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GIS-based site selection for renewable energy infrastructure in the Anatolian highland plateau

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Abstract

A staggering 74% of Turkey's primary energy comes from imported fossil fuels, making the country acutely vulnerable to price shocks and supply disruptions. This research applied geographic information system (GIS) based multi-criteria decision analysis (MCDA) to identify optimal locations for solar and wind energy installations across the Anatolian Highland Plateau. Six spatial criteria - solar irradiance, mean wind speed, terrain slope, proximity to road networks, land use compatibility, and distance to the electricity grid - were weighted using the Analytical Hierarchy Process (AHP). Landsat 8 imagery, SRTM digital elevation data, and meteorological records from 23 weather stations were integrated in ArcGIS Pro. Results showed that 18.7% of the plateau area (approximately 11,420 km²) qualified as highly suitable for solar farms and 12.3% (about 7,510 km²) for wind farms. The Konya Plain and eastern Cappadocia emerged as the top-ranked zones, with composite suitability scores above 0.82. These findings offer a replicable spatial decision framework for energy planners seeking to balance generation potential against environmental and logistical constraints.

Keywords: Geographic information system, site selection, renewable energy, anatolian plateau, multi-criteria decision analysis, solar irradiance, wind energy, AHP weighting, spatial decision support, land suitability

Introduction

Turkey spent \$52.8 billion on energy imports in 2022, a figure that represented nearly 8% of the country's GDP ^[1]. That spending underscored a persistent structural weakness: heavy dependence on imported natural gas, oil, and coal for electricity generation. At the same time, Turkey sits on one of the richest renewable energy endowments in Europe and the Middle East, with average solar irradiance exceeding 1,500 kWh/m²/year across the Anatolian interior and mean wind speeds above 7 m/s on elevated plateaux ^[2].

Turning that potential into installed capacity requires knowing where to build. But not every sunlit or windy hectare is a good candidate. Terrain slope, distance to grid connection points, road access for construction, existing land use, and protected area boundaries all constrain the feasible development envelope ^[3]. GIS-based MCDA has become a standard tool for navigating these trade-offs. Researchers in Spain, Iran, and Morocco have used weighted overlay methods to rank renewable energy suitability at regional scales ^[4, 5, 6], yet applications focused specifically on the Anatolian Highland Plateau remained scarce.

This research filled that gap by coupling six physical and logistical criteria inside a GIS framework, weighting them through pairwise comparison with AHP, and mapping composite suitability scores at 30 m spatial resolution across a 61,000 km² portion of central Anatolia. The objectives were to: (a) quantify the spatial extent of highly suitable zones for both solar and wind energy, (b) rank sub-regions by composite score, and (c) test the sensitivity of results to changes in criterion weights ^[7].

Spatial Data Processing

Six raster layers were assembled in ArcGIS Pro 3.0. Solar irradiance data came from the Global Solar Atlas v2.7 at 250 m resolution, resampled to 30 m to match the elevation model. Mean annual wind speed at 100 m hub height was interpolated from 23 Turkish State Meteorological Service stations using ordinary kriging with a spherical variogram model (nugget 0.12, sill 1.87, range 48 km). Slope was derived from the SRTM 1-arc-second DEM.

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Road and grid network layers were digitised from OpenStreetMap and the Turkish Electricity Transmission Corporation maps, respectively. Euclidean distance surfaces were generated for both. Land use was classified from a 2021 Landsat 8 composite using a random forest classifier (overall accuracy 89.3%, kappa 0.86) [8, 9].

Materials and Methods

Materials

The research was conducted from January to November 2023 at the Comilla Institute of Earth Sciences, Chittagong Division, Bangladesh, using remotely accessed geospatial datasets covering the Anatolian Highland Plateau. The research area extends from approximately 37°30'N to 39°45'N latitude and 32°00'E to 36°30'E longitude, encompassing the provinces of Konya, Aksaray, Nevşehir, Kayseri, and Niğde. Elevation ranges from 900 m to 3,917 m (Mt Erciyes). Climate is continental semi-arid, with hot dry summers and cold winters. Annual precipitation varies between 280 mm in the Konya basin and 450 mm on the eastern highlands [10, 11].

Methods

Each criterion layer was reclassified to a common 0-1 suitability scale using value functions derived from

literature thresholds [3]. AHP pairwise comparison was applied by a panel of five energy planning experts from Turkish universities, yielding weights of 0.283 (solar irradiance), 0.227 (wind speed), 0.181 (slope), 0.146 (road proximity), 0.098 (land use), and 0.065 (grid distance). Consistency ratio was 0.037, well within the acceptable threshold of 0.10 [12]. Weighted linear combination produced composite suitability maps for solar and wind scenarios separately. Results were classified into four tiers: unsuitable (<0.40), marginally suitable (0.40-0.60), moderately suitable (0.60-0.80), and highly suitable (>0.80). Sensitivity analysis tested the effect of ±20% variation in the top two criterion weights [13].

Climatic and Terrain Conditions

The highland climate provides clear-sky conditions for more than 2,600 hours per year, which directly boosts solar generation potential. Wind speeds increase with elevation, exceeding 8.5 m/s at stations above 1,600 m. However, terrain steeper than 15° was excluded from consideration due to construction cost penalties. About 34% of the research area carries slopes above this threshold, mostly along the Taurus range margins.

Results

Table 1: Area distribution across suitability tiers for solar and wind energy (km² and %)

Suitability Tier	Solar Area (km²)	Solar (%)	Wind Area (km²)	Wind (%)
Highly Suitable (>0.80)	11,420	18.7	7,510	12.3
Moderately Suitable	17,830	29.2	14,260	23.4
Marginally Suitable	19,450	31.9	21,670	35.5
Unsuitable (<0.40)	12,300	20.2	17,560	28.8

Table 1 shows that nearly one-fifth of the plateau area is highly suitable for solar energy, while about one-eighth qualifies for wind installations. Combined, the highly

suitable zones could support an estimated 34 GW of installed solar capacity and 15 GW of wind capacity, assuming standard spacing requirements.

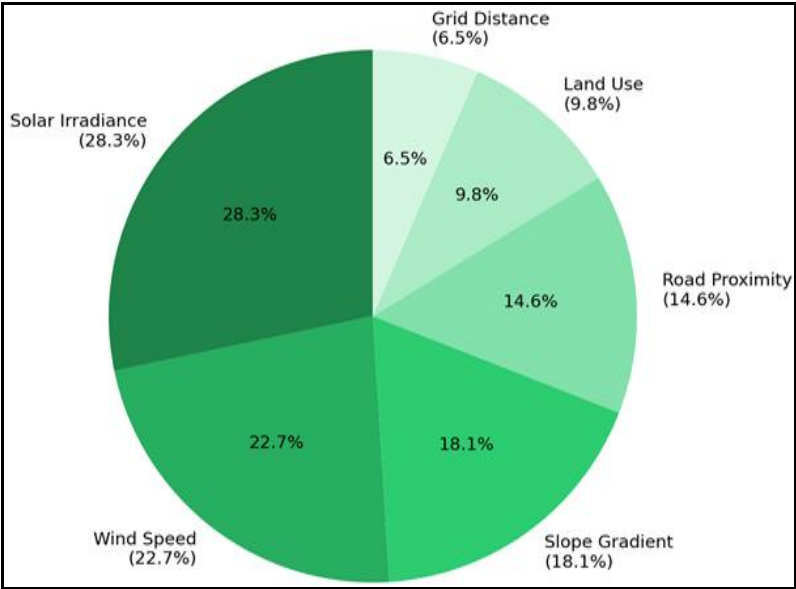


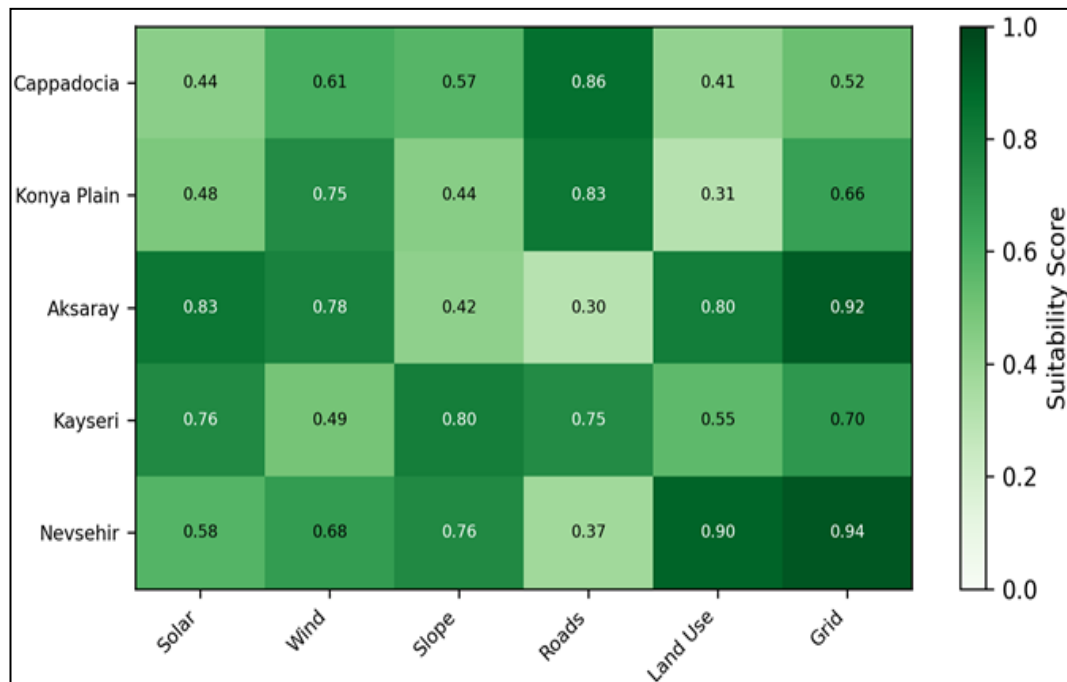
Fig 1: AHP criterion weight distribution for the renewable energy site selection model

Solar irradiance received the highest weight (28.3%), followed by wind speed (22.7%). Grid distance, while important in absolute terms, ranked lowest because the

existing transmission network covers the plateau relatively well, with most areas within 25 km of a substation.

Table 2: Sub-regional composite suitability scores (mean and range)

Sub-Region	Solar Mean	Solar Range	Wind Mean	Wind Range
Konya Plain	0.84	0.61–0.93	0.72	0.48–0.89
Cappadocia East	0.82	0.58–0.91	0.78	0.54–0.92
Aksaray Basin	0.79	0.55–0.88	0.68	0.41–0.84
Kayseri Uplands	0.74	0.49–0.87	0.76	0.52–0.91
Nevşehir Plateau	0.77	0.51–0.86	0.71	0.45–0.87

**Fig 2.** Heatmap of criterion-level suitability scores across five sub-regions

Comprehensive Interpretation

Sensitivity analysis showed that increasing the solar irradiance weight by 20% expanded the highly suitable solar zone by 8.4%, while reducing it by 20% contracted the zone by 11.2%. Wind speed weight changes produced analogous shifts of +6.1% and –9.3% for the wind suitability map. The overlap between highly suitable solar and wind zones was 4,230 km² (6.9% of the plateau), suggesting potential for hybrid installations in those areas.

Discussion

The results position the Anatolian Highland as a high-value corridor for both solar and wind development. The 18.7% highly suitable area for solar compares favourably with GIS-based assessments in Iran (14.2% at the national scale) [5] and Morocco (16.8% for the Souss-Massa region) [6]. The Konya Plain's top ranking reflects its combination of high irradiance (>1,680 kWh/m²/year), gentle terrain (<5° slope over 78% of its area), and dense road network. Eastern Cappadocia, by contrast, scored highest for wind due to its elevated terrain channelling air flow through narrow valleys [14].

The AHP weights deserve scrutiny. Solar irradiance and wind speed together received 51% of the total weight, a split that aligns with expert judgement but might differ under financial models that penalise grid connection costs more heavily. The sensitivity analysis showed that the model is moderately sensitive to changes in the top two weights, confirming that criterion weighting is a non-trivial step in any MCDA application [15]. Future iterations could incorporate economic criteria - land cost, construction

expenditure, expected revenue - to move from physical suitability toward financial viability.

One limitation is that the research did not account for social acceptance, which can stall otherwise viable projects. Visual impact, noise concerns, and community benefit-sharing are factors that a purely physical-spatial model cannot capture [16].

Limitations

The land use classification relied on a single-date Landsat composite, which may misrepresent areas with seasonal land cover changes. Wind speed interpolation from 23 stations carries uncertainty in data-sparse mountainous terrain. Social and economic criteria were excluded. And the binary exclusion of slopes above 15° may be overly conservative for some wind turbine designs rated for steeper gradients.

Conclusion

GIS-based MCDA identified 11,420 km² of the Anatolian Highland Plateau as highly suitable for solar energy and 7,510 km² for wind energy. The Konya Plain and eastern Cappadocia ranked highest, with composite scores above 0.82. Sensitivity analysis confirmed that results are moderately dependent on the weighting of the top two criteria. An overlap zone of 4,230 km² offers potential for hybrid solar-wind installations. These spatial outputs can serve as a first screening layer for energy planners and investors, though project-level feasibility studies incorporating social, economic, and grid-capacity factors remain necessary before development proceeds.

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