149
Mazandaran (A_{27})	0.108	0.284	3283582	3.945	2013	0.401	406274	0.511	1802	0.282
Markazi (A_{28})	0.238	0.161	1429475	4.98	1908	0.326	106055	0.262	2974	0.111
Hormozgan (A_{29})	0.210	0.332	1776415	5.339	5131	0.121	707719	0.284	11420	0.202
Hamadan (A_{30})	0.032	0.187	1738234	4.991	3693	0.480	60880	0.333	1264	0.182
Yazd (A_{31})	0.037	0.170	1138533	5.346	1536	0.062	452742	0.239	2459	0.128

Continuing (Table B)

Alternatives	Criteria								
	Topographical features	Field cost	Infrastructure cost	Provincial finance subsidies	Maintenance cost	Climate condition	Effect on agriculture	Effect on tourism	Overall value
East Azarbaijan (A_1)	1345	5685	0.395	3.54	0.083	0.616	0.042	484668	0.594
West Azarbaijan (A_2)	1363	3677	0.388	1.75	0.085	0.915	0.060	116250	0.5371
Ardabil (A_3)	1338	3833	0.207	1.75	0.316	0.675	0.137	129108	0.406
Isfahan (A_4)	1571	7871	0.638	1.14	0.138	0.591	0.062	300529	0.5514
Alborz (A_5)	1380	5685	0.380	1.79	0.439	0.547	0.450	72617	0.4179
Ilam (A_6)	1387	3766	0.144	1.75	0.107	0.578	0.712	146695	0.5209
Bushehr (A_7)	4	2849	0.202	3.54	0.042	0.372	0.120	151555	0.5773

Alternatives	**Criteria**								
	Topographical features	Field cost	Infrastructure cost	Provincial finance subsidies	Maintenance cost	Climate condition	Effect on agriculture	Effect on tourism	Overall value
Tehran ($\boldsymbol{A_8}$)	1368	47858	0.747	1.14	0.146	0.568	0.130	374940	0.4883
Chaharmahal and Bakhtiari ($\boldsymbol{A_9}$)	2060	5075	0.350	1.14	0.125	0.638	0.184	153063	0.4674
South Khorasan ($\boldsymbol{A_{10}}$)	1444	3037	0.220	1.79	0.182	0.610	0.138	94280	0.4669
Razavi Khorasan ($\boldsymbol{A_{11}}$)	1065	3370	0.638	1.79	0.158	0.558	0.026	786988	0.6305
North Khorasan ($\boldsymbol{A_{12}}$)	1086	3158	0.306	1.14	0.268	0.561	0.128	270717	0.3989
Khuzestan ($\boldsymbol{A_{13}}$)	10	3847	0.489	3.54	0.023	0.452	0.058	345385	0.7893
Zanjan ($\boldsymbol{A_{14}}$)	1638	4599	0.300	1.14	0.643	0.627	0.082	214842	0.4424
Semnan ($\boldsymbol{A_{15}}$)	1130	5296	0.158	1.14	0.089	0.553	0.136	1110164	0.3432
Sistan and Baluchestan ($\boldsymbol{A_{16}}$)	1344	4019	0.417	1.75	0.059	0.615	0.073	592757	0.4929
Fars ($\boldsymbol{A_{17}}$)	1519	5562	0.762	1.79	0.024	0.553	0.030	764802	0.669
Qazvin ($\boldsymbol{A_{18}}$)	1279	6231	0.363	1.14	0.336	0.563	0.082	25344	0.3952
Qom ($\boldsymbol{A_{19}}$)	932	6710	0.114	1.79	0.932	0.537	0.450	30945	0.3811
Kordestan ($\boldsymbol{A_{20}}$)	1463	3759	0.222	1.75	0.423	0.577	0.090	176164	0.5449
Kerman ($\boldsymbol{A_{21}}$)	1756	3185	0.599	1.79	0.024	0.628	0.034	824219	0.5297
Kermanshah ($\boldsymbol{A_{22}}$)	1374	3012	0.380	1.79	0.138	0.575	0.129	120992	0.5633
Kohgeluyeh and Boyer-Ahmad ($\boldsymbol{A_{23}}$)	1816	904	0.140	1.14	0.098	0.592	0.161	182860	0.5139
Golestan ($\boldsymbol{A_{24}}$)	174	2592	0.179	3.54	0.107	0.444	0.123	49420	0.5785
Gilan ($\boldsymbol{A_{25}}$)	8	3450	0.294	3.54	0.097	0.442	0.117	124814	0.5203
Lorestan ($\boldsymbol{A_{26}}$)	1347	2289	0.230	1.14	0.080	0.535	0.133	169069	0.574
Mazandaran ($\boldsymbol{A_{27}}$)	54	3469	0.408	1.79	0.115	0.430	0.070	406274	0.4786
Markazi ($\boldsymbol{A_{28}}$)	1708	6278	0.304	1.79	0.329	0.602	0.064	106055	0.4749
Hormozgan ($\boldsymbol{A_{29}}$)	9	3290	0.313	3.54	0.058	0.363	0.195	707719	0.5182
Hamadan ($\boldsymbol{A_{30}}$)	1741	3611	0.289	1.14	0.294	0.616	0.084	60880	0.5029
Yazd ($\boldsymbol{A_{31}}$)	1230	3058	0.271	1.79	0.085	0.623	0.299	452742	0.4055

Table C. Data and overall value for wind power plant

Alternatives	Criteria									
	Effect on resources and natural reserves	Energy saving	Acceptance	Work force	Wind flow	Demand	Intensity of natural disasters	Access to expert	Access to equipment	Transportation accessibility
East Azarbaijan ($\boldsymbol{A_1}$)	0.561	26905052170	0.084	82.1	5.35	3909652	0.083	82.1	2019	0.531
West Azarbaijan ($\boldsymbol{A_2}$)	0.442	22470257590	0.096	78.8	3.68	3265219	0.085	78.8	1098	0.468
Ardabil ($\boldsymbol{A_3}$)	0.407	8742649314	0.272	80.8	5.75	1270420	0.316	80.8	1368	0.252
Isfahan ($\boldsymbol{A_4}$)	0.192	35240153450	0.085	87.8	5.43	5120850	0.138	87.8	2944	0.753
Alborz ($\boldsymbol{A_5}$)	0.215	18665923080	0.306	90.2	2.67	2712400	0.439	90.2	2019	0.115
Ilam ($\boldsymbol{A_6}$)	0.299	3992473309	0.609	82.3	3.84	580158	0.107	82.3	1439	0.184
Bushehr ($\boldsymbol{A_7}$)	0.224	8006169780	0.310	83.6	4.2	1163400	0.042	83.6	16581	0.205
Tehran ($\boldsymbol{A_8}$)	0.190	91303897540	0.049	90.5	3.36	13267637	0.146	90.5	2547	0.487
Chaharmahal and Bakhtiari ($\boldsymbol{A_9}$)	0.382	6522220637	0.398	82.5	4.42	947763	0.125	82.5	1172	0.180
South Khorasan ($\boldsymbol{A_{10}}$)	0.113	5291325367	0.571	82.5	3.94	768898	0.182	82.5	1380	0.174
Razavi Khorasan ($\boldsymbol{A_{11}}$)	0.600	44280305530	0.049	86.3	4.67	6434501	0.158	86.3	1422	0.658
North Khorasan ($\boldsymbol{A_{12}}$)	0.266	5939540216	0.378	80.3	4.6	863092	0.268	80.3	1629	0.145
Khuzestan ($\boldsymbol{A_{13}}$)	0.806	32416309790	0.077	83.5	3.88	4710509	0.023	83.5	4788	0.703
Zanjan ($\boldsymbol{A_{14}}$)	0.443	7277129364	0.373	82.4	4.06	1057461	0.643	82.4	1523	0.177
Semnan ($\boldsymbol{A_{15}}$)	0.114	4833430812	0.520	88.4	4.03	702360	0.089	88.4	1915	0.196
Sistan and Baluchestan ($\boldsymbol{A_{16}}$)	0.157	19096813840	0.125	71.6	5.35	2775014	0.059	71.6	1321	0.378
Fars ($\boldsymbol{A_{17}}$)	0.459	33385012290	0.068	86.3	3.07	4851274	0.024	86.3	2150	0.783
Qazvin ($\boldsymbol{A_{18}}$)	0.273	8765641074	0.276	84.1	4.85	1273761	0.336	84.1	2033	0.187
Qom ($\boldsymbol{A_{19}}$)	0.093	8893103921	0.629	86.6	4.64	1292283	0.932	86.6	1436	0.137
Kordestan ($\boldsymbol{A_{20}}$)	0.589	11031440800	0.224	78	3.79	1603011	0.423	78	1402	0.356
Kerman ($\boldsymbol{A_{21}}$)	0.217	21778639860	0.115	82.2	5.07	3164718	0.024	82.2	2963	0.564
Kermanshah ($\boldsymbol{A_{22}}$)	0.482	13436065060	0.184	81.7	5.77	1952434	0.138	81.7	1939	0.330
Kohgeluyeh and Boyer-Ahmad ($\boldsymbol{A_{23}}$)	0.416	4907009948	0.622	81.9	3.53	713052	0.098	81.9	1751	0.151
Golestan ($\boldsymbol{A_{24}}$)	0.440	12860651710	0.168	83	3.29	1868819	0.107	83	1181	0.266

Alternatives	Criteria									
	Effect on resources and natural reserves	Energy saving	Acceptance	Work force	Wind flow	Demand	Intensity of natural disasters	Access to expert	Access to equipment	Transportation accessibility
Gilan (A_{25})	0.556	17415490660	0.129	84.3	4.87	2530696	0.097	84.3	1092	0.348
Lorestan (A_{26})	0.554	12116258220	0.193	80.4	4.26	1760649	0.080	80.4	1081	0.309
Mazandaran (A_{27})	0.401	22596626250	0.108	85.7	3.97	3283582	0.115	85.7	1802	0.511
Markazi (A_{28})	0.326	9837218108	0.238	83.8	6.55	1429475	0.329	83.8	2974	0.262
Hormozgan (A_{29})	0.121	12224755110	0.210	83.7	5.025	1776415	0.058	83.7	11420	0.284
Hamadan (A_{30})	0.480	11962004920	0.032	82.6	3.99	1738234	0.294	82.6	1264	0.333
Yazd (A_{31})	0.062	7835042546	0.037	87.8	4.56	1138533	0.085	87.8	2459	0.239

Continuing (Table C)

Alternatives	Criteria									
	Topographical features	Field cost	Infrastructure cost	Provincial finance subsidies	Improvement of life quality	Jobs generated	Infrastructure and industrial development	Effect on agriculture	Effect on tourism	Overall value
East Azarbaijan (A_1)	1345	5685	0.395	3.54	2019	10.4	0.178	0.042	484668	0.6137
West Azarbaijan (A_2)	1363	3677	0.388	1.75	1098	7.5	0.254	0.060	116250	0.4706
Ardabil (A_3)	1338	3833	0.207	1.75	1368	13.6	0.476	0.137	129108	0.5508
Isfahan (A_4)	1571	7871	0.638	1.14	2944	17.4	0.110	0.062	300529	0.571
Alborz (A_5)	1380	5685	0.380	1.79	2019	15.4	0.498	0.450	72617	0.4288
Ilam (A_6)	1387	3766	0.144	1.75	1439	11.2	0.782	0.712	146695	0.4632
Bushehr (A_7)	4	2849	0.202	3.54	16581	11.2	0.401	0.120	151555	0.536
Tehran (A_8)	1368	47858	0.747	1.14	2547	13.3	0.104	0.130	374940	0.4013
Chaharmahal and Bakhtiari (A_9)	2060	5075	0.350	1.14	1172	19.8	0.611	0.184	153063	0.5044
South Khorasan (A_{10})	1444	3037	0.220	1.79	1380	13.4	0.407	0.138	94280	0.4518
Razavi Khorasan (A_{11})	1065	3370	0.638	1.79	1422	12.5	0.116	0.026	786988	0.6081
North Khorasan (A_{12})	1086	3158	0.306	1.14	1629	9.7	0.724	0.128	270717	0.4671
Khuzestan (A_{13})	10	3847	0.489	3.54	4788	14.9	0.143	0.058	345385	0.6542
Zanjan (A_{14})	1638	4599	0.300	1.14	1523	8.2	0.571	0.082	214842	0.4826
Semnan (A_{15})	1130	5296	0.158	1.14	1915	8.1	0.510	0.136	1110164	0.4789

Alternatives	Criteria									
	Topographical features	Field cost	Infrastructure cost	Provincial finance subsidies	Improvement of life quality	Jobs generated	Infrastructure and industrial development	Effect on agriculture	Effect on tourism	Overall value
Sistan and Baluchestan (A_{16})	1344	4019	0.417	1.75	1321	13.8	0.196	0.073	592757	0.425
Fars (A_{17})	1519	5562	0.762	1.79	2150	13.6	0.104	0.030	764802	0.5384
Qazvin (A_{18})	1279	6231	0.363	1.14	2033	11.6	0.600	0.082	25344	0.5013
Qom (A_{19})	932	6710	0.114	1.79	1436	11.4	0.883	0.450	30945	0.4629
Kordestan (A_{20})	1463	3759	0.222	1.75	1402	12	0.375	0.090	176164	0.491
Kerman (A_{21})	1756	3185	0.599	1.79	2963	11.9	0.120	0.034	824219	0.5237
Kermanshah (A_{22})	1374	3012	0.380	1.79	1939	20.3	0.355	0.129	120992	0.59
Kohgeluyeh and Boyer-Ahmad (A_{23})	1816	904	0.140	1.14	1751	13	0.771	0.161	182860	0.4825
Golestan (A_{24})	174	2592	0.179	3.54	1181	12.8	0.453	0.123	49420	0.5083
Gilan (A_{25})	8	3450	0.294	3.54	1092	9.9	0.292	0.117	124814	0.6109
Lorestan (A_{26})	1347	2289	0.230	1.14	1081	12	0.408	0.133	169069	0.5153
Mazandaran (A_{27})	54	3469	0.408	1.79	1802	10.8	0.197	0.070	406274	0.5423
Markazi (A_{28})	1708	6278	0.304	1.79	2974	6.7	0.324	0.064	106055	0.5846
Hormozgan (A_{29})	9	3290	0.313	3.54	11420	10.1	0.268	0.195	707719	0.5345
Hamadan (A_{30})	1741	3611	0.289	1.14	1264	8	0.396	0.084	60880	0.4858
Yazd (A_{31})	1230	3058	0.271	1.79	2459	11.8	0.310	0.299	452742	0.4672