

MULTICRITERIA DECISION-MAKING IN WIND-SOLAR POWER PLANTS

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Abstract

By diversifying energy sources, hybrid power plants can provide a more stable and reliable supply to the grid, reducing the need for fossil fuel backup. Wind and solar energy are among the main renewable sources contributing to the global transition to clean energy. The use of wind turbines and solar panels allows energy to be generated in different weather conditions and times of the day, which contributes to the optimal use of land by integrating both technologies in one site. This, in turn, leads to a reduction of the overall footprint on the environment. Therefore, the selection of a suitable location for constructing wind and solar power plants is a challenge. In this regard, the article's goal is to formulate a suitable multicriteria model for assessing the potential of sites for the construction of wind-solar power plants. This model should be capable of integrating both quantitative and qualitative indicators organized into groups. As proof of the applicability of the described model, a numerical experiment is conducted, the results of which convincingly demonstrate its capability.

Key words: renewable energy, wind-solar power plant, multicriteria model, annual energy production

Introduction. Creating a sustainable economy is directly related to environmental protection, leading to economic growth and social justice. Therefore,

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building a wind-solar power plant (WSPP) is a step in the right direction for several reasons. First, they are complementary resources because wind and solar resources often peak at different times. A hybrid system can improve overall reliability and durability if one source is underperforming the other can help compensate, reducing the likelihood of power shortages. Combining the two energy sources can result in higher overall efficiency in generating electricity [1]. Therefore, the correct selection of sites for WSPP is critical to successfully implementing renewable energy projects [2]. Infrastructure should be optimized to minimize land use and maximize energy production [3]. On the other hand, hybrid installations can reduce overall costs by sharing infrastructure (such as transmission lines and maintenance) and merging the strengths of both technologies, potentially resulting in lower levelized cost of energy [4].

A recent study proposes long-term planning for the transition to 100% renewable energy sources through mathematical programming model, considering site selection [5]. Different scenarios can be realized using different fuzzy MCDM methods for determining the location as shown in the case of Mongolia [6]. Review shows various multicriteria renewable energy site selection applications for power plant construction [7]. These multicriteria decision-making problems are well studied and some of them can be found in [8–12]. All of these determine the goal of the article which presents a multicriteria model capable of integrating both quantitative and qualitative indicators for evaluation of places for WSPP building.

Stages for evaluation of the potential of wind-solar power plant sites. The activities of choosing a suitable site for the construction of WSPP are related to the assessment of various aspects such as (1) geographical and climatic criteria regarding wind speed, solar radiation, temperature, slope, altitude, etc.; (2) technical criteria related to topological characteristics, distance to electrical network, distance to roads, logistics, service life, etc.; (3) socio-economic criteria relating to the initial investment, operation and maintenance costs, construction and land costs, annual income, levelized cost of energy, public acceptance and support of sustainable energy innovations and policies, etc. The potential of these two renewable sources can be estimated by using proper models [13,14]. The most frequently used methods for site selection and renewable energy potential assessment of hybrid systems are AHP and GIS [15]. An assessment of the potential of a site for a WSPP can be divided into four distinct stages as shown in Fig. 1.

In Stage-1, it is necessary to assess the potential of the climatic resources of the site, as well as its accessibility and the possibility of integration into an electrical network including some socio-economic aspects. Then, based on the parameters of the site selected in the previous stage, the appropriate type of wind turbine and solar panel should be determined (Stage-2). In Stage-3, based on the information from the previous stages, it is possible to determine the potentially generated energy and finally make a decision (Stage-4).

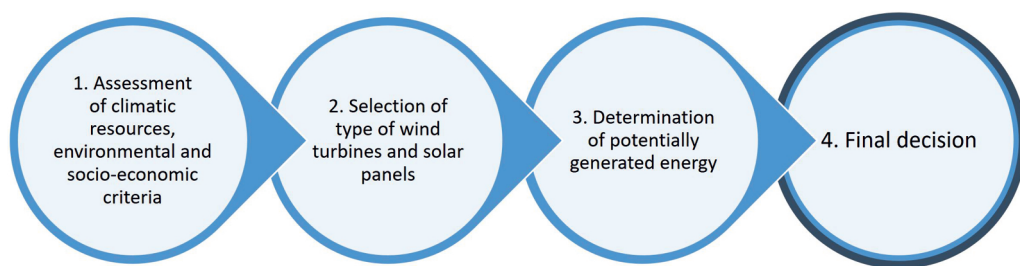


Fig. 1. Stages in assessing the potential of WSPP sites

To implement Stage-1, different groups of criteria could be used to make an assessment based on which to make the best decision for selecting a wind-solar site [16]. In practice, a limited number of the most important indicators can be used to determine the appropriate location with the greatest potential as shown in Table 1.

T a b l e 1

Indicators and groups of criteria for assessing the potential of a site for building of a WSPP

No	Groups of indicators	Indicators	Type of indicator
1	Geographic or resource	1.1. Wind speed	(benefit)
		1.2. Temperature	(cost)
		1.3. Solar irradiation	(benefit)
		1.4. Slope	(cost)
		1.5. Elevation	(benefit)
		1.6. Aspect	(cost)
2	Environmental	2.1. Distance to rivers/water bodies	(cost)
		2.2. Land cover	(cost)
		2.3. Natural hazard	(cost)
3	Socio-economic	3.1. Distance to transport links	(cost)
		3.2. Distance to urban area	(cost)
		3.3. Distance to electricity grid	(cost)
		3.4. Resident acceptance	(benefit)
		3.5. Carbon emission reduction	(benefit)

The geographic or resource group is related to indicators affecting the energy generated by wind turbines and solar panels namely wind speed, temperature, and solar irradiation. The elevation, slope, and aspect are the other essential parameters. The aspect refers to the position of the slopes of the mountains to the sun and its influence on the production of renewable energy. As elevation increases, so does solar and wind power generation as the amount of particles, and clouds above the surface decreases. The higher the slope, the higher the cost of construction, power transmission, and equipment transportation. The proposed methodology can be used to estimate wind and solar energy resources at the WSPP host site based only on data from automatic weather stations [15].

The second group refers to environmental indicators related to the impact assessment and the presence of protected areas are important for obtaining permits and avoiding environmental problems. In addition, land cover type along with the distance to water bodies that can cause natural hazards are considered too.

The third socio-economic group is concerned with indicators of the transport and electrical infrastructure needed to connect the plant to the grid and to transport materials and equipment. The rest of the criteria take into account some social aspects such as resident acceptance and carbon emission reduction.

Multicriteria decision-making model for wind-solar power plant selection. The most important stage of the design of the WSPP is related to the selection of a suitable place for its building. To solve this problem, a modified model based on a weighted sum method for the evaluation of a site for the building of a wind-solar power plant is proposed:

$$(1) \quad A^i = \max \left\{ \alpha \sum_m^M w_m g_m^i + \beta \sum_p^P w_p e_p^i + \gamma \sum_q^Q w_q s_q^i \right\}$$

subject to

$$(2) \quad \sum_m^M w_m = 1,$$

$$(3) \quad \sum_p^P w_p = 1,$$

$$(4) \quad \sum_q^Q w_q = 1,$$

$$(5) \quad \alpha + \beta + \gamma = 1,$$

where index $i = \{1, 2, \dots, I\}$ represents the set of potential alternatives/sites; the weighed coefficients w_m , w_p and w_q express the relative importance between indicators regarding geographical, environmental and socioeconomic groups; the notations g_m^i , e_p^i and s_q^i express the performance of i -th alternative/site toward corresponding indicator from the group of criteria in points. The formulated model assumes the presence of an expert to assess the effectiveness of the alternatives against the groups of criteria using points from a scale from 0 to 1, with a higher value meaning better performance. It is possible to use another scale, for example from 0 to 100, and then normalize the estimates to obtain a range similar to the coefficients of importance. The introduced additional coefficients α , β , and γ are used to express the importance between the groups of indicators based on which the most suitable site selection could be done.

Numerical results and discussion. The proposed model's applicability for WSPP site evaluation and ranking is applied to predefined three potential sites denoted as S-1, S-2, and S-3 as shown in Table 2.

T a b l e 2

Evaluations for performance and weighed coefficients for indicators and groups importance

No	Evaluation indicators by groups	Weighed coefficients for importance of groups & indicators		Performance evaluations		
		Case-1	Case-2	S1	S2	S3
Geographic group		0.45	0.60			
1	Wind speed		0.28	0.81	0.94	0.86
2	Temperature		0.29	0.79	0.87	0.88
3	Solar irradiation		0.22	0.79	0.85	0.89
4	Elevation		0.10	0.80	0.86	0.75
5	Slope		0.11	0.79	0.86	0.81
Environmental group		0.30	0.25			
1	Distance to rivers/water bodies		0.30	0.82	0.78	0.90
2	Land cover		0.40	0.86	0.86	0.8
3	Natural hazard		0.30	0.92	0.88	0.76
Socio-economic group		0.25	0.15			
1	Distance to transport links		0.30	0.87	0.89	0.86
2	Distance to urban area		0.30	0.85	0.81	0.78
3	Distance to grid network		0.40	0.92	0.79	0.94

Each site is evaluated in three groups, consisting of a different number of indicators, shown in the last three columns of Table 2. Along with these assessments, an authorized person has also determined the weighted importance coefficients of the indicators in each group, which are independent according to the constraints (2)–(4) of the proposed model. This information was obtained as a result of an expert assessment of three potential sites considered suitable for the construction of a WSPP. In order to demonstrate the specifics of the model for each group of indicators, two cases of different combinations of the importance of the indicator groups are considered (Case-1 and Case-2). Each of the cases used the same performance ratings and weighted coefficients for the importance of the indicators and differed only in the coefficients expressing the importance of groups. The results of the corresponding tasks are shown in Fig. 2.

In Case-1, the best choice among these three sites is Site-2 as its overall performance is the best with a value of 0.856495, while in Case-2 the best selection is for Site-1 with an overall value of 0.91546. It is interesting to see how groups of indicators contribute through assigned weights in forming the overall assessment of these sites. It can be seen that the location choice is different although the coefficients in both cases for the groups of indicators have the same preferences

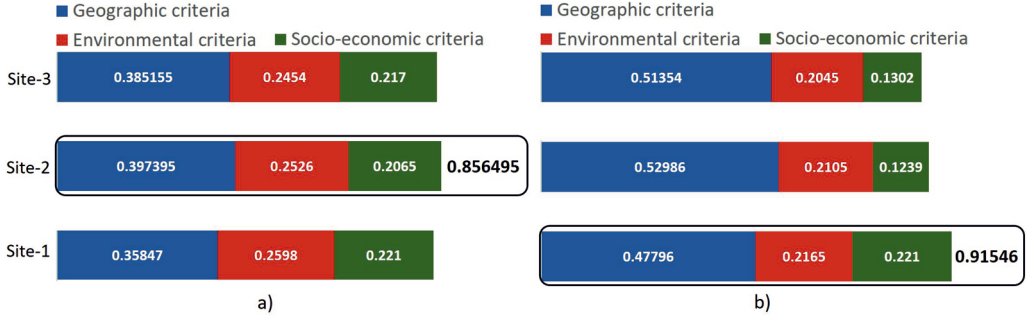


Fig. 2. Evaluation of the sites' performance for WSPP building: a) Case-1, b) Case-2

regarding importance and differ only in values (0.6:0.25:0.15 vs. 0.45:0.3:0.25). The obtained results prove that the proposed model can be used to express not only the preferences for the importance of the indicators but also the importance of the group as a whole. There is no problem with including more indicators in the groups or adding other additional indicator groups to evaluate a site for WSPP.

Stage-2 of the process for building a WSPP is related to determining the appropriate type of wind turbine and solar panel and their placement. If there is no information about the selected items, it is possible to proceed to Stage-3. To do this, the preliminary calculations about the capacity of the future WSPP will be based only on the information from Stage-1. This can be done by considering the area of the particular site. In this situation, the annual energy production for a specific location where a WSPP is planned to be built can be estimated as:

$$E^{ws} = E^{wind} + E^{solar} = 8760 \cdot C \cdot CF^w \cdot 1000 + R \cdot A \cdot CF^s \cdot k,$$

where E^{ws} expresses the annual energy production in TWh, C is the installed capacity, CF^w is the wind turbine capacity factor between 20–30% [17], R is the annual solar irradiation in kWh/m²/year, A is the total area of suitable location in km², CF^s is the area factor of total A that could be converted by solar panels in %, and k is the photovoltaic system effectiveness in % [18].

Once the technical parameters of the selected wind turbine and the type of solar panel are known, the capacity of WSPP can be determined to make the final decision. It is worth mentioning that it is possible that in the formation of the final decision, other factors related to the risks in the construction of such plants can be taken [19]. There are several main groups of risks associated with energy projects relating to 1) development and construction risks; 2) economic risks; 3) risks of cyberattacks; 4) social risks; and 5) political risks [20]. These research activities are planned as future research aimed at reducing the consequences of these risks.

Conclusion. Demonstrating a commitment to innovative energy solutions can attract investment and funding, as systems demonstrate a forward-looking approach to energy generation. Finding a suitable site for the construction of

wind-solar power plants is a challenge, and therefore a wind-solar power plant site evaluation model is proposed. This is a modified weighted sum method applied in the evaluation and ranking of three potential locations to demonstrate its applicability. It is shown that the introduced additional coefficients for the criteria groups influence the final solution even though the same values are used for the alternatives' performance. Based on the selected site, an estimation for the expected annual energy production for wind-solar power plants is presented considering resource indicators and site capacity factors. The obtained results convincingly prove the applicability of the proposed model, which can be used to solve similar decision-making problems.

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