# An Integrated GIS–MCDM Framework Using BWM, SWARA, and MARCOS for Optimal Solar Power Plant Site Selection in Fars Province- Iran

Vahidreza Atabati[1*], Mahdi Arabi[1]

[1] Dept. of Surveying Engineering, Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Lavizan, Tehran, Iran- (v.atabati, mahdi.a)@sru.ac.ir

**Abstract**

The transition toward renewable energy sources is essential for achieving environmental sustainability and mitigating climate change. Among various alternatives, photovoltaic (PV) solar energy stands out due to its high efficiency, low environmental impact, and vast potential for electricity generation. This study presents an integrated GIS based multi-criteria decision-making (MCDM) framework to identify optimal locations for solar power plant development in Fars Province, Iran. Nine spatial and environmental criteria including direct normal irradiation (DNI), photovoltaic potential, temperature, rainfall, slope, elevation, and distances from roads, faults, and urban areas were considered. To determine the relative importance of the criteria, two advanced weighting methods, Best Worst Method (BWM) and Stepwise Weight Assessment Ratio Analysis (SWARA), were applied, and their results were fused using the Dempster-Shafer evidence theory to enhance decision reliability. The weighted criteria were then integrated through the MARCOS model to produce a comprehensive land suitability map. The results indicate that approximately 39% of the study area falls into the high and very high suitability categories for solar power plant installation. The proposed hybrid framework effectively combines expert judgment and quantitative analysis, offering a reliable and replicable model for sustainable solar energy planning and decision making in similar regions.

**Keywords:** GIS, MCDM, MARCOS, Dempster-Shafer evidence theory, Solar Power Plant Site Selection

## 1. Introduction

Owing to their ecological advantages especially their ability to reduce environmental impacts compared with conventional fossil based systems renewable energies are now considered one of the most effective means of mitigating climate change. Nevertheless, these resources must be managed and utilized sustainably to ensure that they can adequately meet the growing energy demands of the future (Owusu & Asumadu-Sarkodie, 2016). Among various renewable energy resources, photovoltaic (PV) solar energy is recognized as one of the most sustainable and environmentally friendly options, with tremendous potential to meet future energy demands (Shorabeh et al., 2019). The selection of suitable sites for solar power plant installation plays a crucial role in the overall success of clean energy projects. An optimal site not only enhances electricity generation efficiency and improves the project's economic performance but also significantly minimizes negative environmental impacts. Conversely, an inappropriate site selection can lead to reduced power output, wasted financial and energy resources, and, in some cases, even exacerbate environmental challenges (Heidary Dahooie et al., 2022). In recent years, Geographic Information Systems (GIS) have emerged as powerful tools for collecting, analyzing, and visualizing spatial data to support informed decision-making in energy planning. The integration of Multi-Criteria Decision-Making (MCDM) techniques with GIS capabilities provides an effective framework for the optimal siting of solar power plants. This combined approach not only enables a more comprehensive evaluation of environmental and technical factors but also facilitates scenario-based analysis for identifying the most suitable locations for sustainable energy development.

### 1.1 Literature review

Building on previous national-level studies, several researchers have explored solar site selection using GIS-based MCDM frameworks. For instance, Atabati and Arabi (2025) employed a combination of SWARA, EDAS, and TOPSIS methods integrated with GIS to identify optimal solar power plant locations in Fars Province, Iran. Their findings demonstrated the strong influence of photovoltaic potential, solar radiation, and proximity to infrastructure on site suitability. However, that study applied a single-layer weighting scheme and did not explicitly handle uncertainty between methods.

The present research expands upon that previous work by introducing a more advanced hybrid framework that integrates BWM and SWARA with the Dempster-Shafer evidence theory for weight fusion, and applies the MARCOS model for ranking. This integration improves the reliability of decision-making and provides a more comprehensive uncertainty treatment compared with the earlier SWARA-EDAS-TOPSIS approach.

Several studies have also investigated optimal site selection for solar power plants using GIS and multi-criteria decision-making (MCDM) methods. (Heidary Dahooie et al., 2022) applied a hybrid MCDM framework combining SWARA with several ranking models such as TOPSIS, TODIM, WASPAS, COPRAS, ARAS, and MULTIMOORA, and synthesized the results using the CCSD technique to identify optimal sites across several Iranian provinces. (Ahadi et al., 2023) employed the AHP method to prioritize provincial capitals in Iran, revealing Zahedan and Shiraz as the most suitable locations for solar farm installation. Similarly, (Shorabeh et al., 2022) used a hybrid AHP-WLC approach enhanced with Decision Tree and Particle Swarm Optimization algorithms, demonstrating that the Decision Tree method provided higher accuracy in predicting suitable solar sites across Iran. (Islam et al., 2024) proposed a hybrid framework combining MCDM techniques with Support Vector Regression to identify suitable solar and wind farm sites in Saudi Arabia, demonstrating improved spatial prediction accuracy. Likewise, (Qasimi et al., 2023) assessed solar energy potential in northern Afghanistan using AHP and a Genetic

* Corresponding author

Algorithm, integrating geographic and environmental factors to locate optimal areas for solar plant installation. Their findings indicated that evolutionary algorithms can outperform traditional decision-making methods and significantly enhance the precision of renewable energy site selection analyses.

## 2. Main body

### 2.1 Objectives

The present study addresses the challenge of solar power plant site selection through an efficient and applicable methodological framework. Spatial datasets were collected to construct decision-making criteria layers, which were then analyzed using both a multi-criteria decision-making approach and a machine learning technique. In the MCDM phase, the decision criteria were weighted using two advanced methods, SWARA and BWM, and their results were integrated through Dempster-Shafer Theory. Finally, the MARCOS model was applied to generate a comprehensive land suitability map for solar plant installation, and the outcomes were validated and compared with previous studies to assess the accuracy and effectiveness of the proposed approach.

### 2.2. Methodology

This study employs a structured MCDM framework integrating BWM, SWARA, the MARCOS model, and Dempster-Shafer theory for information fusion. Each method contributes to improving the accuracy and reliability of the final solar site suitability map.

### 2.2.1 Best Worst Method (BWM)

The BWM, proposed by (Rezaei, 2015)was developed to overcome the excessive number of pairwise comparisons required in traditional methods such as AHP. This approach is based on structured pairwise comparisons between the most and least significant criteria. The decision-maker first identifies the best and worst criteria from a predefined set, then evaluates their relative importance to other criteria, forming two comparison vectors: best-to-others and others-to-worst. An optimization model is then solved to obtain the optimal weight vector by minimizing the maximum deviation between the two comparison ratios.

$$\left|\frac{W_B}{W_j} - a_{Bj}\right| \le \xi, for\ all\ j$$
$$\left|\frac{W_j}{W_w} \quad a_{jw}\right| \le \xi, for\ all\ j \tag{1}$$
$$\sum_{j=1}^{m} w_j = 1$$
,
$$w_j \ge 0, for\ all\ j$$

The consistency ratio (CR) is later calculated to verify the reliability of judgments; values below 0.1 indicate acceptable consistency

### 2.2.2 Stepwise Weight Assessment Ratio Analysis (SWARA)

SWARA is a comparatively simple and expert-driven weighting technique that evaluates the relative significance of criteria based on expert judgment (Zavadskas et al., 2019). Criteria are ranked according to importance, and a comparative coefficient $K_j = 1 + S_j$ is assigned to each. The initial weight of each criterion is obtained through a recursive relation $Q_j = Q_{j-1}/K_j$, and the final normalized weights are computed as This method effectively incorporates subjective expert knowledge while maintaining transparency and simplicity.

$$W_j - \frac{Q_j}{\sum_{j-1}^{m} Q_j} \tag{2}$$

### 2.2.3 MARCOS methode

The Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) method, introduced by (Stević et al., 2020), is a flexible MCDM technique capable of handling a large number of alternatives and criteria. It begins by constructing an extended decision matrix that includes ideal and anti-ideal solutions. After normalization and weighting, the utility degree of each alternative is calculated relative to both reference points using the ratios

$$K_i = \frac{S_i}{S_{AAI}}, K_i^{1} = \frac{S_{AI}}{S_i}, \tag{3}$$

where $S_i$, $S_{AAI}$, and $S_{AI}$denote the total weighted normalized scores for the alternative, anti-ideal, and ideal solutions, respectively. The final utility function $f(K_i)$measures how closely each alternative approaches the ideal solution, enabling the ranking of solar site options based on overall performance.
for each alternative is calculated using Equation (4). This function represents the degree of compromise of each option in relation to the anti-ideal and ideal solutions, indicating how closely an alternative approaches the optimal condition.

$$f(K_i) = \frac{K_i + K_i^{1}}{1 + \frac{1 - f(K_i^{-})}{f(K_i^{-})} + \frac{1 - f(K_i^{1})}{f(K_i^{1})}} \tag{4}$$

$$f(K_i^{-}) = \frac{K_i^{+}}{K_i^{-} + K_i^{+}}$$
(5)

$$f(K_i^{+}) = \frac{K_i^{-}}{K_i^{-} + K_i^{+}}$$
(6)

### 2.2.4 Dempster–Shafer theory

The Dempster–Shafer theory provides a mathematical framework for combining evidence and reasoning under uncertainty. Using Dempster's rule of combination, it integrates information from independent sources to establish a shared degree of belief while redistributing conflicting evidence through a normalization factor. This theory defines a mass function $m(A)$over a power set $P(U)$, satisfying $\sum m(A) = 1$ and $m(\emptyset) = 0$. Owing to its simplicity and high fusion accuracy, this theory has become one of the most reliable approaches for information integration in multi-criteria decision-making applications. Evidence from different sources is fused using Dempster's rule of combination:

$$m_{12} = m_1 \oplus m_2 = m_{12}(A) = \begin{cases} \dfrac{\sum_{B \cap C = A} m_1(B) m_2(C)}{1 - \sum_{B \cap C = \emptyset} m_1(B) m_2(C)} & A \neq \emptyset \quad \forall A \subseteq U \\ 0 & A = \emptyset \end{cases} \tag{7}$$

The resulting combined weights reflect a consensus belief among expert evaluations, minimizing uncertainty and potential bias.
Overall, this integrated methodological framework leverages the strengths of both expert-based and mathematical decision-making models, providing a robust foundation for accurately identifying optimal sites for solar power plant development. To enhance decision reliability, the weighting results obtained from BWM and SWARA were integrated using the Dempster-Shafer evidence theory, which enables the combination of information from independent sources under uncertainty.

### 2.2.5 Sensitivity Analysis of Criteria Weights

To ensure the robustness of the proposed decision-making framework, a sensitivity analysis was carried out on the final integrated weights obtained from the BWM–SWARA–Dempster–Shafer combination. Each criterion weight was perturbed by ±10% while keeping the total normalized weight equal to one. For each modified weight scenario, the MARCOS model was re-executed to assess how the changes affected the suitability classification. The results indicated that the share of “high” and “very high” suitability zones varied only between 38% and 41%, representing less than a 3% deviation from the baseline case. This outcome demonstrates that the model is robust against minor uncertainties in the weighting process and maintains a stable spatial ranking pattern across different perturbation scenarios.

### 2.3 Study Area

Fars Province, located in southern Iran with an area of about 123,946 km², ranks as the fourth-largest province in the country. Geographically extending between 27°02′–31°38′ N and 50°42′–55°38′ E, it features diverse climates moderate, mountainous, and warm within an elevation range of 110 to 3927 meters above sea level.

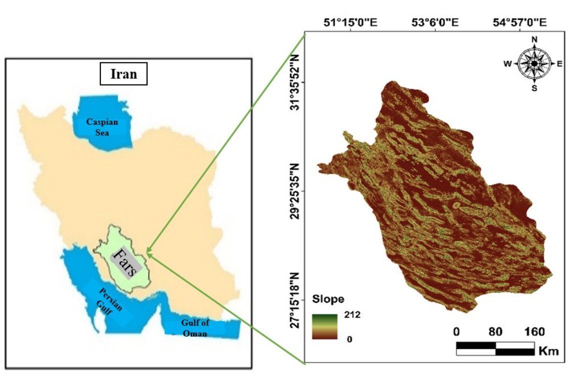


**Figure 1.** Study area.

### 2.4 Data collection

Selecting appropriate criteria plays a vital role in the efficiency and profitability of solar power plants. To optimize productivity and reduce costs, accurate and well-defined criteria are essential in the site selection process. In this study, based on available spatial data and previous research findings, nine key factors photovoltaic potential (PVOUT), direct normal irradiation(DNI), temperature, rainfall, distance from roads, faults, and urban areas, as well as elevation and slope were identified as the main criteria for solar power plant site selection. The detailed description of these criteria is presented in the following table.

| Data source | Abbrev | Criterion |
|---|---|---|
| https://solargis.com | $C_1$ | Direct normal radiation |
| https://solargis.com | $C_2$ | Photovoltaic potential |
| https://solargis.com | $C_3$ | Temperature |
| https://earthexplorer.usgs.gov | $C_4$ | Slope |
| https://www.irimo.ir | $C_5$ | Rainfall |
| https://www.openstreetmap.org | $C_6$ | Distance from roads |
| https://earthexplorer.usgs.gov | $C_7$ | **Elevation** |
| www.iiees.ac.ir | $C_8$ | Distance from faults |
| https://www.openstreetmap.org | $C_9$ | **Urban Areas** |

**Table 1.** Decision-criteria layers (C1-C9), abbreviations, and data sources.

## 3. Results

In this study, several tools available in ArcGIS 10.8 were utilized for spatial data processing. These included Project and Project Raster for coordinate system transformation, Extract by Mask for layer clipping, Kriging for interpolating rainfall station data, Slope for generating the slope layer, and Euclidean Distance for calculating distances from urban areas, roads, and faults. All datasets were processed at a 100 meter pixel resolution, and the resulting spatial layers were prepared as decision making criteria for the solar power plant site selection analysis.figure 2 shows the decision-criteria maps.

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
https://doi.org/10.5194/isprs-annals-X-4-W8-2025-109-2026 | © Author(s) 2026. CC BY 4.0 License.

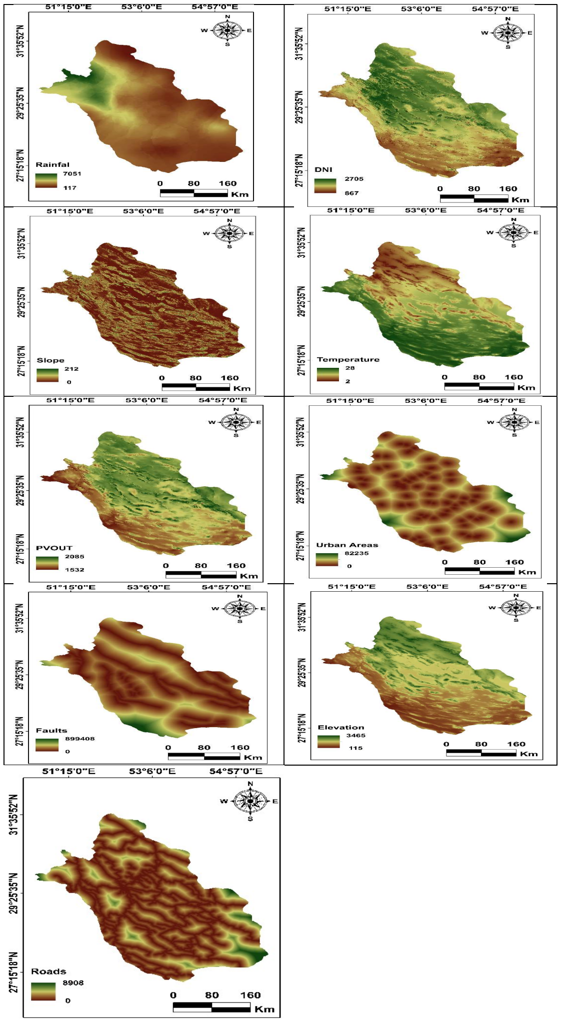


**Figure 2.** Decision-making criterion maps.

In this section, the numerical results obtained from the weighting process and the preparation of the land suitability map for solar power plant site selection are presented. The decision making criteria were first weighted using the BWM and SWARA methods, and their results were subsequently integrated through the Dempster-Shafer theory to obtain the final combined weights for each criterion.

| Integrated Method | SWARA | BWM | Criterion |
|---|---|---|---|
| 0.182 | 0.153 | 0.171 | $C_1$ |
| 0.434 | 0.170 | 0.373 | $C_2$ |
| 0.108 | 0.135 | 0.117 | $C_3$ |
| 0.054 | 0.109 | 0.075 | $C_4$ |
| 0.063 | 0.120 | 0.082 | $C_5$ |
| 0.032 | 0.088 | 0.055 | $C_6$ |
| 0.021 | 0.075 | 0.043 | $C_7$ |
| 0.030 | 0.084 | 0.052 | $C_8$ |
| 0.059 | 0.114 | 0.079 | $C_9$ |

**Table 2.** Results of the weights obtained from the BWM and SWARA methods and the final integrated weights derived through the Dempster-Shafer evidence theory.

### 3.1 Land Suitability Map

To integrate the decision-making criteria using the MARCOS method, the weight vector obtained from the combined Dempster-Shafer theory was first employed as input for the criteria aggregation process. In the next step, the land suitability map was generated and implemented using the MARCOS approach, as illustrated in Figure 3.

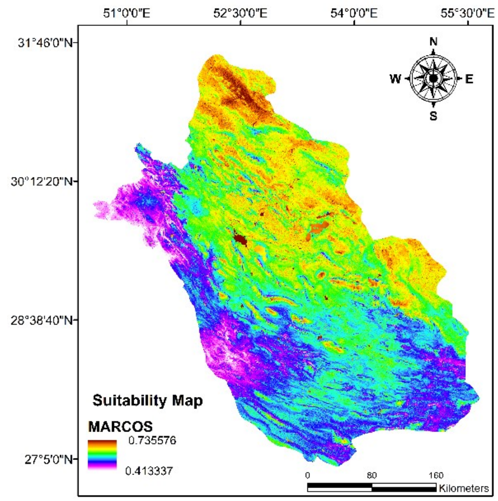


**Figure 3.** Land Suitability Map generated using the MARCOS method

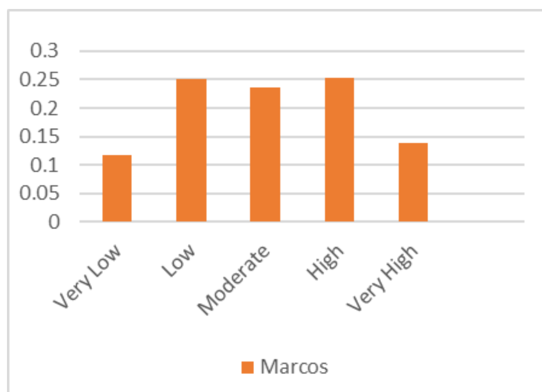


**Table 3.** MARCOS Suitability Classes for Fars Province

Based on the results obtained from the MARCOS model, approximately 39% of the total study area was classified as highly suitable or very highly suitable for the establishment of solar power plants. These areas are characterized by favorable geographic and environmental conditions such as optimal solar radiation, gentle slopes, appropriate distances from urban areas, and minimal geological risks. The remaining portions of the region were categorized as moderately suitable or low suitability, primarily due to limitations in topography, climatic conditions, or infrastructural accessibility.

This comprehensive spatial evaluation assists decision-makers in prioritizing zones for solar development by considering both technical and environmental aspects. Consequently, it provides a scientific foundation for sustainable energy planning, allowing authorities to minimize environmental impacts while


https://doi.org/10.5194/isprs-annals-X-4-W8-2025-109-2026 

maximizing the efficiency and profitability of future solar power projects.

The sensitivity assessment confirmed that moderate variations in the weights of decision criteria have a negligible impact on the final suitability results. The dominant influence of photovoltaic potential and direct normal irradiation remained consistent in all scenarios, while less significant criteria such as elevation and distance from faults showed minimal sensitivity. These findings validate the reliability of the proposed hybrid weighting fusion approach, as the spatial distribution of suitable areas remained largely unchanged under different weighting conditions.

As shown in Table 4, the overall suitability distribution remains nearly unchanged under both perturbation scenarios. The maximum variation in the high and very high suitability classes is below 3%, indicating that the integrated weighting process based on BWM, SWARA, and Dempster–Shafer theory provides reliable and stable results. Hence, the model's decision outputs are robust even in the presence of moderate uncertainty in expert-assigned weights.

| **Scenario** | **Description** | **Area of High + Very High Suitability (%)** | **Change Compared to Baseline (%)** |
|---|---|---|---|
| **Base Case** | Original integrated weights (BWM–SWARA–Dempster–Shafer) | 39.0 | – |
| **Weights +10%** | All criteria weights increased by 10% (normalized total = 1) | 41.0 | +2.0 |
| **Weights -10%** | All criteria weights decreased by 10% (normalized total = 1) | 38.2 | –0.8 |

**Table 4.** Results of the sensitivity analysis under ±10% variation of the integrated criteria weights. The results indicate that the total area classified as "high" and "very high" suitability fluctuates only within a narrow range (38%–41%), corresponding to less than 3% deviation from the baseline. This confirms that the proposed hybrid weighting–integration model is stable and robust against minor uncertainties in weight assignment.

## 4. Conclusion

In this study, the criteria for photovoltaic (PV) solar power plant site selection were determined based on previous research and the availability of spatial data. To ensure efficiency and accuracy, only the most relevant and influential factors were considered. The selected criteria included direct normal irradiation (DNI), photovoltaic potential, temperature, slope, rainfall, distance from roads, elevation, distance from faults, and distance from urban areas. These parameters have been widely used in earlier solar siting studies. Specifically, photovoltaic potential was employed by (Neisani Samani & Tahouni, 2019) and (Imam et al., 2024), while DNI was applied in limited studies such as (Islam et al., 2024) and (Qasimi et al., 2023), and is emphasized here as a key determinant for evaluating solar suitability.

The multi-criteria decision-making (MCDM) approach adopted in this research consisted of two main stages: (1) criteria weighting and (2) integration of spatial layers to produce the final land suitability map. For weighting, two structured and reliable methods BWM and SWARA Methodes were applied. Compared to the conventional AHP, BWM offers higher consistency and requires fewer pairwise comparisons. To enhance reliability and mitigate differences between the two weighting methods, their results were combined using the Dempster–Shafer evidence theory, one of the most robust information-fusion frameworks for decision analysis under uncertainty. This integration effectively reduced ambiguity and improved the accuracy of the final criterion weights.

Subsequently, the MARCOS model was applied to combine the weighted layers and generate the land suitability map for solar power plant development. The results revealed that approximately 14%, 25%, 24%, 25%, and 12% of the total study area fell into the classes of very high, high, moderate, low, and very low suitability, respectively. Overall, more than 39% of Fars Province was classified as highly or very highly suitable for solar power plant installation. This outcome highlights the province's strong solar energy potential and provides a scientific foundation for identifying optimal locations for sustainable solar infrastructure development.

Furthermore, because the input datasets (e.g., Solargis, USGS, OpenStreetMap) are globally accessible and the selected criteria are universally recognized in solar site selection research, the proposed GIS-MCDM framework can be easily adapted to other geographical regions. By recalibrating the local environmental parameters or adjusting the expert-defined weights, the same hybrid methodology can support renewable energy planning and policy decisions in various climatic and infrastructural contexts. This generalizability confirms the applicability of the model beyond Fars Province and reinforces its potential as a transferable and replicable decision-support tool for sustainable solar energy development.

## References

Owusu, P. A., Asumadu-Sarkodie, S., 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*, *3*(1), 1167990.

Shorabeh, S. N., Firozjaei, M. K., Nematollahi, O., Firozjaei, H. K., Jelokhani-Niaraki, M., 2019. A risk-based multi-criteria spatial decision analysis for solar power plant site selection in different climates: A case study in Iran. *Renewable Energy*, *143*, 958-973.

Heidary Dahooie, J., Husseinzadeh Kashan, A., Shoaei Naeini, Z., Vanaki, A. S., Zavadskas, E. K., Turskis, Z., 2022. A Hybrid Multi-Criteria-Decision-Making Aggregation Method and Geographic Information System for Selecting Optimal Solar Power Plants in Iran. *Energies*, *15*(8).

Atabati, V., Arabi, M., 2025. Utilizing GIS with SWARA, EDAS, and TOPSIS Multi-Criteria Decision-Making (MCDM) Methods for Solar Power Plant Site Selection in Fars Province. *Geography and Environmental Planning*, *35*(4).

Ahadi, P., Fakhrabadi, F., Pourshaghaghy, A., Kowsary, F., 2023. Optimal site selection for a solar power plant in Iran via the Analytic Hierarchy Process (AHP). *Renewable Energy*, *215*, 118944.


https://doi.org/10.5194/isprs-annals-X-4-W8-2025-109-2026 | © Author(s) 2026. CC BY 4.0 License.

Shorabeh, S. N., Samany, N. N., Minaei, F., Firozjaei, H. K., Homaee, M., Boloorani, A. D., 2022. A decision model based on decision tree and particle swarm optimization algorithms to identify optimal locations for solar power plants construction in Iran. *Renewable Energy*, *187*, 56-67.

Islam, M. R., Aziz, M. T., Alauddin, M., Kader, Z., Islam, M. R., 2024. Site suitability assessment for solar power plants in Bangladesh: A GIS-based analytical hierarchy process (AHP) and multi-criteria decision analysis (MCDA) approach. *Renewable Energy*, *220*, 119595.

Qasimi, A. B., Toomanian, A., Nasri, F., Samany, N. N., 2023. Genetic algorithms-based optimal site selection of solar PV in the north of Afghanistan. *International Journal of Sustainable Energy*, *42*(1), 929-953.

Rezaei, J., 2015. Best-worst multi-criteria decision-making method. *Omega*, *53*, 49-57.

Zavadskas, E. K., Čereška, A., Matijošius, J., Rimkus, A., Bausys, R., 2019. Internal Combustion Engine Analysis of Energy Ecological Parameters by Neutrosophic MULTIMOORA and SWARA Methods. *Energies*, *12*(8).

Stević, Ž., Pamučar, D., Puška, A., Chatterjee, P., 2020. Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). *Computers & Industrial Engineering*, *140*, 106231.

Imam, A. A., Abusorrah, A., Marzband, M., 2024. Potentials and opportunities of solar PV and wind energy sources in Saudi Arabia: Land suitability, techno-socio-economic feasibility, and future variability. *Results in Engineering*, *21*, 101785.

Neisani Samani, N., Tahouni, A., 2019. The Evaluation of suitable Sites for Solar Farms by Multi Criteria Decision Making in GIS (Case Study: East Azarbaijan Province). *Human Geography Research*, *51*(3), 747-764.