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A Hybrid Multi-Criteria-Decision-Making Aggregation Method and Geographic Information System for Selecting Optimal Solar Power Plants in Iran

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Abstract: Policy-makers should focus on solar energy due to the increasing energy demand and adverse consequences such as global warming. Conflicting criteria influence choosing the most desirable place to construct a Solar Power Plant (SPP). Researchers have popularized multicriteria decision-making (MCDM) methods because of the potential. Although the simultaneous use of several methods increases the robustness and accuracy of the results, existing methods to integrate MCDM methods mainly consider the same weight for all methods and utilize the alternatives ranking for the final comparison. This paper presents a hybrid decision-making framework to determine the best location for SPPs in Iran using a set of criteria extracted from the literature and expert opinions. An initial list of decision-making alternatives is prepared and evaluated using GIS software in terms of criteria. Decision-makers prioritized the identified alternatives using the MCDM methods, including SWARA and different ranking methods (TOPSIS, TODIM, WASPAS, COPRAS, ARAS, and MULTIMOORA). Finally, the CCSD method aggregates the results and identifies the best location. Results highly correlate with the results of previous methods and demonstrate the robustness of the proposed approach and its capability to overcome the limitations of previous methods.

Keywords: solar energy; power plant location; multicriteria decision-making; MCDM; aggregation method

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1. Introduction

Nowadays, accessing competitive and sustainable energy resources is a fundamental and crucial factor for economic growth and social development [1]. Energy falls into three main groups: fossil energy, nuclear energy, and renewable [2]. Among these, solar energy (SE), with its benefits, such as lack of environmental pollution (e.g., CO_2 mitigation, noise), installation flexibility, and high reliability [3,4], is regarded as one of the most promising and reliable energy sources [5]. These benefits have encouraged governments to promote the SE share in their energy portfolios [6]. As a result, this has led to significant annual growth in the construction of solar power plants.

According to the specific climate and geographic location, Iran is among the countries with a great potential to use SE [7]. However, not all parts of the country have the same potential for multiple criteria to choose the best place to establish a Solar Power Plant (SPP). Besides, locating SPPs has become a critical issue for investors, owners, and the renewable energy system industry [8] due to the numerous impacts of solar power generation on the economy and development of the region [2]. Proper location selection maximizes the value and productivity of the plant, reduces production costs, and minimizes environmental impacts [9]. However, choosing not right location increases environmental pollution and wastes resources and energy [10].

Stakeholders must consider multiple criteria to choose the right place to build an SPP. Area, capacity, type of production, design, and others determine the criteria set [11]. The decision is complicated, with some of the goals and objectives of decision-makers contradicting each other. Therefore, SPP locating issues are multicriteria decision-making (MCDM) problems. Many researchers investigated and addressed this problem using different MCDM methods [12,13]. Recently, due to the high reliance on multiple geographic data, decision-makers have considered the combination of MCDM and Geographic Information Systems (GIS) as a practical approach to determining SPPs' location [14,15].

The critical thing about utilizing MCDM methods is that each method has distinctive features and qualities and may exhibit different results on the same problem [16]. Therefore, one method cannot be considered better than the others [17]. Choosing the most appropriate method is an important challenge for decision-makers [18]. To solve this challenge and increase the results' robustness [19], many researchers have suggested using different MCDM methods [20]. However, the techniques used so far to aggregate the results of MCDM methods have some shortcomings that the authors of this paper attempted to overcome.

The structure of the rest of this paper is as follows. In Section 2, the authors discuss the necessity of utilizing renewable energy resources and review related studies regarding locating SPP construction using MCDM methods. Section 3 presents the methodology and implementation steps of the research. Section 4 presents the general introduction of the case study and research findings. Finally, Section 5 provides the conclusion and suggestions for future research.

2. Literature Review

Researchers have used various SPP site selection approaches in the last decade, including mathematical programming, feasibility studies, and MCDM techniques [7]. On the other hand, due to the dependence of the location problem on the climate [21], GIS is used to access geographic information. Considering the diversity of location criteria, different importance (weight) of decision criteria, and sometimes the inconsistency of these criteria, in recent years, several researchers have proposed different MCDM methods and their combination with GIS tools to address these difficulties [22].

Table 1 presents some essential research in the SPP site selection field using MCDM methods done in recent years.

Table 1. Summary of solar power location research using MCDM methods.

Reference	Country	Case Study	Method
[23]	Iran	Solar plants	DEA/PCA
[24]	Spain	PV	AHP
[25]	US	Wind and solar farms	ANP
[26]	Spain	Solar farms	AHP/TOPSIS
[21]	Turkey	Hybrid power plant (solar & wind)	Fuzzy OWA
[14]	Turkey	Solar farms	AHP
[27]	China	Solar thermal power plant	Linguistic Choquet operator/fuzzy measure
[28]	Iran	Solar project	SWARA-WASPAS
[29]	Spain	Solar-thermal power plant	AHP-ANP

Table 1. *Cont.*

Reference	Country	Case Study	Method
[30]	Spain	PV	ELECTRE-TRI/Decision support system
[31]	UK	Wind and solar farms	AHP
[32]	Spain	Solar thermoelectric power plant	AHP/fuzzy TOPSIS/ELECTRE-TRI
[2]	Iran	SPP	AHP/fuzzy logic/WLC
[33]	Spain	PV	AHP/TOPSIS/ELECTRE TRI
[34]	Serbia	PV	AHP
[35]	Afghanistan	Wind farm/solar PV/CSP	MCDA
[36]	Turkey	SPP	AHP/ELECTRE/TOPSIS/VIKOR
[1]	Iran	Solar farm	AHP
[8]	China	PV	Grey cumulative/TOPSIS
[37]	Turkey	SPP	AHP
[38]	Saudi Arabia	PV	AHP
[39]	Morocco	PV	AHP
[40]	Tanzania	PV/CSP	AHP
[3]	Vietnam	SPP	DEA/fuzzy AHP/TOPSIS
[41]	Turkey	Solar PV power plant	AHP
[42]	Iran	PV/CSP	AHP
[43]	India	SPP	Fuzzy logic/VIKOR
[7]	Iran	SPP	BWM/GRA/VIKOR

Data Envelopment Analysis (DEA); Principal Component Analysis (PCA); Photovoltaic (PV); Analytic Hierarchy Process (AHP); Analytic Network Process (ANP); Technique for Order Preference by Similarity to Ideal Solution (TOPSIS); Ordered Weighted Averaging (OWA); Step-Wise Weight Assessment Ratio Analysis (SWARA); Weighted Aggregated Sum Product Assessment (WASPAS); Elimination Et Choix Traduisant la REaite (ELECTRE); Solar power plant (SPP); Weighted Linear Combination (WLC); Concentrating solar power (CSP); Multi-Criteria Decision Analysis (MCDA); VIseKriterijumska Optimizacija i Kompromisno Resenje (VIKOR); Best Worst Method (BWM); Grey Relational Analysis (GRA).

MCDM approaches are one of the most popular topics in decision-making theory [44,45]. Table 1 shows that some research studies have used several methods to rank the alternatives [8,32,33,36]. A closer look at these studies shows that these methods helped solve various problems, particularly weighting criteria (AHP and SWARA) and ranking alternatives (TOPSIS, ELECTRE, VIKOR, and WASPAS). Although using two or more parallel methods in the ranking is purely for sensitivity analysis and validation of the results, as pointed out in [16], each method has different qualities and features. When used to solve the same problem, they may produce different results. As Table 1 shows, given the ability of MCDM methods to deal with multiple and sometimes conflicting criteria, the use of these methods in locating SPPs is of interest to researchers and decision-makers.

Therefore, one MCDM method cannot be considered better than others [17], and selecting the appropriate one is essential in the decision-making process [18]. On the other hand, using a single MCDM method for prioritization cannot ensure robust results [19]. Hence, some researchers have suggested using a combination of different MCDM methods. Especially, using a robust aggregation method becomes more necessary when alternatives are intrinsically close together or the number of alternatives increases [20].

Borda and Copeland's law are two standard methods of aggregating results [46]. In the Borda method, the most wins in pairwise comparisons are the base of alternatives ranking. The Copeland method is complementary to the Borda method, in which decision-makers prioritize alternatives based on the number of wins minus the number of defeats in pairwise comparisons. These methods have some significant shortcomings [47], making it essential to use a systematic and scientific model to reach the final ranking. Therefore, researchers have proposed other methods for aggregating the results of MCDM methods.

Varmazyar et al. (2016) introduced an integrated approach to combine the results of Additive Ratio Assessment (ARAS), COmplex PRoportional ASsessment (COPRAS), Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods to evaluate research and technology organizations using the balanced scorecard [20]. Using linear programming, the authors used the utility interval to combine the results when determining each option's utility upper and lower limits for each method. Next, the weight of each method is determined based on the correlation between the rankings performed by the methods. Finally, decision-makers consider the weighted average utility for ranking the alternatives. Wang et al. (2016) also proposed a hybrid MCDM approach to integrating the results of Simple Additive Weighting (SAW), TOPSIS, and Grey Relational Analysis (GRA) methods following experimental design [48]. In this method, decision-makers calculate the criteria weights using the design of the experiments. Then, they evaluate the alternatives using the MCDM methods and prioritize based on the average score earned in each method. In another study, Mousavi-Nasab et al. (2017) presented a comprehensive method for combining the TOPSIS and COPRAS methods in a material selection problem using data envelopment analysis as an auxiliary tool for the final choice [16]. Recently, Mohammadi and Rezaei (2020) proposed a new approach based on assembling ranking, which uses the half-quadratic theory to aggregate the ranking outputs of different MCDM methods [49]. They tested their method to the aggregate ranking produced by various MCDM methods for five ontology alignment evaluation initiative (OAEL) competition tracks.

The authors of this paper identified the following limitations in the literature; at the final stage of aggregation of results in the methods mentioned above, decision-makers consider all methods equally important and assign them the same weight [49]. Nonetheless, these two elementary assumptions in current aggregation approaches are not reasonable in some cases and do not appropriately demonstrate the actual difference between alternatives in the final aggregation results. Besides, the basis of ranking in the aggregation step is the ranking of alternatives in each method, not their attained score [50]. On the other hand, the rank cannot represent the distance between alternatives because decision-makers present rankings on an ordinal scale that does not adequately reflect the difference between [50].

To take advantage of different MCDM tools, a set of methods, including TOPSIS, TOmada de Decisao Interativa Multicriterio (TODIM), Weighted Aggregated Sum Product Assessment (WASPAS), COPRAS, ARAS, and MULTIMOORA methods, were used to locate the SPP. Besides, the Correlation Coefficient and Standard Deviation (CCSD) method, an excellent objective method, is used to integrate the results of these MCDM methods to solve the challenges mentioned above in the aggregation process. Wang and Luo [51] described the advantages of the CCSD over other objective methods to choose it.

In the proposed approach, decision-makers calculate the weight of each MCDM tool from the distribution of scores obtained by each method. Besides, to better differentiate the alternatives, decision-makers calculate the final ranking using the scores by multiplying the scores by the determined weights of methods and aggregating the results. This method better illustrates the difference between alternatives.

3. Methodology

Following the government policies of Iran, the policy-making committee decided to build an SPP in the southeastern region of Iran. For this reason, the policy-making committee was tasked with selecting proper candidates from five provinces of the southeastern part of Iran with high solar potential. This paper presents a hybrid GIS-MCDM aggregation method for determining optimal SPP, addressing the shortcomings identified in previous research.

The method consists of four phases and several steps (see Figure 1), explained in the following.

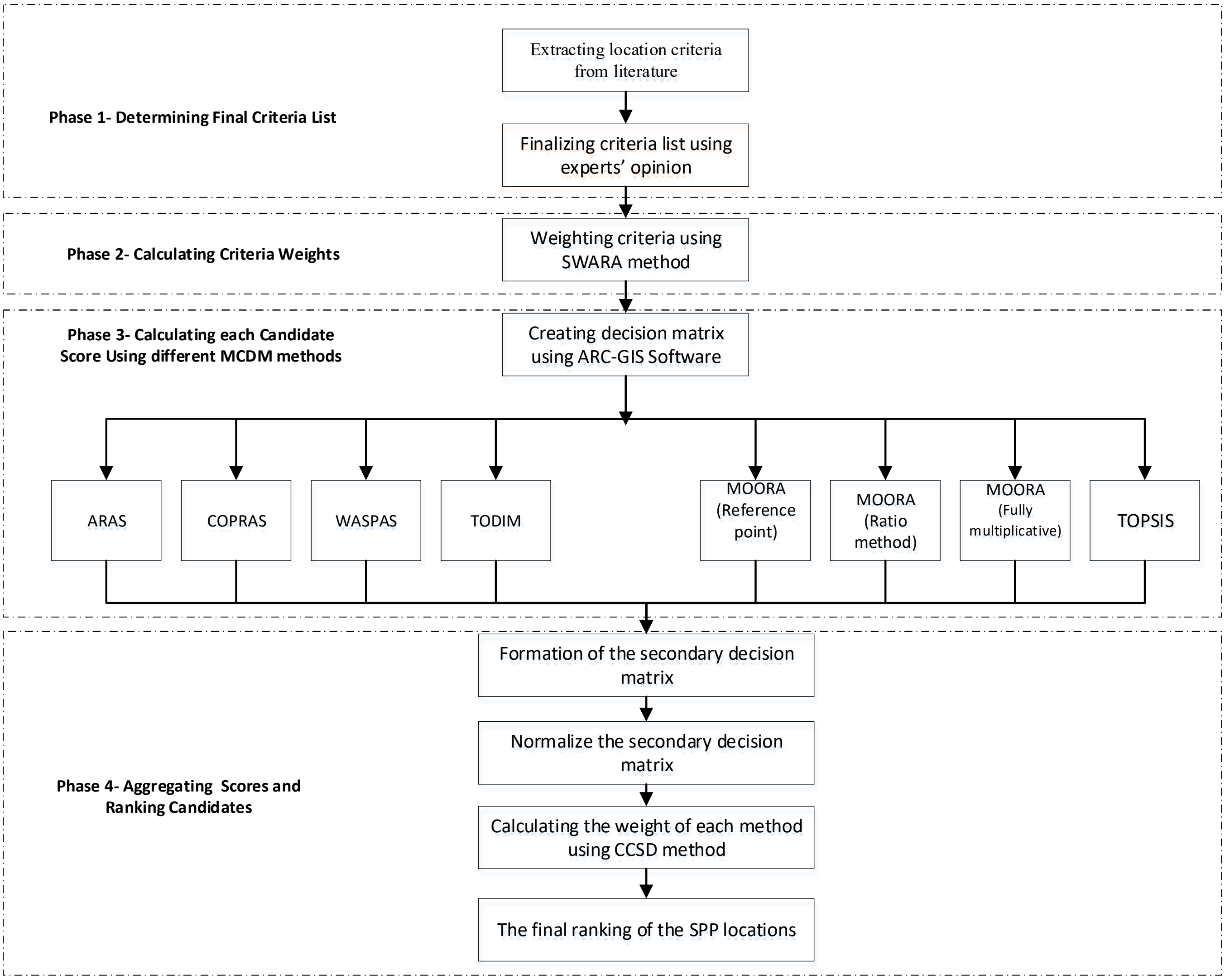


Figure 1. Steps to choosing the SPP location.

3.1. Phase 1: Determining Final Criteria List

The first phase of this approach consists of two steps.

3.1.1. Step 1a: Extracting Location Criteria from the Literature

Policy-makers reviewed relevant literature to the study to identify the criteria set needed to locate SPPs. For this purpose, using related keywords (in both MCDM and SPP), the most relevant articles in WoS (Clarivate Analytics) and Scopus as a reputable database were identified. Then, by examining the titles of the extracted articles, the articles that were out-of-scope filed were identified. Then articles were filtered considering the abstract and keywords. Finally, some of these publications were excluded from the synthesis and criteria extracted after carefully reading.

3.1.2. Step 1b: Finalizing Criteria List Using Experts' Opinion

This step presents the final criteria list of SPP locations. The team members, some university professors, and experts in SE technologies localized this list with the studied conditions (in Iran). Finally, policy-makers formed the list of criteria.

3.2. Phase 2: Calculating Criteria Weights

The decision-making committee members prioritized and weighed the final criteria set using the SWARA method at the next step.

Researchers proposed several methods of criteria weighting. However, many are complex and not sufficiently accurate [52]. Keršulienė et al., in 2010, introduced the SWARA method, which has less relative complexity. It is one of the newest weighing methods [53]. In addition to user-friendliness, less complexity, and less implementation time, this method allows decision-makers to select, evaluate, and weigh the criteria. It also will enable experts to apply their knowledge and experience in the field. Experts play a central role in assessing and weighing criteria [54]. Readers can read Keršulienė et al. work to become acquainted with applying this method [53].

3.3. Phase 3: Calculating Each Candidate's Score Using Different MCDM Methods

In the first step of the third phase, the decision-making team forms the decision table to evaluate candidate locations in some criteria using the ArcGIS 10.3.1 software (Esri®, Redlands, CA, USA).

In the next step, decision-makers should calculate the final score of each candidate using MCDM methods and obtain the necessary data for ranking different options. As discussed in the introduction and literature review, using different MCDM methods and aggregating their results increases the decision-making process's robustness.

For this purpose, decision-makers calculated the scores of each candidate using six different MCDM methods: TOPSIS, TODIM, WASPAS, COPRAS, ARAS, and MULTIMOORA.

3.3.1. Step 3a: Identifying the List of Candidate Locations and Creating the Decision Matrix

Since selecting the preferable location for constructing the SPP in the desert area of Iran is intended, we use MCDM techniques to rank candidate locations. The problem is inherently a continuous location problem, and the construction can be potentially anywhere in the desert area of Iran. The GIS helps to eliminate unsuitable locations. A list of criteria has been extracted from the literature, and the performance of locations was assessed concerning each criterion using ArcGIS tools.

To select the appropriate locations, we first obtain the scoring map of the studied area for each indicator using ArcGIS 10.3.1 software. The software works so that first, the Raster images of each index are converted to Shape-File. Rasters are maps containing contour lines (discrete data) for each index converted to Shape-File (continuous data) with an interpolation mechanism. Then the intersection of existing layers (indicators) with AND logic is obtained by which the appropriate areas or locations with all the intended indicators (Shared overlap) are determined. All digitization, conversion, and analysis of maps were done by ArcGIS 10.3.1 software.

3.3.2. Step 3b: Calculating Candidate Scores Using the TOPSIS

Hwang and Yoon, in 1981, introduced the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In this method, an ideal and an anti-ideal point are determined. The desired option is the one with the minimum Euclidean distance to the ideal point and the maximum Euclidean distance to the anti-ideal point. Readers should refer to Hwang and Yoon's book [55] for a detailed examination of this method.

3.3.3. Step 3c: Calculating Candidate Scores Using the TODIM

Gomes and Lima introduced the TODIM (an acronym in Portuguese for the interactive and Multi-Criteria Decision-Making) method in 1991. This method first identifies the difference between alternatives for each criterion. Then, the method calculates the relative dominance of the alternatives. Finally, the method ranks the alternatives according to the normalized global index. Readers could read Gomes and Lima's [56] work to study this method [56] further.

3.3.4. Step 3d: Calculating Candidate Scores Using the WASPAS

Zavadskas et al. introduced the Weighted Aggregated Sum Product Assessment (WASPAS) method in 2012. This method combines the Weighted Sum Model (WSM) and Weighted Product Model (WPM) to rank alternatives. Readers can read Zavadskas et al. [57] work for further details on the steps of this method.

3.3.5. Step 3e: Calculating Candidate Scores Using the COPRAS

Zavadskas et al., in 1994, presented the Complex Proportional Assessment (COPRAS) method to help determine the best solution among investigated and rank choices. This method essentially extends the AHP method, where alternatives have two criteria: benefits and costs. Decision-maker divides these criteria into benefit type sub-criteria and cost type sub-criteria. Alternatively, the COPRAS method presents the degree of utility of each alternative compared with the score of the best alternative among investigated ones. Readers can read Zavadskas et al. work to find a basis for the steps of this method [58].

3.3.6. Step 3f: Calculating Candidate Scores Using the ARAS

In essence, it is an extension of the additive form of the AHP method. Here the degree of efficiency compares the relative values of the multi-attribute utility function with the Pareto optimal solution (an alternative with optimal values for each criterion—there is no single alternative with a better value for even one measure). Inclusion of such a utopia alternative prevents the rank reversal phenomenon, and the multi-attribute utility degree of each choice remains the same or slightly changes when decision-makers add or remove some options. Readers can read details about this method in Zavadskas and Turskis' article [59].

3.3.7. Step 3g: Calculating Candidate Scores Using the MULTIMOORA

Brauers and Zavadskas, in 2006, proposed the Multi-Objective Optimization based on the Ratio Analysis method (MOORA) [60]. Brauers' work [61] is the basis of this method. It consists of the Ratio Analysis (RA) and Reference Point (RP) methods. Later, Brauers and Zavadskas extended the MOORA, adding a Full Multiplicative (FM). The authors named extension as the MULTIMOORA method. Readers can read Brauers and Zavadskas work for further details on the steps of this method [62].

3.4. Phase 4: Aggregating Scores and Ranking Candidates

As mentioned in the previous sections, in the proposed aggregation method, the final score of candidates in each technique is used instead of the rank obtained from different MCDM methods. As different methods will not have the same weight in the aggregation phase, the CCSD method has been used to calculate the importance of each method.

3.4.1. Step 4a: Formation of the Secondary Decision Matrix

The secondary decision matrix represented as $\ddot{X} = (\ddot{x})_{n\times 8}$, is formed, where n is the number of candidates. This matrix contains eight columns, the first to the third column representing the final scores of the alternatives in the MULTIMOORA method (having Ratio System (RS), Reference Point (RP), and Full Multiplicative Form (FM)). The rest of the columns contain candidate scores in the other five MCDM methods.

3.4.2. Step 4b: Normalize the Secondary Decision Matrix

In this step, it is necessary to normalize the secondary decision matrix. Decision-makers normalize initial data using the following equations:

$$z_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \text{ , } i = 1, \ldots, n; j \in \Omega_b \tag{1}$$

$$z_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \text{ , } i = 1, \ldots, n; j \in \Omega_c \tag{2}$$

In this equation, $x_j^{min} = \min\limits_{1 \le i \le n} \{x_{ij}\}$, $x_j^{max} = \max\limits_{1 \le i \le n} \{x_{ij}\}$, and Ω_b and Ω_c are the set of positive and negative criteria indices, respectively. Whenever an alternative (location) with a lower final score takes a higher rank by the corresponding MCDM method (criterion), we treat that method as a negative criterion.

3.4.3. Step 4c: Calculating the Weight of Each Method Using the CCSD Method

Wang and Lu [51] developed a new weighing method, CCSD. Combining the correlation coefficient (CC) and the standard deviation (SD) of each criterion is the basis of this method. Unlike the Entropy method, there is no need for a unique normalization method. It is a more straightforward technique than the CRITIC method. Decision-makers calculated each method's weight using the CCSD method to determine the significance of each way in the final aggregation. Readers should read Wang and Lu's work [51] to study this method further.

3.4.4. Step 4d: The Final Ranking of the SPP Locations

Decision-makers obtained the final score of each candidate by multiplying the normalized values by the weight of each method (from Step 4c). Therefore, Equation (3) helps decision-makers calculate the performance value and determine the final rank of options.

$$\ddot{S}_i = \sum_{j=1}^{8} (\ddot{z}_{ij} \times \ddot{w}_j) \tag{3}$$

There $\ddot{w}_j$ represents the weight of jth method in the final aggregation, and $\ddot{z}_{ij}$ is the normalized value in the secondary decision matrix.S_i is the basis for ranking the alternatives. Accordingly, the higher the value of $\ddot{S}_i$, the greater the utility of ith alternative.

4. Case Study

Iran is in southwest Asia and the Middle East. Due to its geographical location, Iran has rich natural energy resources that should maximize its use. Besides, Iran has a unique climate. In winter, the temperature difference in the coldest and hottest parts of the country reaches 50 degrees Celsius. In terms of rainfall, Iran is one of the arid and semi-arid countries. Therefore, SE is one of the essential sources of energy for the country. According to high-level documents and approved service descriptions, the southeastern region of Iran is the geographical area for constructing the SPP. According to these upstream laws, the policy-making committee identified five provinces of the country's southeastern region as areas with high solar potential. These provinces were distinguished by brown on the map shown in Figure 2. The article describes some of the features that influence this choice below.

Figure 2. Map of the eastern regions of the Islamic Republic of Iran.

Yazd Province: This province, with an area of 74,493 km^2, is one of the arid regions. The global dry belt and distance from the Oman and Persian Gulf seas, inland lakes, and marine moisture winds have caused the area to dry. Besides, due to the global dry belt, summers in Yazd are long, hot, and dry, while winters are cold and relatively humid.

Kerman Province: Kerman is the largest province of Iran, with 181,785 km^2. The climate variation of Kerman province is noteworthy due to the specific climatic conditions. The province is dry in the north, northwest, and central regions. It is warm and humid in the south and southeast. The maximum temperature in some parts of the province exceeds 70 degrees Celsius.

South Khorasan Province: This region has a warm and dry climate and a dry and mild climate. There are no permanent rivers in the province. The rivers flow seasonally due to the desert climate.

Khorasan-e-Razavi Province: This province, with an area of 128,420 km^2, is one of the semi-arid regions of Iran. It is also one of the least humid regions in the world.

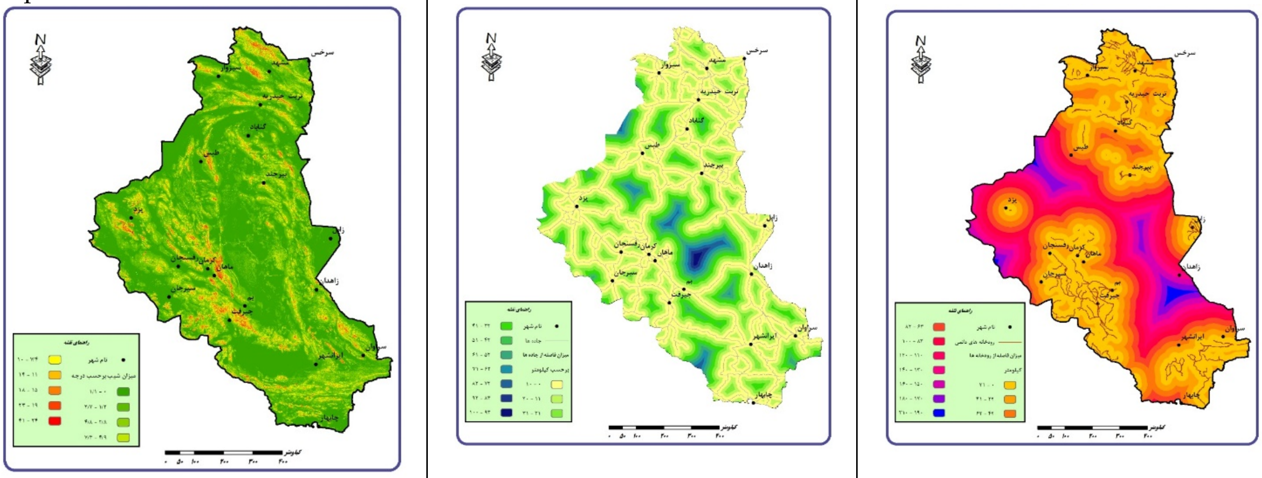
Sistan and Baluchestan Province: The 187,502 km^2 area has long, hot summers and short winters. On average, there is no rainfall in the province for seven months. Due to the high average temperature and monsoon winds, the evaporation rate in Sistan and Baluchestan Province is high.

As mentioned in the methodology section, GIS helped identify the list of candidate locations and create the decision matrix. Figure 3 represents the sample shapefiles of the study concerning some evaluation criteria.

Slope

Distance from the roads

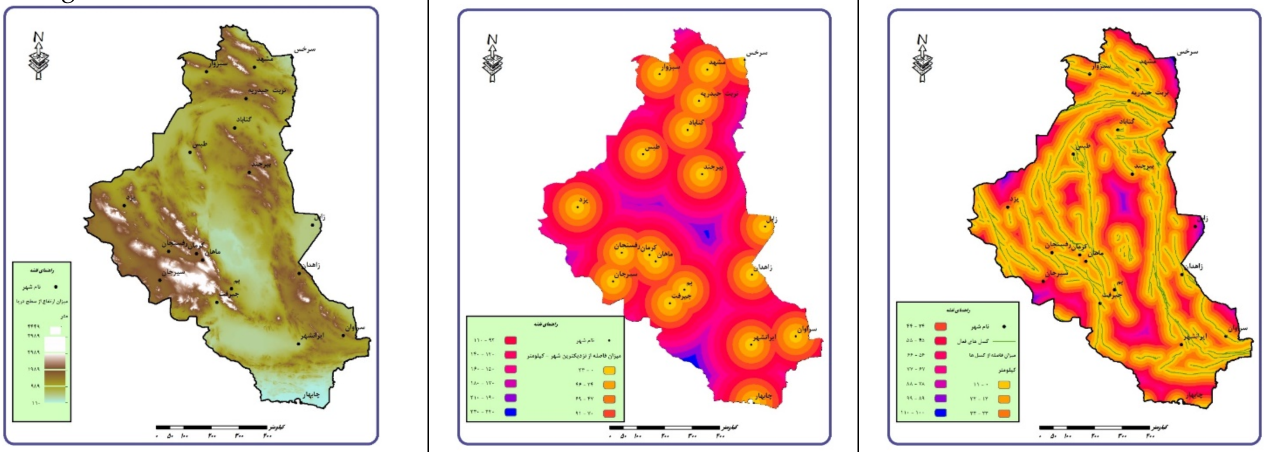
Distance from water resources



Average Elevation

Distance from urban area

Distance from nearest fault



Distance from the railway network

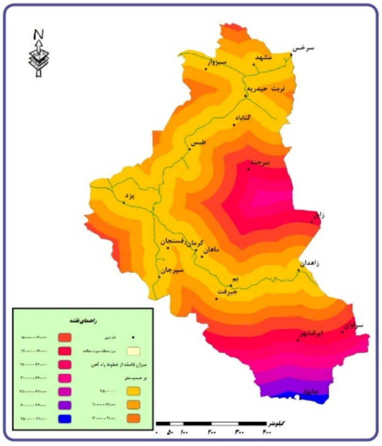


Figure 3. Different criteria layers.

Finally, 19 choices are in these five provinces. Candidate site locations (alternatives) are denoted in Figure 4.

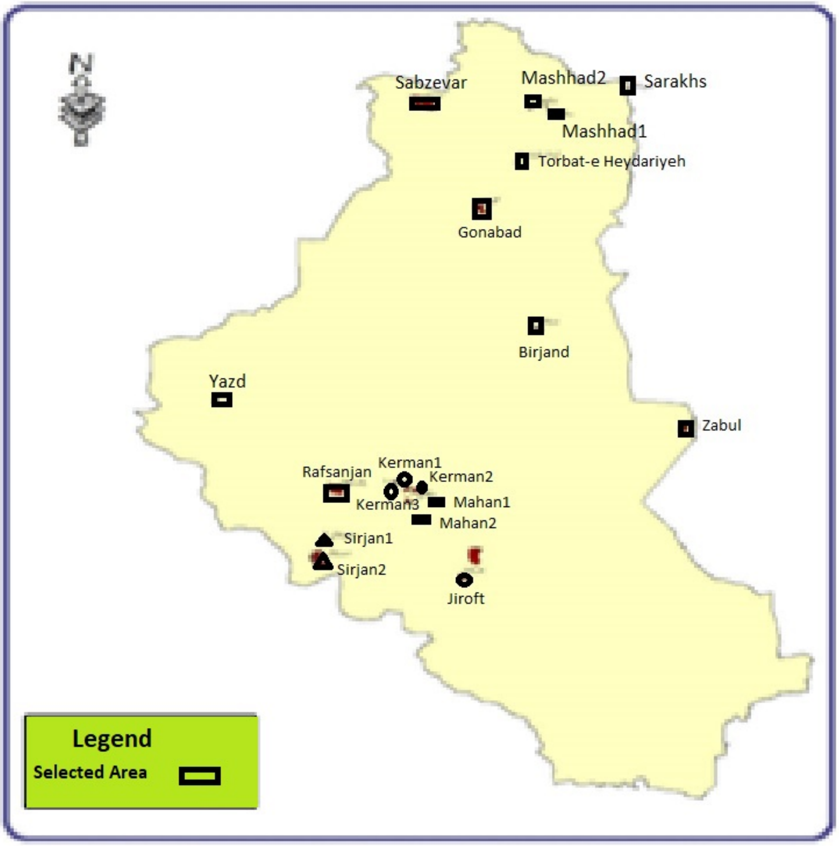


Figure 4. Map of alternative areas for SPP construction.

4.1. Determining Final Criteria List

As mentioned earlier, numerous articles investigated the location problems of SPPs around the world. Although there is relative agreement among the authors on the most critical criteria, sometimes the list of criteria differs due to the specific conditions of each country and the available data. Table 2 presents the list of criteria used in the literature.

SPP location project team members received the list of these criteria. They formed a final set of criteria according to local Iranian conditions and the availability of the necessary information (Table 3). Iran is one of the most earthquake-prone areas globally, and because policy-makers should locate the plant safely, decision-makers added the criterion of distance from the nearest fault. However, this criterion is very close to the likelihood criterion of natural disasters (floods and earthquakes) that Azadeh et al. [23] have previously emphasized as a critical criterion in Iran [23]. Decision-makers, according to the area's conditions, divided the criterion of distance from the transport routes into two conditions—distance from road and rail. They divided the distance from the population centers into the distance from the provincial center and the nearest city.

Table 2. The list of final criteria.

Reference	Criteria										
	Average Temperature	**Distance from Transporta-tion Network**	**Distance from the Power Line**	**Distance from Urban Area**	**Distance from Wildlife Protection Areas**	**Distance from Agricul-tural Lands**	**Slope (%)**	**Average Elevation**	**Orientation**	**Land Use**	**Distance from Water Resource**
[23]			*	*			*	*	*		*
[24]	*	*		*	*	*	*		*	*	*
[25]		*	*	*	*						*
[26]	*	*	*	*			*		*		*
[21]		*	*	*		*	*				*
[14]		*	*	*	*	*	*			*	*
[27]		*	*							*	*
[28]			*								
[29]		*	*								*
[30]	*	*	*	*			*		*		*
[31]		*	*	*	*	*	*				
[32]	*	*	*	*	*		*		*		*
[2]		*	*	*	*		*	*		*	*
[33]	*	*	*	*	*	*	*				*
[34]	*						*				
[35]		*	*	*		*	*	*		*	
[36]			*				*				
[1]		*		*	*	*	*				*
[8]	*							*			
[37]		*	*	*			*			*	*
[38]	*	*	*	*	*	*	*		*	*	*
[39]		*	*	*			*				*
[40]		*	*	*			*			*	*
[41]	*	*	*					*			
[42]		*									
[43]	*	*	*	*	*		*	*	*	*	
[44]		*	*				*				
[7]	*	*		*		*				*	*

Table 3. Calculating the weight of the criteria using the SWARA method.

NO	Criteria	Criteria Type	S_j	K_j	W_j	q_j
C_1	Average temperature	positive	—	1	1	0.163
C_2	Average elevation	positive	0.19	1.19	0.840	0.137
C_3	Distance from the power line	negative	0.12	1.12	0.750	0.122
C_4	Distance from nearest fault	positive	0.11	1.11	0.676	0.110
C_5	Distance from the center of the province	negative	0.17	1.17	0.578	0.0949
C_6	Distance from the nearest city	negative	0.19	1.19	0.485	0.079
C_7	Distance from a water resource	negative	0	1	0.485	0.079
C_8	Distance from a road	negative	0.04	1.04	0.467	0.076
C_9	Slope (%)	negative	0.04	1.04	0.449	0.073
C_{10}	Distance from the railway network	negative	0.14	1.14	0.394	0.064

4.2. Calculating Criteria Weights

The policy-making committee members ranked the criteria in the following step and calculated their weights. Table 3 presents the results of the SWARA method.

As Table 3 shows, the average temperature and average elevation criteria with significance levels of 16% and 14%, respectively, the project team considered the most important criteria, followed by distance-related criteria.

4.3. Calculating Each Candidate Score Using Different MCDM Methods

In the first step, the decision-making committee calculated each alternative's performance (SPP construction score) for each criterion using the information obtained from ArcGIS 10.3.1 software based on the available information sources. Table 4 presents the final decision matrix. The first row of this matrix shows the weight of each criterion. The weights are the results of the SWARA method.

Table 4. Decision matrix based on the data collected.

Weight of Criteria	**0.163**	**0.137**	**0.122**	**0.110**	**0.094**	**0.079**	**0.079**	**0.076**	**0.073**	**0.064**
Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Bam	35	1255	4.85	19.3	189	15.22	1.8	5.05	0.79	2.21
Birjand	29	2134	8.23	28.3	21	21.59	14.43	7.1	2.43	212.6
Torbat-e Heydariyeh	26	1664	7.12	15.89	154	14.03	5	0.66	7.9	4.18
Jiroft	33	2308	15.02	13.89	225	23.02	1	12.43	9.86	35.8
Rafsanjan	29	1788	4.76	6.8	120	17.13	15.7	2.14	1.56	29.26
Zabul	35	486	1.35	80.3	210	14.8	0.7	2.14	0.09	181.71
Sabzevar	27	1579	15.74	20	241	23.11	20.55	4.92	3.65	16.77
Sarakhs	24	294	9.22	99.14	194	12.1	1.8	0.63	0.24	5.54
Sirjan 1	26	1753	8.15	50.91	189	12.82	15.33	1.78	0.59	14.24
Sirjan 2	26	1820	28.48	76.24	189	35.91	26.92	3.55	2.49	22.27
Kerman 1	30	1779	7.72	21.47	12	12.1	14.53	2.11	0.07	10.79
Kerman 2	30	1748	4.38	16.62	11	11.84	11.62	1.95	0.14	4.25
Kerman 3	29	1745	5.87	16.5	12	12.67	11.04	2.19	0.08	0.13
Gonabad	31	879	24.63	41.82	284	39.91	12.2	0.54	0.58	5.72
Mahan 1	28	2059	3.94	22.32	37	12.18	19	6.22	3	11.28
Mahan 2	28	2216	1.13	16.71	37	12.25	13.31	0.46	2.28	25.87
Mashhad 1	27	940	1.47	15.93	12	12.27	3.6	2.04	0.69	6.5
Mashhad 2	27	1482	6.04	1.8	13	13.38	5.5	7.53	0.87	13.9
Yazd	31	3027	8.71	27.74	34	34.67	40.74	3.38	8.48	31.74

In the next step, decision-makers used TOPSIS, TODIM, WASPAS, COPRAS, ARAS, and MULTIMOORA methods to rank the SPP construction alternatives as valid and widely used methods.

Table 5 presents the final scores of the alternatives calculated in each MCDM tool. The numbers in parentheses indicate the alternative's rank.

Table 5. Scores and ranking of alternatives in each method.

Weight of Criteria	**MULTIMOORA**				**ARAS**	**COPRAS**	**WASPAS**	**TODIM**	**TOPSIS**
Alternatives	**FM ***	**RM ***	**RP ***	**DT ***					
Bam	0.038	0.028	1.985	4	0.304 (2)	100 (1)	0.267 (5)	0.960 (3)	0.652 (2)
Birjand	0.052	−0.057	1.202	16	0.222 (7)	56.7 (15)	0.179 (15)	0.525 (11)	0.434 (16)
Torbat-e Heydariyeh	0.040	−0.019	1.669	7	0.214 (8)	72.6 (5)	0.269 (4)	0.500 (12)	0.566 (5)
Jiroft	0.042	−0.025	1.842	9	0.144 (16)	71.0 (7)	0.190 (13)	0.599 (9)	0.529 (11)
Rafsanjan	0.032	−0.066	1.327	13	0.162 (14)	54.6 (16)	0.185 (14)	0.280 (18)	0.445(15)
Zabul	0.048	−0.076	0.951	18	0.156 (15)	50.4 (17)	0.151 (17)	0.398 (13)	0.407 (17)
Sabzevar	0.044	−0.104	0.943	19	0.104 (18)	45.4 (19)	0.136 (18)	0.000 (19)	0.379 (18)
Sarakhs	0.038	−0.048	1.236	15	0.135 (17)	60.7 (14)	0.159 (16)	0.544 (10)	0.475 (14)
Sirjan 1	0.025	0.019	2.293	2	0.263 (3)	88.8 (2)	0.301 (2)	1.000 (1)	0.639 (3)
Sirjan 2	0.036	−0.032	2.572	3	0.407 (1)	66.7 (12)	0.323 (1)	0.372 (15)	0.549 (6)
Kerman 1	0.046	−0.085	0.991	17	0.096 (19)	48.0 (18)	0.124 (19)	0.368 (17)	0.370 (19)
Kerman 2	0.046	−0.038	1.323	14	0.177 (11)	67.4 (11)	0.235 (8)	0.372 (16)	0.535 (8)
Kerman 3	0.033	−0.041	1.536	10	0.212 (9)	61.9 (13)	0.228 (10)	0.602 (8)	0.489 (13)
Gonabad	0.0531	−0.019	1.429	12	0.235 (5)	71.6 (6)	0.212 (12)	0.760 (4)	0.521 (12)
Mahan 1	0.030	−0.024	1.568	8	0.176 (12)	68.8 (9)	0.236 (7)	0.394 (14)	0.575 (4)
Mahan 2	0.044	−0.021	1.474	11	0.175 (13)	69.1 (8)	0.225 (11)	0.649 (6)	0.534 (9)
Mashhad 1	0.019	0.036	1.809	1	0.201 (10)	88.1 (3)	0.280 (3)	0.964 (2)	0.706 (1)
Mashhad 2	0.038	−0.023	1.688	6	0.241 (4)	68.3 (10)	0.267 (6)	0.620 (7)	0.542 (7)
Yazd	0.054	−0.016	1.802	5	0.230 (6)	74.3 (4)	0.229 (9)	0.664 (5)	0.531 (10)

* Fully-multiplicative (FM)/Ratio-method (RM)/Reference-point (RP)/Dominance theory (DT).

4.4. Aggregating Scores and Ranking Candidates

After calculating previous scores, a secondary decision matrix was formed. Table 5 shows this matrix.

The normalized secondary decision matrix is calculated using Equations (1) and (2) In the next step. Table 6 shows the normalized secondary decision matrix.

Table 6. Normalized Secondary Decision Matrix.

Alternatives	Fully-Multiplicative (FM)	Ratio-Method (RM)	Reference-Point (RP)	ARAS	COPRAS	WASPAS	TODIM	TOPSIS
Bam	0.446	0.943	0.639	0.668	1	0.722	0.960	0.838
Birjand	0.056	0.337	0.159	0.405	0.207	0.277	0.525	0.195
Torbat-e Heydariyeh	0.404	0.609	0.445	0.379	0.498	0.732	0.500	0.583
Jiroft	0.342	0.564	0.552	0.153	0.468	0.331	0.599	0.473
Rafsanjan	0.639	0.269	0.236	0.210	0.170	0.306	0.280	0.223
Zabul	0.179	0.195	0.005	0.192	0.092	0.138	0.398	0.110
Sabzevar	0.305	0	0	0.024	0	0.064	0	0.028
Sarakhs	0.474	0.397	0.180	0.126	0.281	0.176	0.544	0.312
Sirjan 1	0.834	0.884	0.829	0.536	0.795	0.890	1	0.800
Sirjan 2	0.524	0.515	1	1	0.390	1	0.372	0.532
Kerman 1	0.232	0.135	0.029	0	0.048	0	0.368	0
Kerman 2	0.243	0.472	0.233	0.259	0.402	0.559	0.372	0.491
Kerman 3	0.596	0.447	0.364	0.374	0.303	0.524	0.602	0.355
Gonabad	0.030	0.610	0.298	0.448	0.481	0.445	0.760	0.449
Mahan 1	0.701	0.570	0.383	0.258	0.430	0.564	0.394	0.609
Mahan 2	0.306	0.594	0.326	0.253	0.434	0.509	0.649	0.490
Mashhad 1	1	1	0.531	0.339	0.782	0.787	0.964	1
Mashhad 2	0.458	0.578	0.457	0.465	0.419	0.718	0.620	0.512
Yazd	0	0.626	0.527	0.431	0.529	0.528	0.664	0.479

The next step calculates the weight of each MCDM method by formulating and solving the related optimization problem according to the CCSD method. Decision-makers calculated these weights based on the data from Table 6. Table 7 presents the estimated weights.

Table 7. Weight of MCDM methods using the CCSD method.

Method	MULTIMOORA			ARAS	COPRAS	WASPAS	TODIM	TOPSIS
	Reference-Point (RP)	Ratio-Method (RM)	Fully-Multiplicative (FM)					
Weight	0.1217	0.1398	0.1148	0.0885	0.1144	0.1490	0.1437	0.1282

Finally, Equation (3) helps calculate the performance value and determine the final rank of alternatives. Table 8 shows the performance values and final ranking of options.

Table 8. Performance values and the final ranking of alternatives using the developed method.

Alternatives	Final Score	Final Rank
Bam	0.787	3
Birjand	0.274	16
Torbat-e-Heydariyeh	0.532	6
Jiroft	0.447	12
Rafsanjan	0.295	15
Zabul	0.169	17
Sabzevar	0.052	19
Sarakhs	0.322	14
Sirjan 1	0.837	1
Sirjan 2	0.654	4
Kerman 1	0.109	18
Kerman 2	0.391	13
Kerman 3	0.454	10
Gonabad	0.451	11
Mahan 1	0.500	7
Mahan 2	0.461	9
Mashhad 1	0.826	2
Mashhad 2	0.540	5
Yazd	0.483	8

5. Discussion and Comparison

In this section, we first compare our findings with earlier literature studies. Besides, to analyze the stability of the proposed method, the similarity of the final ranking with other used methods is compared.

5.1. Discussion

According to the results of the weighting criteria (Table 3), we can indicate that average temperature is the most critical parameter for selecting the SPP location. As mentioned in the literature, it correlates with other climatological parameters (e.g., solar radiation, wind speed, vapor pressure, humidity, precipitation, and others). The results are in line with the findings of the literature survey on SPP location selection [3,23].

On the other hand, for establishing each SPP, a set of topographical conditions is necessary. Considering the conditions of selected locations in Iran, decision-makers introduced average elevation as one of the essential criteria from the experts' point of view. It is in line with Zoghi et al. [2] and Azadeh et al. [23] in Iran.

Decision-makers selected the distance from the power line as another influential factor. Being Far from power transmission lines causes voltage dropping, wastes more energy, and reduces the overall efficiency of industrial processes [2,63].

The following essential criteria are that establishing the SPP location with a high degree of natural disasters (e.g., earthquakes and torrents) could be hazardous and increase maintenance costs. Accordingly, policy-makers must select a safe and secure place for locating an SPP [63,64]. Azadeh et al. [23] also stressed the importance of this issue, especially in Iran [23].

Similarly, proximity to the city's center with a higher population is advantageous [25,38]. For this reason, decision-makers ranked this criterion ranked next in importance. Moreover, the vicinity of SPP to locations with the capability of water supply and major roads can give an idea about construction and supply chain costs [3,14,64]; and these have caused these two criteria to be in the following ranks.

5.2. Comparison

Table 9 presents the ranking results of the developed integrated approach with the results of different methods. The results of comparator methods, i.e., Borda and Ensemble Ranking, have been summarized in the last two columns of Table 9. The Borda method is one of the most widely used methods identified in previous research. The Ensemble Ranking method is a recently proposed approach whose rationale aligns with the proposed method, and hence the comparison is valid.

Table 1 shows that alternative Sirjan 1, based on the proposed method results, has the highest priority in constructing SPP. Different methods ranked it as 1–3. Another place (Mashhad 1) has a second priority ranking because the ARAS method put it in tenth place. Besides, Bam ranks third in the method the authors propose, fourth in the MULTIMOORA method, and fifth in the WASPAS method. However, decision-makers calculated the final ranks for the different techniques based on the CCSD method (Table 6).

Table 9. Summary and comparison of rankings of methods with the developed integration approach.

Alternatives	MULTIMOORA	ARAS	COPRAS	WASPAS	TODIM	TOPSIS	Proposed Method (CCSD)	Borda	Ensemble Ranking
Bam	4	2	1	5	3	2	3	2	3
Birjand	16	7	15	15	11	16	16	14	14
Torbat-e-Heydariyeh	7	8	5	4	12	5	6	6	5
Jiroft	9	16	7	13	9	11	12	12	11
Rafsanjan	13	14	16	14	18	15	15	16	15
Zabul	18	15	17	17	13	17	17	17	17
Sabzevar	19	18	19	18	19	18	19	19	19
Sarakhs	15	17	14	16	10	14	14	15	16
Sirjan 1	2	3	2	2	1	3	1	1	1
Sirjan 2	3	1	12	1	15	6	4	4	4
Kerman 1	17	19	18	19	17	19	18	18	18
Kerman 2	14	11	11	8	16	8	13	13	12
Kerman 3	10	9	13	10	8	13	10	11	13
Gonabad	12	5	6	12	4	12	11	9	9
Mahan 1	8	12	9	7	14	4	7	8	8
Mahan 2	11	13	8	11	6	9	9	10	10
Mashhad 1	1	10	3	3	2	1	2	3	2
Mashhad 2	6	4	10	6	7	7	5	5	6
Yazd	5	6	4	9	5	10	8	6	7

Here, the authors applied the Spearman rank correlation coefficient to evaluate the performance of the proposed method and to measure the similarity of the results obtained from the proposed method with the results of other ways. Zavadskas et al. [45], using Equation (4) [65], applied this method also.

$$r_s = 1 - \frac{6\sum\limits_{i} d_i^2}{n^3 - n}. \tag{4}$$

There d_i indicates the difference between the rank of ith alternative in the proposed method and the other methods, and n denotes the number of available pair values. Table 10 presents the values of the Spearman rank correlation coefficient.

Table 10. Spearman's rank correlation coefficient between the proposed method and MCDM methods.

	MULTIMOORA	ARAS	COPRAS	WASPAS	TODIM	TOPSIS	Borda	Ensemble Ranking
CC	0.967	0.753	0.840	0.947	0.679	0.942	0.983	0.975

The results show that the proposed method is highly correlated with the MULTIMOORA, WASPAS, and TOPSIS methods and less correlated with the TODIM and ARAS ways. One reason for this is the different normalization approaches and their different steps (differences are in logic and how they deal with the ranking issue). These differences have caused the final ranking of alternatives in these methods to be different, and, therefore, the Spearman rank correlation coefficient has decreased significantly. Besides, the comparison of the results of this table with the final weight calculated for the methods (Table 6) shows the simultaneous effect of the correlation coefficient (CC) and the standard deviation (SD) in calculating weights using the CCSD method.

On the other hand, comparing the findings of the proposed method with the results of the Borda and Ensemble Ranking methods (as aggregation methods) is closed. Examining the Spearman rank correlation coefficient value also shows this similarity.

6. Conclusions

Growing demand for electricity and climate changes such as global warming and many other factors have led countries to use renewable energy more. SE has attracted much interest from decision-makers and researchers because of its many advantages over other RES. Iran has excellent potential for using SE. Building an SPP in an inappropriate place wastes cost, time, and resources and causes numerous environmental problems. This study aimed to find a suitable location for constructing an SPP in the southeastern region of Iran. Given the multitude of effective criteria and the varying importance of these criteria, many studies in the literature have used MCDM methods to solve this problem. The critical thing about utilizing MCDM methods is that they have distinctive features and qualities, and when used to solve the same problem, they may produce different results. Therefore, combining different ways increases the robustness of the results. Accordingly, the aggregation of different MCDM methods has emerged as a new area of decision-making. The methods used so far to aggregate the results of MCDM methods have some shortcomings that the authors have attempted to overcome in this paper using the CCSD method.

The experts first extracted the SPP locating evaluation criteria from the literature during the study. Later, the experts determined the final list of criteria. ArcGIS software has helped decision-makers build an initial list of feasible alternatives. In the next phase of the study, the SWARA method helped assess the criteria weights. Decision-makers then calculated performance scores for possible options. They used six MCDM methods: TOPSIS, TODIM, WASPAS, COPRAS, ARAS, and MULTIMOORA methods. Finally, they summarized the problem solution results and identified the best choice using the CCSD method. Based on the problem-solution results, decision-makers consider the average temperature and average altitude as the most important criteria, followed by distance-related criteria. Besides, Sirjan 1, Mashhad 2, and Bam are the three highest priority alternatives. Policy-makers should keep in mind that these methods only favor possible solutions. When choosing the best location for constructing an SPP, project managers and investors consider the results and constraints of the task solution and decide why, where, when, and which project to implement.

Results show that the proposed approach to integrating the results of MCDM methods and eliminating the limitations of previous methods has increased the robustness of the results. Results also have a high correlation with the results of previous methods. The authors of this article suggest that future research address the issue of uncertainty in the decision-making process and develop the approach proposed in this paper using fuzzy or interval-valued intuitionistic fuzzy (IVIF numbers to calculate the alternatives' score. The authors suggest improving this technique to suit hesitant fuzzy (HF) operators if experts are skeptical about the proposed numbers.

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