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Suitability analysis for implementing wind and solar farms based AHP method: Case study in Inner Mongolia, China

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Abstract

As important green energy, wind power and photovoltaic power have great development prospects. The suitability evaluation of wind and solar power plants is a popular research field, which is related to the sustainable and healthy development of wind and solar power generation. In this paper, based on multiple dimensions such as land types, climatic conditions, topographic features and policy environment, we selected 10 indicators and combined (analytical hierarchy process) AHP method to build a suitability assessment model for evaluating the suitability of solar and wind power in Inner Mongolia, China. The findings revealed that, Inner Mongolia has a great potential to generate wind and solar electricity, for wind power, the category of 'excellent' regions covers 83855 km^2 and represents 7.10% of the total surface area; for solar power, 7.66% (nearly 90420 km^2) are classified as 'excellent'. The suitability of both solar and wind energy in the western region is considered to have the most suitable development region, parts of Alxa League and Bayannur City have great potential for combined wind and solar power generation. The research results could provide important technical and data support for capacity evaluation and power station location decision.

1. Introduction

For the low-carbon and sustainable development of energy, the global demand for renewable energy is increasingly urgent (Carty and Claveria, 2024, Simoes and Lima, 2023, Mohsin et al., 2022). Natural green energy sources, such as wind, solar, hydro, biomass, and geothermal energy, do not emit pollutants or greenhouse gases (Parthasarathy et al., 2024, Yang et al., 2024). Among these, wind and solar have reached technological and economic maturity, with wind standing out for its less land occupation, stable performance and large power generation, and solar for its advantages of wide distribution, perpetuation, and clean energy (Gouareh et al., 2021, Liu et al., 2022, Wang et al., 2022). As important renewable energy, wind and solar energy have great potential for future development (Carty and Claveria, 2024). The International Energy Agency (IEA) has reported that the global renewable energy power generation capacity is expected to increase to 7300 GW during 2023-2028, of which solar photovoltaic and wind energy account for 95% of the new capacity, and will surpass coal as the world 's largest power source by early 2025. China announced an ambitious goal of combating climate change, that is, achieving carbon neutrality by 2060. Committed to low-carbon transition, China has announced the ambitious goal of reaching its carbon peak by 2030 and achieving carbon neutrality by 2060. So far, that goal seems achievable. According to the 2023 Renewable Energy report, in 2023, China's new installed capacity of wind energy increased by 66% over the previous year, the new installed capacity of solar photovoltaic is equivalent to the total installed capacity of global solar photovoltaic in 2022, and it is expected that by 2028, China will account for 60% of the world's new renewable energy generation. In the current situation of the rapid expansion of wind and solar power, suitability analysis of wind and solar farms is of great significance to the potential evaluation and rational distribution of wind power and photovoltaic (Almasad et al., 2023, Benti et al., 2023).

Suitability analysis for implementing wind and solar farms demands meticulous consideration of diverse variables, not just wind and solar radiation intensity. There are many studies on the suitability evaluation of wind power and solar photovoltaic, and the evaluation factors used in these studies are different (Levosada et al., 2022, Halder et al., 2022, Gacu et al., 2023, Shorabeh et al., 2022, Purohit and Purohit, 2017). For example, some studies mainly combined the spatial distribution of wind and solar energy resources with the type of land use to evaluate the suitability (Wang et al., 2022), some studies pay more attention to the impact of technology level on wind and solar power generation (Sun et al., 2022), and other studies also believe that the possibility of photovoltaic power depends largely on the distribution and intensity level of solar radiation (Prăvălie et al., 2019). However, more studies consider multiple factors to assess the development of wind and solar power plant, they have carried out suitability evaluation of wind power or solar power from different dimensions such as natural environment, economy and society (Jangid et al., 2016, Zalhaf et al., 2021). For example, one study assessed the suitability of wind power in Tunisia by taking into account meteorological, topographic, land use and socio-economic factors (Rekik and El Alimi, 2023), while another examined 12 impact factors from both technical and economic aspects to carry out siting suitability analysis of solar photovoltaic power plants in Saudi Arabia (Almasad et al., 2023), and so on. Significantly, many studies have overlooked factors that limit power plants. For policy reasons, some areas are considered not allowed to build wind and solar power plants, if these restrictive construction factors are not taken into account, the reliability of the evaluation results will undoubtedly be weakened. Many researchers have developed and utilized various methods to determine the optimal locations for wind and solar power farms, such as AHP, TOPSIS, FAHP, FTOPSIS, DEA, ELECTRE, VIKOR, WASPAS, SWARA and others. The basic principle and steps of ana-

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lytical hierarchy process (AHP) are simple and clear, and the calculation is simple. In addition, this method can combine qualitative method with quantitative method organically, and can deal with many practical problems that cannot be dealt with by traditional quantitative technique. Moreover, when dealing with determining the suitability of wind and solar power generation installations allocating optimal locations, the AHP is considered adequate and has been successfully applied to determine the suitability of wind and solar power generation installations (Akkas et al., 2017, Feng et al., 2020, Pambudi and Nananukul, 2019, Rezaei et al., 2018). In this work, to increase the reliability and scientificity of the evaluation results, we comprehensively consider natural environment factors and socio-economic factors. Based on the spatial geographic information such as land type, climatic conditions, topography, and policy requirements, a suitability evaluation model is established by using the AHP and geographical information systems (GIS), which is used to evaluate the suitability of wind and solar farms construction in Inner Mongolia, China. This study is of great scientific significance and practical value for guiding the rational distribution of renewable energy.

2. Study Area

The study area of this research is the Inner Mongolia, situated in the north of China, accounting for 12.3 % of China 's land area (Figure 1). Inner Mongolia is rich in solar and wind energy resources and is one of the important new energy development bases. Over the quasi-totality of the Inner Mongolia area, an annual average of more than 2600 sunny hours can be accounted, which reached approximately 3400 h in Alxa region. The annual average number of gale days in Inner Mongolia is 10 40 days, and about 108 days in Alxa region. Benefit to high-quality large base and scenic resource endowment, in 2022, Inner Mongolia will surpass Guangdong Province to become the region with the highest power generation, ranking first in China. At present, Inner Mongolia plans to build four desert scenery bases to accelerate the transition to new energy, and is expected to install 155 million kilowatts of large bases in 2030, which can meet the peak electricity demand of 14 Shanghai and 19 Beijing.

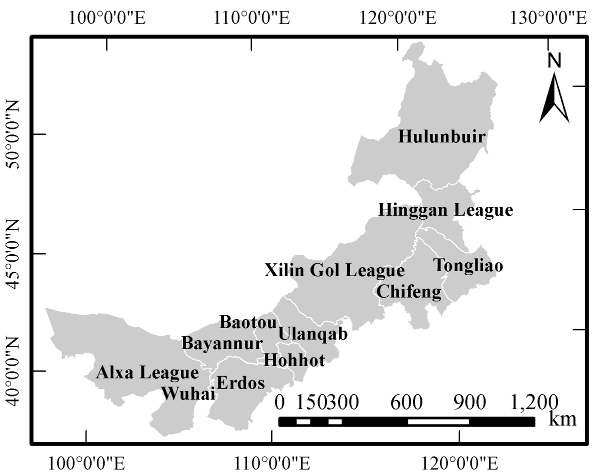

Figure 1. Location map of the study area.

3. Data and Methods

The main purpose of this study is to evaluate the suitability of implementing wind and solar farms based on multiple factors, combined with the method of AHP and GIS. In this paper, a four-step analysis is carried out to assist the decision-making process of wind and solar farms site selection. First, for each evaluation factor, the ArcGIS tool was used to screen out the unsuitable region. Second, the AHP method is used to assign the relative weight of each factor. Third, the weighted superposition analysis of the data layer of each factor is carried out to obtain the final suitability distribution map, the suitability of wind farms and solar farms was divided into five levels: unsuitable, poor, moderate, good, excellent. The flowchart of the research method is shown in Figure 2.

3.1 Data

To establish suitability evaluation model, a set of indicators was selected, which are detailed in Table 1. The thematic maps for indicators in Figure 3-5.

Layers	Indicators
Climatic indicators	Wind speed Global horizontal irradiance Annual sunshine duration Precipitation
Terrain indicators	Slope Aspect Altitude
Landuse indicators	Land use
Socio-economic indicators	Policy restricted areas Distance to city, town or village

Table 1. Assessment indicators of wind and solar farm.

3.2 Restricted areas

It is necessary to consider a number of economic, technical and environmental constraints, when analyzing the feasibility of selecting solar and wind farms. The constraints shown in Table 5 are based on previous similar studies. Using Boolean algebras (1 and 0), the integration tool of ArcGis 10.8, to generating and all layers are aggregated into one layer. '1' means there are no restrictions, allowing the development of solar and wind farms, and '0' means restrictions, meaning these facilities cannot be built.

3.3 AHP method

AHP is a mathematical method developed by Saaty (Saaty et al., 2012) and can also be used as a decision analysis tool. It is used to assign weights to climatic indicators, terrain indicators, landuse indicators, and socio-economic indicators in this work. The calculation process is as follows (Rekik and El Alimi, 2023).

The elements of the judgment matrix are normalized by column:

$$b'_{ij} = b_{ij} / \sum_{i=1}^{n} b_{ij} \tag{1}$$

Elements normalized by column are calculated by adding rows:

$$b'_{i} = \sum_{j=1}^{n} b'_{ij} \tag{2}$$

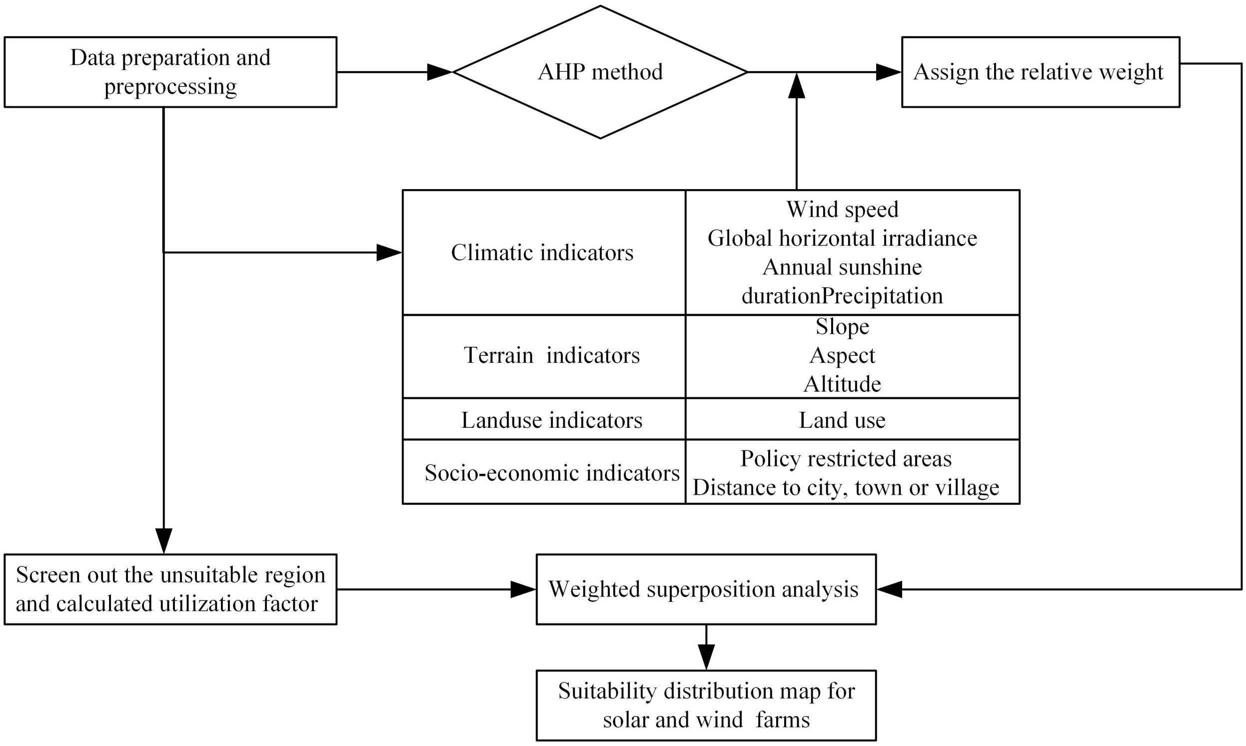

Figure 2. Flowchart of suitability assessment model.

Layers	Restriction
Wind speed	<6.0 m/s
Global horizontal irradiance	<1000kWh/m^2
Slope	>3%(solar), >30°(wind)
Aspect	the north is 0°, between 0° and 45°,315° and 360°
Distance to city, town or village	<500m
Landuse	not shrub land, low cover grassland, desert, Gobi, bare land
Altitude	>5000m
Policy restricted areas	ecological protection areas, urban areas and others

Table 2. Constraints considered for developing solar power farms and wind power farms.

Divide the column elements calculated by adding rows by the order n of the judgment matrix to obtain the weight of each evaluation index:

$$Q_i = b'_i/n \quad (3)$$

$$CI = (f_{max} - n)/(n-1) \quad (4)$$

$$CR = CI/RI \quad (5)$$

where f_{max} = the maximum eigenvalue
CI = consistency index
RI = random consistency index

After the weights are obtained, the eigenvector, calculate f_{max} and CI. Compute the relative consistency index (CR) according to RI, when CR is less than 0.1, it indicates that the consistency test is passed, otherwise the judgment matrix needs to be revised again.

4. Result analysis

The wind suitability distribution has shown in Figure 6. Statistical results reveal that the category of 'excellent' regions covers 83855 km^2 and represents 7.10% of the total surface area in Inner Mongolia, while areas that fell under 'good', 'moderate', 'poor' and 'unsuitable' areas were 4069 km^2, 1385 km^2, 545 km^2 and 1090945 km^2 respectively, accounting for 0.34%, 0.12%, 0.05% and 92.39% of the total area. It has also been found that most of the 'excellet' areas are located in the western of the land, especially in the Alxa League and Bayannur City. Moreover, a small number of areas in the central and northern parts that are considered ideal for wind farms, such as the western part of Hulunbuir City. According to the suitability results analysis, these areas with high suitability have a series of advantages for the establishment of wind farms, such as policy permits, perfect land slope and elevation, high wind activity, and distance from urban and rural settlements.

Likewise, the solar suitability map (Figure 7) shows that the potentially viable areas were categorized as follows: 7.66% (nearly 90420 km^2) are classified as 'excellent', 2.58 % (nearly 30410 km^2) are classified as 'good', 0.08 % (nearly 901 km^2) are classified as 'poor', and 89.69 % (nearly 1059070 km^2) are classified as 'unsuitable'. The most suitable solar sites are mainly located in the western and southern regions of Inner Mongolia, among which the Alxa League has the largest area, followed by Erdos. This is mainly due to the high solar insolation, less precipitation, gentle slope, and more Gobi, desert, sparsely populated in those regions. In addition, in the central region, there are some areas that fell under 'good' or 'moderate', such as Xilin Gol League and Chifeng City. From the

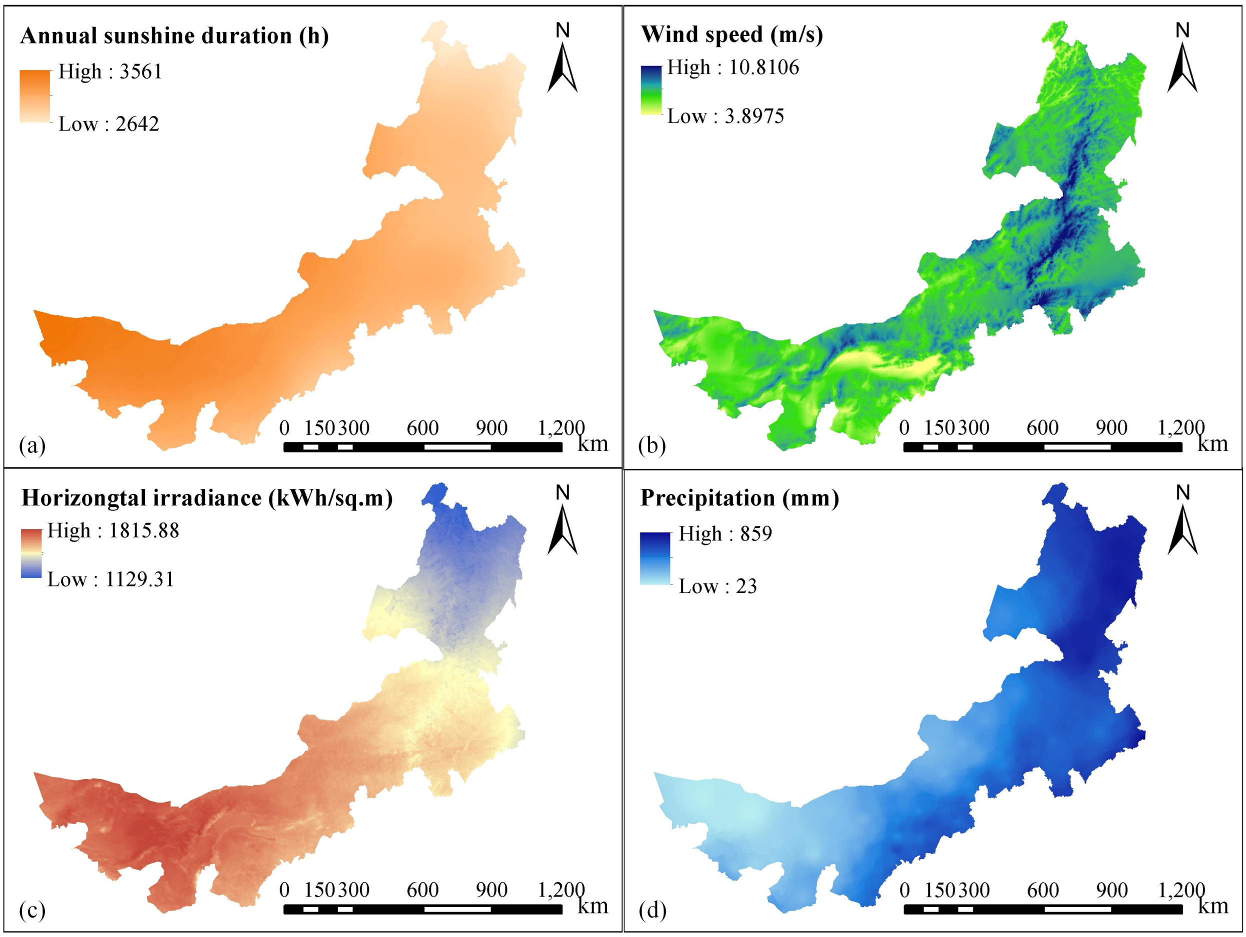

Figure 3. Maps for climatic indicators. (a) Annual sunshine duration (h); (b) Wind Speed (m/s) at 100 m; (c) Global horizontal irradiance (kWh/m^2 per year); (d) Precipitation (mm).

province-wide distribution, suitability of solar energy is similar to that of wind energy.

In contrast, the most suitable areas for solar power more than that for wind power. Although the western part of Hulunbuir city is mostly suitable for wind energy, the area classified as 'excellent' for solar energy in Alxa League and Ordos is much higher than the wind energy 'excellent' area. Notably, the suitability of both solar and wind energy in the western region is considered to have the most suitable development region, which is because wind and solar have the same advantages in terms of, land use, topography, and policy requirements. The same significant resource endowment, suitable topographic characteristics and good surface conditions make Inner Mongolia have great potential for wind energy and solar energy development. Therefore, if a combined wind and solar power station is established, it can make full use of wind and solar energy resources and improve power generation efficiency.

5. Conclusion

The aim of this study has been to evaluate the suitability for siting wind and solar farms in Inner Mongolia. The obtained results are explored as follow.

(1) Inner Mongolia has a great potential to generate solar and wind electricity. More than 7.6% of Inner Mongolia's land is considered excellent for photovoltaic development, and wind power is 7.1%. About 0.5% of the land is considered good for wind power and 2.7% for solar power development.

(2) From the spatial distribution, most of the areas suitable for photovoltaic development are distributed in the western part of Inner Mongolia, a small amount is distributed in the central part, and the northeast is almost an unsuitable area. The regional distribution suitable for the development of wind power is more uniform than that of solar energy, dispersed in the eastern, central and western regions, of which the western region is the most.

(3) There are many areas in the Alxa League, both suitable for the development of wind power and photovoltaic power generation, it will be more conducive to improving the efficiency of power generation if the establishment of wind power and photovoltaic power farms.

To sum up, these 'excellent' regions make Inner Mongolia have huge potential of wind and solar power generation. The results of this study have important reference value for the site selection of the next power station, and also provide data support for the production capacity estimation.

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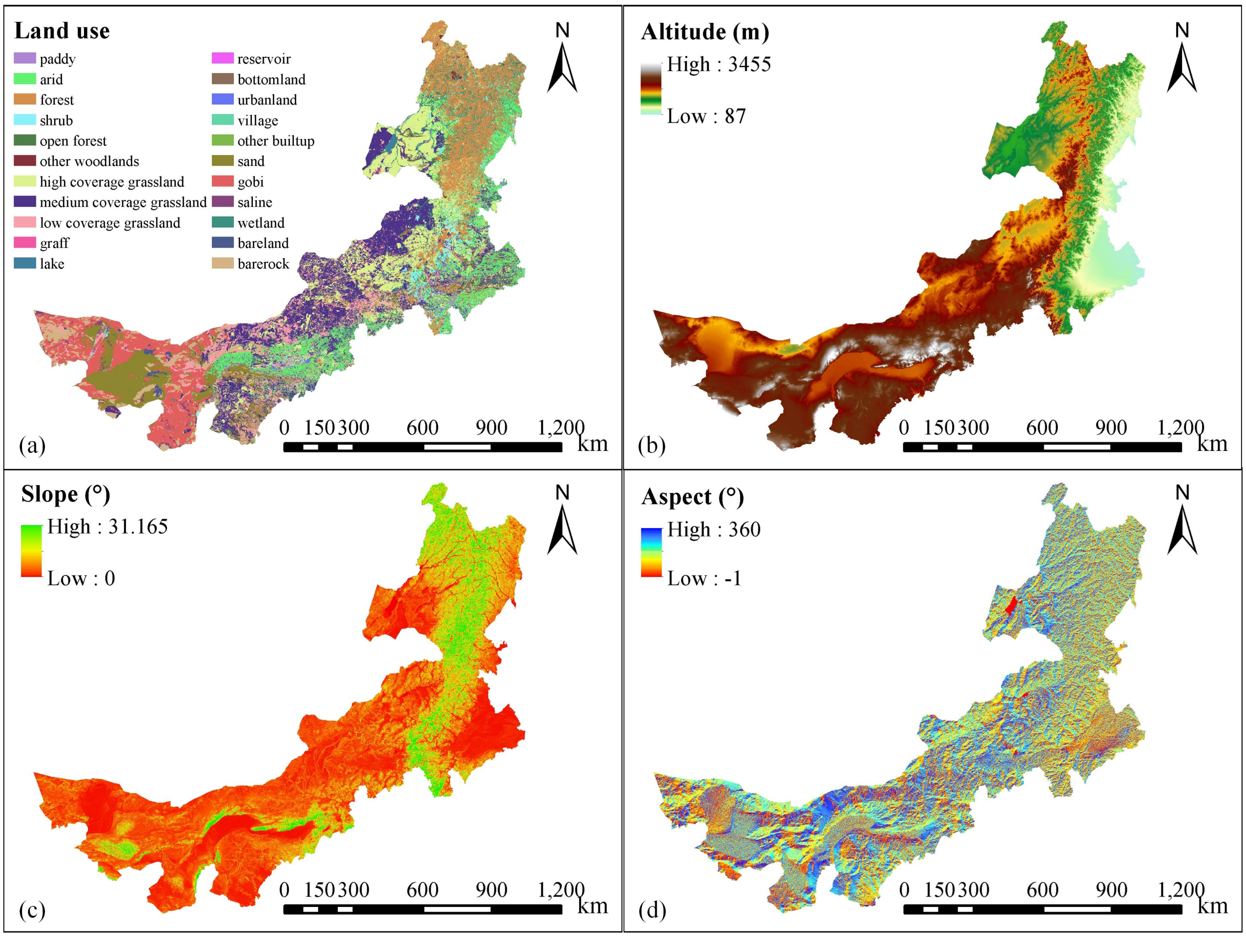

Figure 4. Maps for terrain and landuse indicators. (a) Land use; (b) Altitude (m); (c) Slope (°); (d) Aspect (°).

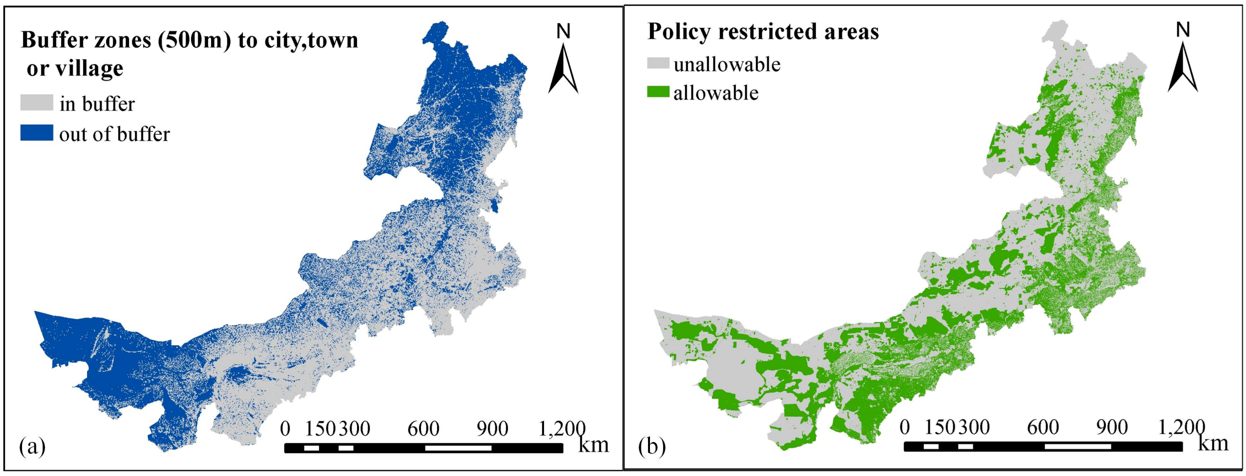

Figure 5. Maps for socio-economic indicators. (a) Buffer zones (500m) to city, town or village; (b) Policy restricted areas.

wind power and photovoltaic power station target information (No.2022YFF1303401).

References

Akkas, O. P., Erten, M. Y., Cam, E., Inanc, N. et al., 2017. Optimal site selection for a solar power plant in the Central Anatolian Region of Turkey. *International Journal of Photoenergy*, 2017.

Almasad, A., Pavlak, G., Alquthami, T., Kumara, S., 2023. Site suitability analysis for implementing solar PV power plants using GIS and fuzzy MCDM based approach. *Solar Energy*, 249, 642–650.

Benti, N. E., Alemu, Y. B., Balta, M. M., Gunta, S., Chaka, M. D., Semie, A. G., Mekonnen, Y. S., Yohannes, H., 2023. Site suitability assessment for the development of wind power plant in Wolaita area, Southern Ethiopia: an AHP-GIS model. *Scientific Reports*, 13(1), 19811.

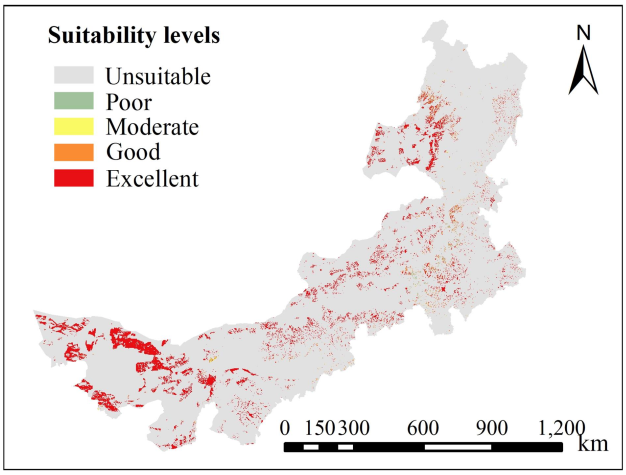

Figure 6. Suitability map of potential wind sites.

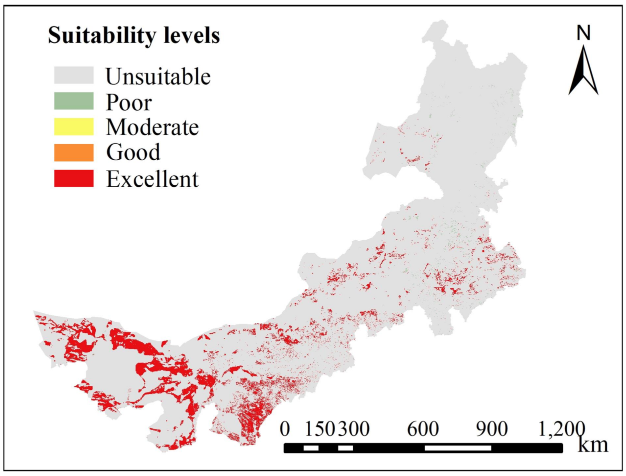

Figure 7. Suitability map of potential solar sites.

Carty, C., Claveria, O., 2024. A synergistic analysis of solar and wind energy deployment in Europe. *Environmental Development*, 100967.

Feng, J., Feng, L., Wang, J., King, C. W., 2020. Evaluation of the onshore wind energy potential in mainland China—Based on GIS modeling and EROI analysis. *Resources, Conservation and Recycling*, 152, 104484.

Gacu, J. G., Garcia, J. D., Fetalvero, E. G., Catajay-Mani, M. P., Monjardin, C. E. F., 2023. Suitability Analysis Using GIS-Based Analytic Hierarchy Process (AHP) for Solar Power Exploration. *Energies*, 16(18), 6724.

Gouareh, A., Settou, B., Settou, N., 2021. A new geographical information system approach based on best worst method and analytic hierarchy process for site suitability and technical potential evaluation for large-scale CSP on-grid plant: An application for Algeria territory. *Energy Conversion and Management*, 235, 113963.

Halder, B., Banik, P., Almohamad, H., Al Dughairi, A. A., Al-Mutiry, M., Al Shahrani, H. F., Abdo, H. G., 2022. Land suitability investigation for solar power plant using GIS, AHP and multi-criteria decision approach: a case of megacity Kolkata, West Bengal, India. *Sustainability*, 14(18), 11276.

Jangid, J., Bera, A. K., Joseph, M., Singh, V., Singh, T., Pradhan, B., Das, S., 2016. Potential zones identification for harvesting wind energy resources in desert region of India–a multi criteria evaluation approach using remote sensing and GIS. *Renewable and Sustainable Energy Reviews*, 65, 1–10.

Levosada, A. T. A., Ogena, R. P. T., Santos, J. R. V., Danao, L. A. M., 2022. Mapping of Suitable Sites for Concentrated Solar Power Plants in the Philippines Using Geographic Information System and Analytic Hierarchy Process. *Sustainability*, 14(19), 12260.

Liu, L., Wang, Y., Wang, Z., Li, S., Li, J., He, G., Li, Y., Liu, Y., Piao, S., Gao, Z. et al., 2022. Potential contributions of wind and solar power to China's carbon neutrality. *Resources, Conservation and Recycling*, 180, 106155.

Mohsin, S. M., Maqsood, T., Madani, S. A., 2022. Solar and wind energy forecasting for green and intelligent migration of traditional energy sources. *Sustainability*, 14(23), 16317.

Pambudi, G., Nananukul, N., 2019. A hierarchical fuzzy data envelopment analysis for wind turbine site selection in Indonesia. *Energy Reports*, 5, 1041–1047.

Parthasarathy, T. N., Narayanamoorthy, S., Sulaiman, R., Elamir, A. M., Ahmadian, A., Kang, D., 2024. An end-to-end categorizing strategy for green energy sources: Picture q-rung orthopair fuzzy EXPROM-II: MADA approach. *Sustainable Energy Technologies and Assessments*, 63, 103658.

Prăvălie, R., Patriche, C., Bandoc, G., 2019. Spatial assessment of solar energy potential at global scale. A geographical approach. *Journal of Cleaner Production*, 209, 692–721.

Purohit, I., Purohit, P., 2017. Technical and economic potential of concentrating solar thermal power generation in India. *Renewable and Sustainable Energy Reviews*, 78, 648–667.

Rekik, S., El Alimi, S., 2023. Optimal wind-solar site selection using a GIS-AHP based approach: A case of Tunisia. *Energy Conversion and Management: X*, 18, 100355.

Rezaei, M., Mostafaeipour, A., Qolipour, M., Tavakkoli-Moghaddam, R., 2018. Investigation of the optimal location design of a hybrid wind-solar plant: A case study. *International journal of hydrogen energy*, 43(1), 100–114.

Saaty, T. L., Vargas, L. G., Saaty, T. L., Vargas, L. G., 2012. The seven pillars of the analytic hierarchy process. *Models, methods, concepts & applications of the analytic hierarchy process*, 23–40.

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.

Simoes, S. G., Lima, A., 2023. Materials, resources, and CO2 impacts of building new renewable power plants to reach EU's goals of carbon neutrality. *Journal of Cleaner Production*, 418, 138138.

Sun, T., Shan, M., Rong, X., Yang, X., 2022. Estimating the spatial distribution of solar photovoltaic power generation potential on different types of rural rooftops using a deep learning network applied to satellite images. *Applied Energy*, 315, 119025.

Wang, Y., Chao, Q., Zhao, L., Chang, R., 2022. Assessment of wind and photovoltaic power potential in China. *Carbon Neutrality*, 1(1), 15.

Yang, J., Li, R., Solangi, Y. A., 2024. Assessing and prioritizing drivers and strategies for transition to a green energy for sustainable development in China. *Heliyon*.

Zalhaf, A. S., Elboshy, B., Kotb, K. M., Han, Y., Almaliki, A. H., Aly, R. M., Elkadeem, M., 2021. A high-resolution wind farms suitability mapping using GIS and fuzzy AHP approach: A national-level case study in Sudan. *Sustainability*, 14(1), 358.

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