

A CONTEXT-AWARE-MULTI-CRITERIA DECISION MAKING FRAMEWORK FOR WIND ENERGY SITE SELECTION

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Abstract

Sustainable and renewable energy will have a major role in future infrastructure development and maintain the ecological balance. Wind energy is one of the most suitable and reliable resources for sustainable and clean energy. Building a wind energy infrastructure requires a huge investment and ecological concerns, so selection of an appropriate installation location is major factor in wind energy management. Existing multi criteria decision making frameworks are majorly rely on a large number of heterogeneous criteria, which includes infrastructural and socio-economic factors, which increase computational complexity and reduce interpretability. This paper presents a Context-Aware-AHP-TOPSIS decision making frame work to rank potential wind energy sites for installation and maintenance. A dataset derived from multiple sites is used to demonstrate the effectiveness of the proposed approach. To determine the importance of criteria, is done by Analytic Hierarchy Process (AHP) is used, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is applied to rank the

sites based on the geographical and meteorological information. Experimental results show that the proposed method achieves more stable, efficient, and interpretable rankings compared to the existing solutions. The proposed framework is well-suited for efficient and climate-driven wind power planning..

Keywords: multi-criteria-decision, criteria selection, AHP, TOPSIS, wind energy, renewable energy, site-ranking.

I. Introduction

The United Nations published 17 SDG goals which includes clean and affordable energy [2] and the wind energy is one of the reliable energy resources has a potential to meets the goal of UN in sustainable energy requirements. However, the performance and economic viability of wind power plants are highly dependent on site-specific constraints which includes geological factors and climatic conditions. Selecting an optimal

location for installation remains a challenging multi-criteria decision-making problem involving various conflicting parameters.

Several studies have addressed wind farm site selection using multi criteria decision making techniques such as Fuzzy oriented multi criteria decision frameworks [3][7][9][11], Analytic hierarchy process for determining the parameter weight [4][6][10] and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [4][5][6] for site ranking. In the literature survey the multi criteria decision making models selecting the wind installation sites in four major categories which includes environmental, technical, social, infrastructural and climate aspects. In comprehensive such approaches introduce high dimensionality, increased computational cost, and reduced clarity regarding the dominant physical drivers of wind power generation.

In contrast, wind energy production is fundamentally governed by climatic and environmental factors, particularly wind speed, air density (related to temperature and altitude) and humidity. Motivated by this observation, this paper proposes a Context-Aware-AHP-TOPSIS decision making framework that considers only geo location and climatic parameters. The main contributions of this work are:

- Reduction of decision criteria without loss of ranking reliability.
- Use of an adaptive AHP for transparent, expert-driven weight estimation.

- Comparative evaluation against a reference full-criteria study.

II. Dataset Description

The dataset consists of 50 candidate wind farm locations distributed across eastern and north-eastern regions [1]. Each site is associated with multiple attributes including geographical, climatic, and socio-economic parameters.

III. Methodology

The proposed context aware multi criteria decision making framework integrates intelligent attribute selection and weight estimation for increase the efficiency and optimal site selection with TOPSIS ranking.

A. Context Specific Attribute Selection

Attribute selection is one of the major concerns for dimensionality reduction which increase the efficiency of the proposed method and interpretability of the model with real world constraints. Context aware criteria selection is the process to select the most influential attributes in wind farm installation [1] which includes environmental and climatic information. This process is to choose only the optimal parameters to reduce the operational cost and make the frame work as more interpretable.

From a physical standpoint, the extractable wind power at a given location can be expressed as

$$P = \rho A v^3 / 2 \quad (1)$$

where P denotes the available wind power, ρ represents air density, A is the

rotor swept area, and is v the wind speed. The fundamental relationship of wind power generation is highly relied on wind speed and air density. The air density is indirectly relied on geological information such as altitude, temperature and humidity. The environmental and climatic parameters constitute the

dominant physical drivers of wind energy potential.

The dataset consists of 50 candidate wind farm locations distributed across eastern and north-eastern regions [1]. Each site is associated with multiple attributes including geographical, climatic, and socio-economic parameters.

Table I Dataset Description

No	Criterion	Type	Description/Justification
C1	Area (hectares)	Benefit	This criterion represents the available land area for wind turbine installation.
C2	Distance to Power Lines (km)	Cost	The distances to existing power transmission lines.
C3	Distance to Substation (km)	Cost	The distance between the wind farm site and the nearest electrical substation
C4	Distance to Road (km)	Cost	Road proximity
C5	Estimated Capacity (MW)	Benefit	The projected energy production potential of the site
C6	Distance to City Center (km)	Benefit	distance from urban areas
C7	Altitude (meters)	Benefit	Altitude of location
C8	Population	Benefit	Areas population
C9	Population Density	Benefit	Population density.
C10	Annual Rainfall (mm)	Cost	Average rainfall of the location
C11	Average Temperature (°C)	Cost	Average temperature of the location
C12	Average Wind Speed (m/s)	Benefit	Average Wind speed of the location
C13	Relative Humidity (%)	Cost	Average Humidity of the location

The context aware criteria selection retained the only the following five environmental and climatic attributes which have the more influential parameters in energy production than other social and economic concerns. This data driven approach reduces the dimensionality reduction which makes the model more intuitive and make the decisions very fast without loss the accuracy of the ranking. The selected criteria are listed in Table II with its type.

Table 2 Context-Aware Attribute Selection

Criterion	Type
Altitude (meters)	Benefit
Annual rainfall (mm)	Cost
Average temperature (°C)	Cost
Average wind speed (m/s)	Benefit
Relative humidity (%)	Cost

This attribute selection is motivated by physical relevance to wind power generation and the desire to improve

computational efficiency. To eliminate scale effects, all criteria are normalized using vector normalization. Benefit and cost criteria are treated accordingly to ensure consistency.

Let

$A = \{A_1, A_2, \dots, A_m\}$ be the set of alternatives (wind sites)

$C = \{C_1, C_2, \dots, C_n\}$ be the set of decision attributes

The original decision matrix D is expressed as:

$$D = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

where x_{ab} denotes the performance of alternative A_a with respect to criterion C_b .

In the proposed framework, a relevance-driven attribute selection is applied by retaining only criteria that directly influence wind energy potential. Hence, a reduced subset S' is defined as:

$$S' \subset S, |S'| \ll |S|$$

This dimensionality reduction improves interpretability and computational efficiency while preserving decision reliability.

B. AHP-Based Weight Assignments

The Analytic Hierarchy Process is used to compute criterion weights based on pairwise comparisons. wind speed and altitude are prioritized here due to their direct influence on power generation. pairwise comparison matrix yields from the normalized weight vector. Consistency of judgments is verified using the Consistency-Ratio (CR), which is maintained below 0.1

1) **The priority (weight) vector is obtained from the principal eigenvector:**

$$W = \lambda_{\max} w$$

W - obtained weight of each criterion

λ_{\max} - Average weighted sum

2) **The normalized weight of each criterion is computed as:**

$$w_j = \frac{w_j}{\sum_{k=1}^n w_k}, j = 1, 2, \dots, n \quad (2)$$

3) **Consistency Verification is done by consistency index (CI) which is given by:**

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (3)$$

The consistency ratio (CR) is computed by

$$CR = \frac{CI}{RI} \quad (4)$$

RI - random index which is pre-Computed based on the number of criteria selected for the weight calculation. A judgment matrix is considered consistent if $CR < 0.1$

TOPSIS Ranking Procedure

Using the AHP-derived weights, TOPSIS is applied as follows:

- Construction of the weighted normalized decision matrix.
- Identification of positive ideal and negative ideal solutions.
- Computation of Euclidean distances from ideal solutions.
- Calculation of the closeness coefficient for each site.
- Sites are ranked in descending order of the closeness coefficient.

4) **Normalization of Decision Matrix is computed as:**

Vector normalization is applied with euclidean distance in all selected criteria. The benefit and cost same formula used.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (5)$$

5) **Weighted Normalized Matrix v is calculated Using AHP-derived weights:**

$$v_{ij} = w_j \cdot r_{ij} \quad (6)$$

6) **Compute the Ideal and Negative Ideal Solution:**

The positive ideal solution A^+ and negative ideal solution A^- are defined as:

$$A^+ = \{\text{maximum}(v_{ij}) \mid j \in J_b; \text{min}(v_{ij}) \mid j \in J_c\} \quad (7)$$

$$A^- = \{\text{minimum}(v_{ij}) \mid j \in J_b; \text{max}(v_{ij}) \mid j \in J_c\} \quad (8)$$

where J_b and J_c denote benefit and cost criteria, respectively.

7) **Separation Measures**

$$D_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - A_j^+)^2} \quad (9)$$

$$D_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - A_j^-)^2} \quad (10)$$

8) **Closeness Coefficient and Ranking**

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}, 0 \leq C_i \leq 1 \quad (11)$$

Alternatives are ranked in descending order of C_i , where a higher value indicates greater suitability in ranking.

IV. Experimental Results and Discussion

The proposed context-aware-ahp-topsis decision making frame work produces a clear ranking of all 50 candidate sites. Sites are characterized by higher wind speed, moderate altitude, low humidity, and lower rainfall where consistently achieve higher closeness coefficients. The top-ranked sites largely matched with high-performing locations identified in the reference study that confirming the validity of the reduced-criteria approach.

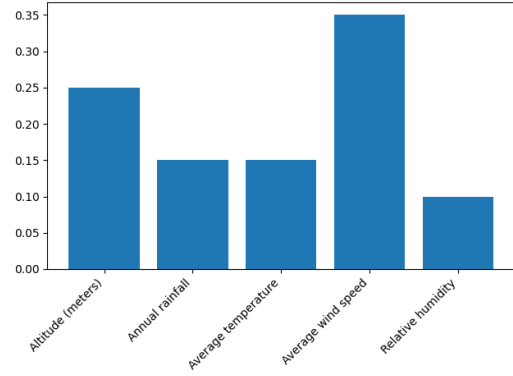


Fig 1: context-aware-AHP-derived weights

Compared to the reference work using 13 criteria with Shannon entropy weighting [1], the proposed method demonstrates only use the five most influential criteria for energy production which reduce computational cost and improve the interpretability of results.

The existing methods take into the consideration of all factors such as environmental, social, economic and geographical information. The proposed approach prioritizes climatic suitability and environmental factors, making it more appropriate for early-stage site screening and large-scale assessments without considering other factors.

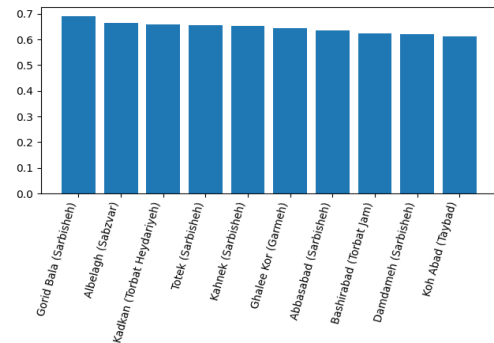


Fig 2: Ranking of sites Context-Aware-AHP-TOPSIS

As illustrated in Fig.2, the proposed context-aware AHP-TOPSIS decision

frame work demonstrates a superior performance in terms of computational efficiency, interpretability, ranking stability, and physical relevance when compared to the existing approaches. Fig.3 is illustrated that the performance of the proposed context-aware-AHP-TOPSIS decision frame work is out performs from the base model in computational efficiency, interpretability.

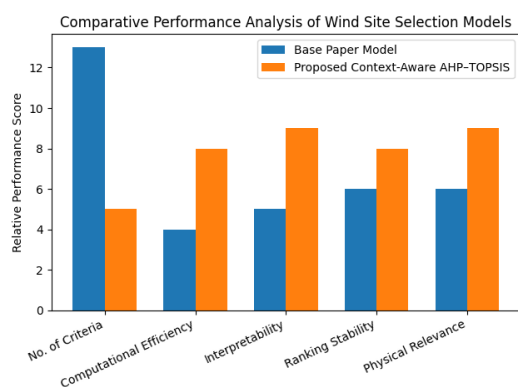


Fig. 3. Comparative performance analysis of the context-aware AHP-TOPSIS framework with base model.

V. Conclusion

This paper presented a Context-Aware-AHP-TOPSIS framework for wind power site selection based solely on environmental and climatic parameters. By reducing the number of criteria from 13 to 5, the proposed method improves computational efficiency and interpretability while maintaining reliable ranking performance. Comparative analysis confirms that climate-driven site selection is sufficient for identifying high-potential wind farm locations. The proposed framework is particularly suitable for rapid decision support for initial screening.

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