GEOGRAPHICAL ASSESSMENT OF WIND ENERGY POTENTIAL IN KHIZI DISTRICT: TECHNICAL AND ECONOMIC ANALYSIS

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Abstract

The article is devoted to the study of the possibilities of using the wind resources of the Khizi region in energy production. The study emphasizes territorial geographic characteristics and resource availability as primary determinants for power plant siting. The research database is based on the analysis of information obtained from various sources, such as measurements of meteorological stations, the Global Wind Atlas, and NASA Power data. The wind energy potential of the region was assessed based on meteorological indicators, and prospective areas were identified using GIS, taking into account factors such as land use, environmental impact, and energy demand. The collected data was processed using mathematical models, GIS analyses, economic analyses, and cartographic methods. Optimal areas for the construction of wind power plants (WPP) were identified based on the main wind parameters, including average wind speed, wind direction, and seasonal wind regime, which reflects long-term va-riability and intra-annual fluctuations. As a result, the wind energy potential of the Khizi region was assessed using GIS-based microzoning and 1981–2022 of meteorological data. The selected location covers an area of 250 km², and 20 deployment zones with 40 turbines can be built in this field. The potential wind energy production in the area is possible to be 295.7 GWh, which could contribute 12% to Azerbaijan's 2030 renewable energy targets.

1. Introduction

The growth of the world population and the development of industry are deepening the global challenges related to energy security and climate change [3]. According to the Renewable Global Status Report (REN21), global electricity production from wind energy will reach 10% in 2023 [15]. In particular, rapid growth in wind energy production is observed in Europe and China. In accordance with this trend, expanding the use of alternative energy sources in Azerbaijan is also important from an economic and environmental perspective. Here, the use of renewable energy sources is not only relevant, but also increases the strategic importance of wind energy in particular. Thus, wind energy constitutes a key component of Azerbaijan's renewable energy strategy due to its sustainability and resource abundance.

Khizi district, located within the Khizi-Absheron economic region, possesses the highest wind energy potential in Azerbaijan. Long-term analysis of wind speed data over a 41-year period (1981–2022) indicates an average wind speed of approximately 5.5 m/s [17]. Although the district is considered highly suitable for wind power plant (WPP) development, aspects such as GIS-based microzoning have not been comprehensively investigated. This study aims to quantify the wind energy potential of the Khizi district and evaluate its prospective contribution to Azerbaijan’s 2030 renewable energy targets. The region's geographical characteristics-such as its proximity to the Caspian Sea, presence of low hills, and availability of uncultivable land-along with the prevalence of strong northerly winds during the winter months, position Khizi as one of the most promising regions for wind energy development in the country. However, while previous research has assessed Azerbaijan’s general wind energy potential, detailed investigations focusing on site-specific meteorological conditions, GIS-based spatial analysis, and optimized wind turbine placement strategies in Khizi District remain limited and insufficiently substantiated [14].

In order to ensure effective deployment of WPPs in the Khizi district, it is necessary to conduct a thorough analysis of climatic factors', particularly wind speed analysis, and to evaluate the region's potential for green energy development. The Government of Azerbaijan has set a strategic goal to increase the share of renewable energy in electricity generation by 2030 [12]. The Khizi District is well-positioned to support this objective, as it possesses some of the most favorable conditions in the country in terms of wind energy potential and land use conditions. In addition, the construction of WPPs in the Khizi district can contribute significantly to environmental protection, carbon emission reduction, and economic development of the region. For instance, considering Azerbaijan's electricity generation mix, replacing fossil fuel energy with 295.7 GWh of wind energy could reduce CO_2 emissions by approximately 100452 tons annually, assuming an emission factor of 0.45 kg (CO_2/kWh).

1.1. Problem statement.

While previous studies have acknowledged the high wind energy potential of the Khizi–Absheron economic region [1; 11; 12; 13], a critical research gap persists in the form of a detailed, spatially-explicit assessment for the Khizi District itself. Existing works, such as those by Gardashov et al. [12], Aliyev [2], and Salamov [19], provide valuable insights into Azerbaijan's general wind potential but lack the granular, location-specific analysis required for practical Wind Power Plant (WPP) deployment. Although Ismayilov et al. [14] contributed to a geographical atlas [9], their study did not incorporate a comprehensive GIS-based micro-siting methodology. Consequently, there is a lack of a scientifically robust framework that integrates long-term meteorological data with GIS-based multi-criteria analysis to identify optimal turbine placement locations within the Khizi District. This study aims to address this gap by conducting a high-resolution assessment of the region's wind resources, combining statistical analysis of a 41-year wind dataset with GIS spatial modeling to provide a precise and actionable evaluation of Khizi's wind energy potential for effective project planning.

1.2. Review of previous studies

Research on Azerbaijan's wind energy potential has established a foundational understanding of the resource, though site-specific studies for optimal WPP placement remain limited. Key national assessments, such as those by Gardashov and Gardashov [12], have applied analytical methods like the Weibull distribution to evaluate the general wind potential, highlighting coastal zones as particularly promising. Similarly, Aliyev [2] and Salamov et al. [19] provided early estimations of wind resources, focusing broadly on the Absheron Peninsula and identifying it as a key area of interest.

The critical role of geospatial analysis in wind farm planning is well-documented in international literature. Bandoc et al. [4] demonstrated the efficacy of GIS for large-scale wind potential assessments, integrating topographic and meteorological data. This approach is essential for identifying viable locations while considering land use constraints. Furthermore, studies like those by Şahin et al. [20] in the Iğdır Province of Turkey provide valuable methodological frameworks for regional wind energy site suitability analysis that can be contextualized for similar semi-arid, moderate-wind regions like Khizi.

A significant contribution to the national dataset was made by Ismayilov et al. [14], who developed a wind atlas for Azerbaijan using Weibull analysis. However, their work did not fully leverage GIS-based multi-criteria decision analysis for micro-siting, which is crucial for addressing local infrastructural, environmental, and socio-economic factors. This gap is particularly relevant for the Khizi district, which, despite being recognized in strategic documents [12] and preliminary assessments [16] as a high-potential zone, lacks a detailed, spatially-explicit feasibility study that integrates long-term wind data, land use compatibility, and economic viability to identify deployable sub-zones and calculate realistic energy yields.

This study builds upon these previous works by implementing a integrated methodology that combines a 41-year meteorological dataset with advanced GIS spatial analysis to perform a micro-scale assessment of the Khizi district, thereby transitioning from general potential to actionable project development insights.

2. Materials and Methods

For the analysis of wind speed, hourly data from the Khizi meteorological station, 0.5°×0.5° grid data from the NASA POWER platform for the period 1981–2022 [17], and microzonation models from the Global Wind Atlas were utilized [21]. Long-term variability was statistically evaluated using the Mann–Kendall trend test and Sen's slope estimator. The suitability of areas was assessed using GIS-based spatial analysis, mathematical models (energy production equations), and economic assessments. The materials used to investigate the strategic importance of wind energy sources include the following:

Literature and reports: Key references include the Agroclimatic Atlas of Azerbaijan, the Geographical Atlas of Azerbaijan, and reports from the Hydrometeorological Service Bureau.

Official statistical data: Based on the data provided by the Ministry of Energy of Azerbaijan, the State Agency for Renewable Energy Sources, and the State Statistical Committee, analyze the national energy balance, fuel-based production, and the share of renewable energy.

Energy Sector Strategy: Government-led strategic documents and projects focusing on the development of the alternative energy sector were reviewed.

Comparative Analysis: Wind speed data from the Khizi District were compared with those of other regions in Azerbaijan to assess relative performance.

Turbine models: The hub-height wind speed (100 m) was extrapolated from the 10 m observational dataset using the power-law with an exponent $\alpha = 0.14$, resulting in a representative wind speed of approximately 6.8 m/s. α was selected based on coastal semi-flat terrain characteristics consistent with Class II wind regimes. Based on this value, the expected capacity factor of the selected 3.45 MW IEC Class II turbine is approximately 24.5%, which corresponds to typical performance levels for medium-wind Class II sites. Therefore, this turbine type is fully compatible with the meteorological characteristics of the study area.

3. Results.

The average annual wind speed at a height of 10 meters in the Khizi region between 1981 and 2022 were studied based on NASA Power data [17]. The analysis focused on monthly and seasonal wind speeds. The results indicated that the lowest wind speed in summer is observed in July. The monthly wind speed in the region varies between 4.2 m/s and 6.5 m/s. Relatively low wind speeds are observed in this season, especially in July and August (Table 1, Figure 3).

Long-term wind speed analysis (1981-2022) reveals distinct seasonal patterns in the Khizi district (Table 1). Winter and autumn months exhibit the highest wind speeds, optimal for energy generation, while summer months show significantly lower velocities. October consistently emerges as the windiest month across most observational periods.

An analysis of the overall annual average wind speeds determined that there were certain changes in wind speed between 1981 and 2022. In particular, although a relative stabilization in wind speeds was observed after the mid-1990s, significant increases in wind speed were recorded in some years. The wind speed distribution map of the Khizi region illustrates the spatial variability of the distribution of wind speed across the territory and demonstrates the highest wind energy potential of the Caspian Sea coast (Fig. 1).

In terms of seasonal variation, the wind speed in winter months was higher than in other seasons. In contrast, the average wind speed in summer months (June-August) was in the range of 4.1-5.2 m/s, representing a 28% decrease compared to winter values (Table).

Table

Seasonal and 3-year average wind speeds at 10 m height in Khizi district (1981-2022) [17]

Year Range	Winter (Dec-Feb)	Spring (Mar-May)	Summer (Jun-Aug)	Fall (Sep-Nov)	Average Annual Wind Speed
1981-1983	5.91	5.20	4.88	5.05	5.43
1984-1986	5.82	4.89	5.05	5.23	5.53
1987-1989	5.87	4.93	4.98	5.18	5.52
1990-1992	5.76	4.96	4.81	5.33	5.41
1993-1995	5.84	4.82	5.00	5.50	5.55
1996-1998	5.42	4.61	4.95	5.38	5.53
1999-2001	5.49	4.72	4.79	5.37	5.38
2002-2004	5.35	4.87	4.90	5.48	5.26
2005-2007	5.62	4.96	4.76	5.48	5.45
2008-2010	5.84	4.83	4.83	5.44	5.31
2011-2013	5.37	4.60	4.90	5.33	5.28
2014-2016	5.91	4.93	4.86	5.43	5.69
2017-2019	5.71	4.78	5.17	5.47	5.59
2020-2022	5.61	4.89	5.15	5.32	5.51

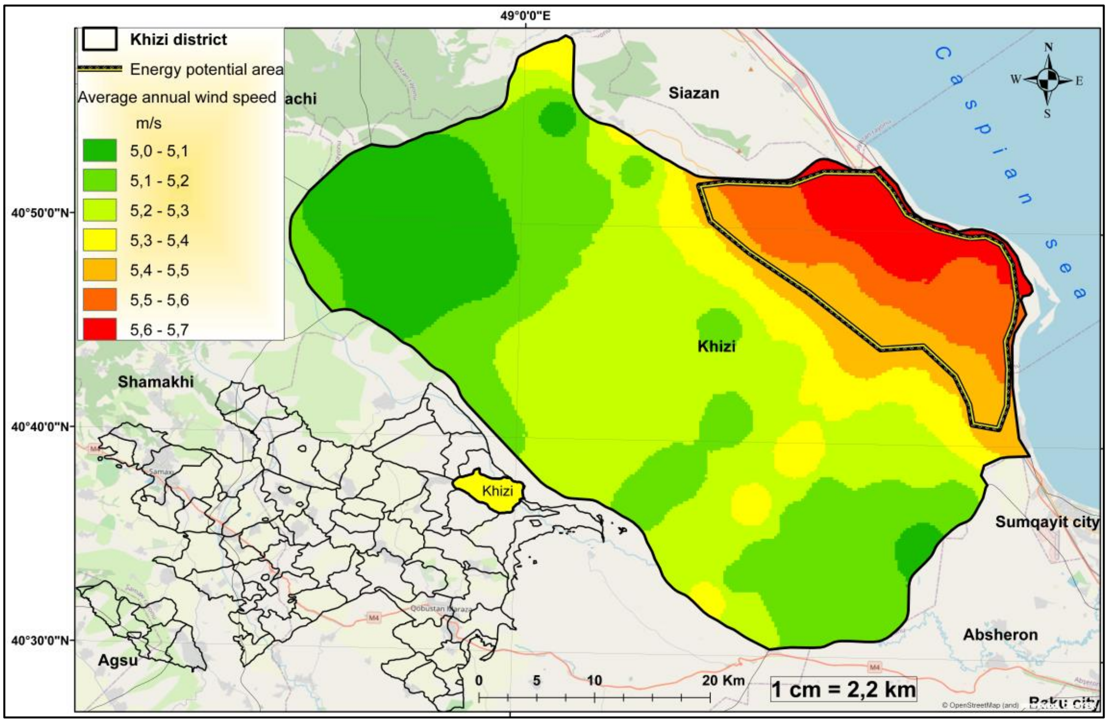

Figure 1. Average annual wind speed in Khizi district (1981-2022)

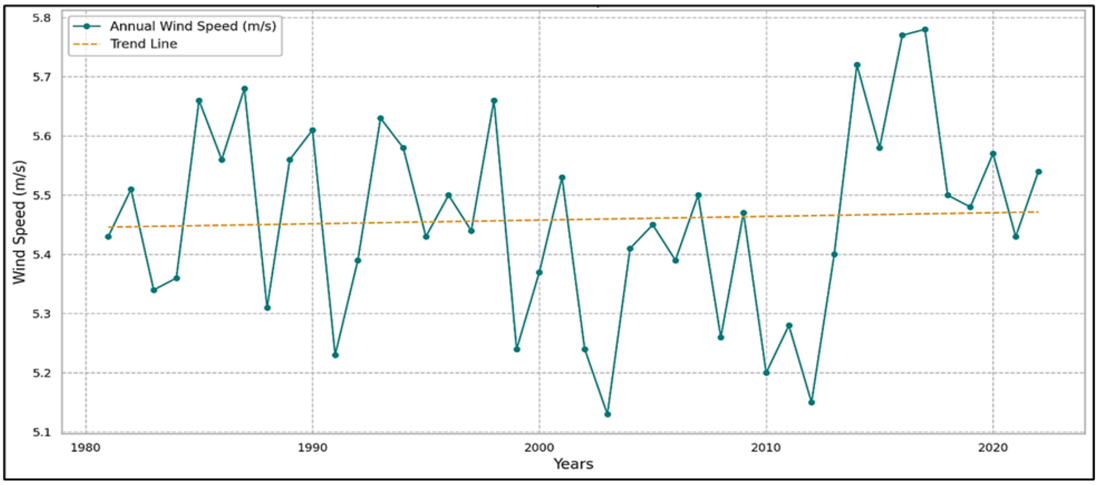

Figure 2. Annual average wind speed trend (1981-2022) [17]

However, it is 24% lower than that of the Danish coastal zones (7.2 m/s). Nevertheless, the large expanse of undeveloped land and the simplicity of land ownership make Khizi district more economically efficient. This can also be seen from the table showing the wind energy potential of this area. The annual variation in wind speed was visualized as the annual variability of wind speed in the area with a trend line (Fig. 2).

This trend may be attributed to the negative phase of the North Atlantic Oscillation (NAO). Also, the average wind speed of Khizi is approximately 15% higher than that of the Iğdır Province of Turkey (4.8 m/s) [20].

To assess the wind energy production potential in Khizi district, the data for the years 1981-2022 at a standard height of 10 meters were analyzed, and the average monthly wind speed for this period was calculated. According to the analysis results, since the intensity of the northern winds is higher in the cold seasons of the year, a trend is clearly reflected in the seasonal wind speed values. The dynamics of wind speed by season (*Table*) and peak speeds in the autumn months were spatially analyzed using GIS tools, and in December, the maximum speed zones (6.5–7.0 m/s) were identified approximately 2 km inland from the Caspian Sea coastline. Thus, the average wind speed in January was 5.68 m/s, in February 5.85 m/s, and in March 5.86 m/s [17]. A decrease in wind speed was observed in the summer months: 5.2 m/s was recorded in April, 4.8 m/s in May, and 4.73 m/s in June.

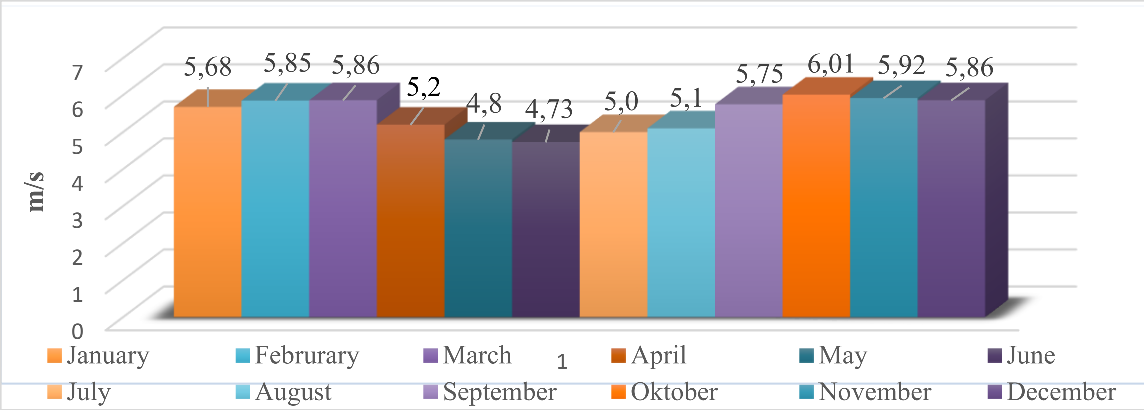

Figure 3. Average wind speed by month (1981-2022) [17]

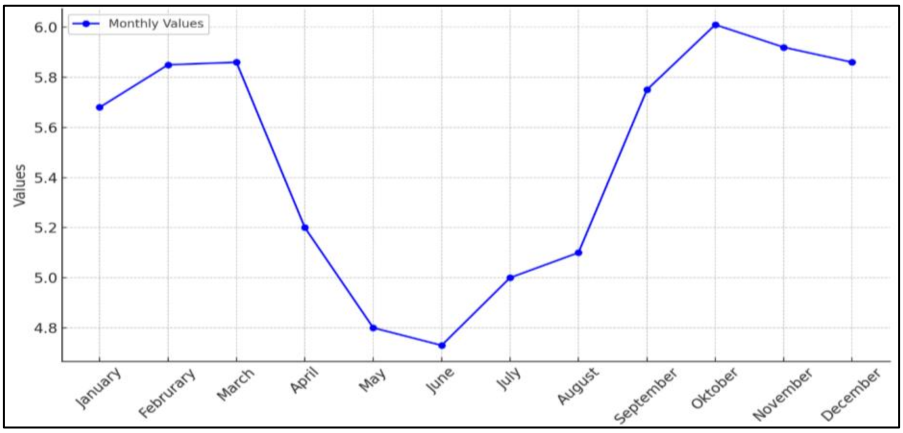

Figure 4. Average monthly wind speed data trend (1981-2022) [17]

An increase in wind speed was observed during the late summer months: 5.0 m/s in July, 5.1 m/s in August, and 5.75 m/s in September. In the autumn months, wind speed remained high: 6.01 m/s in October, 5.92 m/s in November, and 5.86 m/s in December [17]. These findings confirm the favourable meteorological conditions for the exploitation of wind energy for the potential use of wind energy. This research represents the presented data and provides a robust scientific foundation for the efficient use of natural resources in promising areas such as the Khizi region in terms of wind energy. It is significant not only as the first comprehensive and multidimensional analysis to quantify the wind energy potential of Khizi, but also of importance both scientifically (GIS and meteorological model synthesis) and from an applied (roadmap for the 2030 strategy) perspective.

The trend line in the monthly wind speed values in the graph below shows that the wind speed does not remain constant over the years, or that there is an average speed difference of 1.2 m/s between June and October, and that it suggests a consistent seasonal trend. The differences in wind speed between seasons are significant (Fig. 4). The average speed difference between winter and autumn is 1.3 m/s, and between summer and winter is 2.1 m/s. From the point of view of site suitability for WPP construction, wind speed is a key indicator for electricity generation. If the average speed is between 5 and 6 m/s and no large fluctuations are observed, this may indicate favorable conditions for a WPP. Linear trend analysis is favorable for wind power generation, along with the statistical stability of wind speed over 41 years, with no extreme anomalies. This wind speed data contributes to the stable and predictable energy production in the area, which is an important factor for economic feasibility and grid integration. Also, the wind regime of the region is characterized by fairly intense wind conditions that do not threaten the mechanical integrity of wind turbines. Thus, for the efficient operation of modern wind turbines, a minimum wind speed of 4-5 m/s is required. The analyzed data reaffirms that the average wind speed consistently exceeds this threshold, making the region favorable for the development of wind energy.

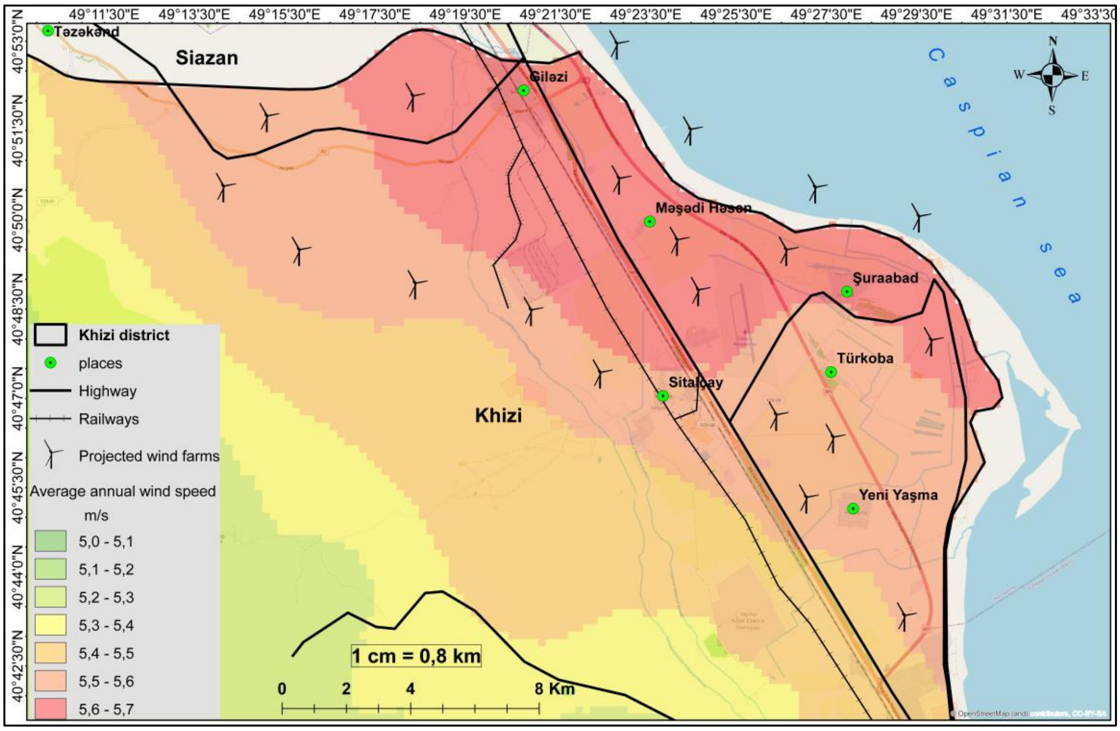

Figure 5. Optimal area for wind power plants installation

The spatial variability of wind speed (spatial variability of wind speed) in the Khizi region was modelled using NASA's POWER data platform and GIS (ArcMap 10.8) based on available long-term meteorological data [4]. The areas suitable for the placement of turbines in the area were considered based on land use (e.g., agriculture, residential areas) and constraints (e.g., protected natural areas, transportation and utility infrastructure). As can be seen in the figure, the wind speed in the region is more intense around the coast, and the vacant areas also coincide with these areas. GIS-based spatial analysis identified optimal zones for turbine placement based on wind speed (>5.5 m/s) and proximity constraints (>500 m from settlements) (Figure 5). The total suitable area covers 250 km², accommodating 40 turbines across 20 deployment zones. Based on turbine spacing standards (600–900 m) and exclusion buffers, each sub-zone can host between 1 and 4 turbines, resulting in a total capacity of 40 turbines across the 20 deployment zones. These 20 optimal zones and 40 turbine locations take into account wind potential, relief, land use type, environment and social constraints through a GIS-based microzoning method.

The annual energy yield was calculated using the capacity factor method. For the selected 3.45 MW IEC Class II turbine operating at a hub-height wind speed of 6.8 m/s, the capacity factor is 24.5%, resulting in an annual output of approximately 7.4 GWh per turbine. This approach enables precise forecasting of both installed capacity and energy generation for each selected site, while also providing a basis for economic valuation and revenue potential assessment. The following standard wind energy equation was employed to estimate the annual energy output:

$$\boldsymbol{E} = \mathbf{0.5} \times \boldsymbol{\rho} \times \boldsymbol{A} \times \boldsymbol{v}^3 \times \boldsymbol{t} \times \boldsymbol{\eta} \quad (1)$$

Where:

- E: Estimated energy output (kWh or MWh)
- ρ: Air density (typically 1.225 kg/m³ at sea level)
- A: Swept area of the turbine blades (m²)
- v: Average wind speed (m/s)
- t: Time duration (hours/year)
- η: Capacity Factor of the turbine.

In here the cubic power equation is provided for theoretical context; annual energy was calculated using the capacity factor (CF) method. This formula provides a scientific basis for quantifying the wind energy potential of the Khizi district and supports investment planning for WPP infrastructure. Based on the technical characteristics of wind turbines, their electricity generation capabilities at different wind speeds and rotor diameters were assessed. The analysis focused on identifying the most efficient turbine models compatible with the region's wind resource profile. As a result, the "Generic IEC Class" turbine with a rated capacity of 3.45 MW was selected as the most suitable option due to its high performance, cost-effectiveness, and opera-tional efficiency under moderate wind conditions. Based on 41 years of wind observations in the Khizi region (average annual wind speed of 5.5 m/s, approximately 6–7 m/s at 100 m hub height, low turbulence intensity, and rare extreme wind events), the site corresponds to the medium-wind category defined as IEC Class II under the IEC 61400 standard. Therefore, selecting the 3.45 MW 'Generic IEC Class's turbine is both technically and economically optimal for the region. Class I turbines would be unnecessarily robust and costly for Khizi's wind regime, while Class III turbines would underperform under the local wind conditions. Hence, the chosen IEC Class turbine model is fully compatible with the wind characteristics of the study area. The 3.45 MW IEC Class II turbine was selected as optimal for Khizi's wind regime. This class provides the ideal balance between performance and cost-effectiveness for the region's moderate wind speeds, avoiding the over-engineering of Class I turbines and the underperformance of Class III models in these conditions. Due to their high performance and reasonable price, these turbines provide more efficient results in the field. The tower height of this turbine is 100 m, the blade diameter is 126 m, and the nominal power is 3450 kW. The wind speed for this turbine is calculated to be 8.5 m/s at 100 meters above ground level. As an example, the power of this turbine is given in more detail in the following example according to formula 1.

"Generic IEC Class" wind turbine

- Rotor diameter = 126 m
- Wind speed, v = 6.8 m/s (extrapolated from 10 m data using the power-law with $\alpha = 0.14$)
- Blade length, l = 63 m
- Air density, ρ = 1,23 kg/m³
- Area, $A = (\pi \times r^2)$
- $A = \pi 63^2 = 12466$ m²
- T = 8760
- $\eta = 0.2446$

The theoretical annual energy output can be estimated using the standard wind power equation (1). However, for practical energy yield calculations, the capacity factor (CF) method was employed. The net annual production per turbine was calculated as follows:

$E = P \times CF \times 8760$ h

The calculation of Wind energy based on the average annual energy production of a single turbine is as follows:

$E = 1/2 \times 1{,}23 \times 12466 \times 6.8^3 \times 8760 \times 0.2446 = 7.4$ GWh

The wind energy potential of the Khizi region was estimated using a standard wind power calculation formula. These estimations were applied to the technical specifications of a single turbine, yielding the aforementioned energy output. It is important to note that the required total capacity can be achieved by increasing the number of installed turbines in proportion to the regional energy demand. The actual energy production of a wind turbine is highly dependent on wind speed. While energy generation typically occurs in the range of 3 to 12 m/s, the turbine reaches its rated (nominal) power output of 3,450 kW once wind speeds exceed 12 m/s, after which the output remains constant. Given that daily average wind speeds in Khizi generally fluctuate between 4.5 and 6.5 m/s, the expected average operational output of the turbine is approximately 690 kW. Based on the extrapolated hub-height wind speed of 6.8 m/s, the calculated capacity factor of the selected 3.45 MW IEC Class II turbine is approximately 24.5%.

According to the average annual energy production of a single turbine and based on the average annual electricity consumption per household in Azerbaijan (approximately 2,000–3,000 kWh for homes without electric heating systems), one 3.45 MW wind turbine producing around 7.4 GWh/turbine per year can meet the electricity demand of approximately 2957 households (7,4 GWh/2,500 kWh/house≈2957 households). For consistency, the total annual output of the 40-turbine configuration is standardized as: E_{total} = 295.7 GWh/year, and this value is used uniformly in all later calculations (CO_2 reduction and economic analysis).

By evaluating the region's suitability under prevailing wind conditions, an economic analysis was conducted on the initial installation costs of the turbines, maintenance costs, and income from energy production. An economic analysis was also conducted, factoring in the initial capital investment, operation and maintenance costs, and expected revenue from electricity generation. The calculated LCOE of $0.045/kWh reflects comprehensive economic modeling, incorporating capital expenditures (turbine procurement, civil works, grid connection), operational costs (maintenance, insurance, administration), and standard financial parameters (20-25-year lifetime, 7-8% discount rate, 24.5% capacity factor). This cost level demonstrates strong competitiveness against current Azerbaijani electricity prices ($0.050-0.055/kWh) and enhances project bankability. In addition, the environmental impact (e.g., bird migration routes and noise pollution) should also be taken into account when placing turbines, and the placement of turbines should be consistent with the interests of the community living in the area [5]. To mitigate environmental risks, it is essential to map ecologically sensitive areas, especially protected zones, and ensure that turbine placement does not conflict with wildlife conservation or the interests of local communities [22].

Field photographs were collected in 2025 by the author of the study area and visually demonstrates the practical application potential of the Sitalchay, Yeni Yashma and, Shorabad area. As can be seen, the flat relief and sparse vegetation create favorable conditions for the transportation and installation of wind turbines. The lack density and wide spacing of agricultural areas and settlements is an additional advantage from a social and environmental perspective. At the same time, the proximity to existing power transmission lines and transport infrastructure (road, rail and sea) allows for cost reduction and easier integration into the grid when building new wind turbines.

When analyzing the photographs of the area. it is clear that the relief is open and favorable conditions for wind energy production. The photographs demonstrate socio-technical compatibility (agriculture. distance from settlements. open terrain) (Fig. 6a–d)

a) (40°49′20″N. 49°25′16″E) – relatively smooth terrain and sparse agricultural areas;

b) (40°48′03″N. 49°26′57″E) – flat terrain and sparse vegetation opportunities for combining agriculture with energy infrastructure;

c) (40°49′21″N. 49°26′17″E) – open terrain and distance from nearby settlements;

d) (40°52′01″N. 49°31′28″E) – open terrain sparse agricultural areas and proximity to existing power lines and transport infrastructure.

Field photographs (Fig. 6) visually confirm the key characteristics of the identified sites: predominantly flat terrain, sparse vegetation, and proximity to existing infrastructure such as roads and power lines. These factors collectively reduce installation costs, simplify logistics, and facilitate grid connection, enhancing the overall feasibility of WPP development in the study area.

4. Discussion

This study provides the first comprehensive assessment of wind energy potential in the Khizi district, integrating long-term meteorological data with GIS spatial analysis. The identified seasonal pattern-with peak winds in winter and autumn-aligns with the regional climate dynamics influenced by Caspian Sea effects and the North Atlantic Oscillation.

The calculated capacity factor of 24.5% for the selected 3.45 MW IEC Class II turbine positions Khizi competitively against other moderate-wind regions. For comparison, similar regions in Eastern Turkey achieve capacity factors of 17-20%, while Georgian sites report 16-19% with comparable turbine technology.

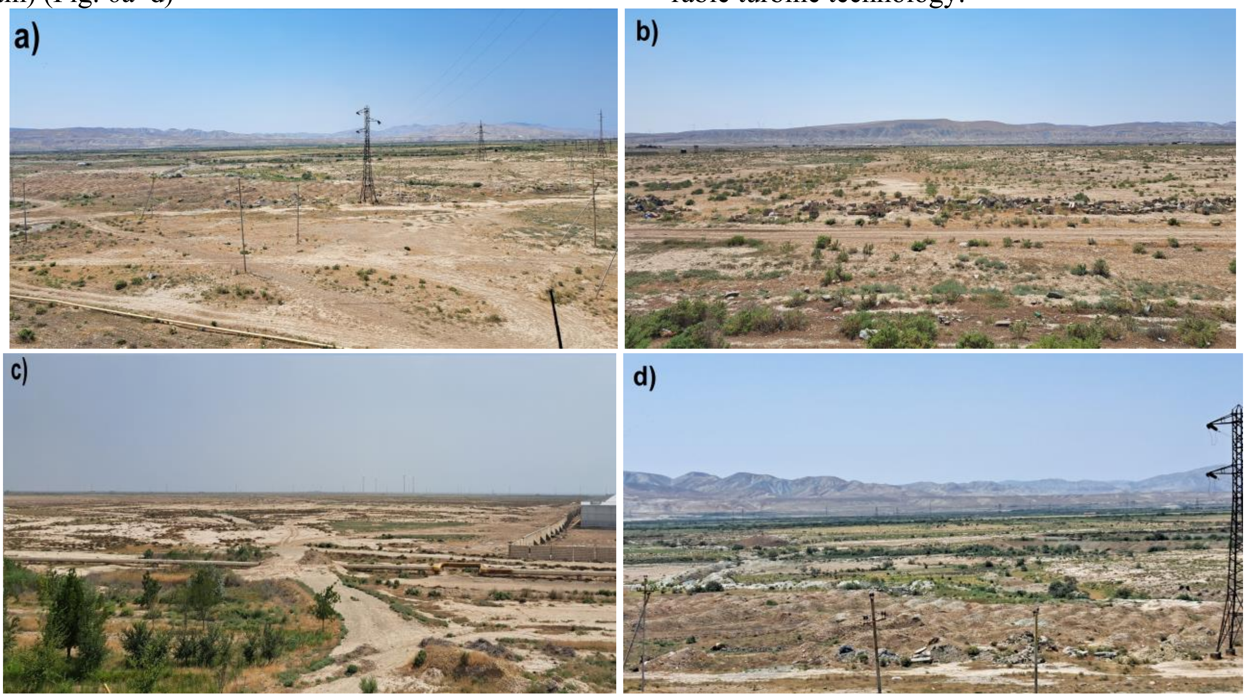

Figure 6 (a–d). Potential areas for the construction of WPP in the study area

The proposed 138 MW wind farm could generate approximately 295.7 GWh annually, contributing significantly to Azerbaijan's 2030 renewable energy targets. With an estimated LCOE of $0.045/kWh, the project demonstrates economic viability compared to current electricity costs in Azerbaijan ($0.050-0.055/kWh).

The significant seasonal variation in wind speed, particularly the lower velocities during summer months, highlights the potential for hybrid wind-solar systems. As identified in this study, the region receives high average annual solar radiation (1550 kWh/year), creating ideal conditions for complementary solar energy generation. Following models such as the Tamil Nadu hybrid system, an optimal ratio of 30% wind and 70% solar could substantially improve supply stability throughout the year. During peak solar periods in summer, solar generation would compensate for reduced wind speeds, while increased wind resources in autumn and winter would offset declining solar radiation.

The reliance on NASA POWER and Global Wind Atlas data, while comprehensive, may not capture micro-scale topographic effects. Future studies would benefit from high-resolution local measurements and detailed feasibility analysis of hybrid wind-solar configurations to optimize renewable energy integration in the Khizi district.

5. Conclusions.

This study assessed the wind energy potential of the Khizi region through GIS-based analyses, meteorological data, and economic analyses, providing a scientific basis for the efficient use of renewable energy sources in the region. Data collected for the years 1981-2022 show that the average annual wind speed in the Khizi region is 5.5 m/s. Although the wind speed varies by season, it is higher in winter and autumn (5.5-6.5 m/s) and relatively lower in summer (4.1-5.2 m/s). These values consistently exceed the minimum speed limit (4-5 m/s) required for the effective operation of modern wind turbines, confirming that the region is suitable for wind energy production. As a result of the GIS-based modelling used during the study, a potential area of more than 250 km² was identified. It is possible to establish a 40-turbine power plant with a total capacity of 138 MW (40 × 3.45 MW = 138 MW) on these lands. The proposed 40×3.45 MW turbines have an estimated annual production capacity of approximately 295.7 GWh, equivalent to an average continuous output of 25.5 MW (295.7 GWh/8,760 hours). The WPP's total installed capacity is 138 MW, representing approximately 1.7% of Azerbaijan's current national installed capacity (≈8 GW). This level of production would be sufficient to meet the annual electricity needs of roughly 103,880 households (assuming 2,500 kWh per household per year). GIS analyses, land use, environmental constraints, and infrastructure factors were taken into account for the optimal placement of turbines. If realized, the proposed wind energy projects could result in a reduction of carbon emissions by approximately 100,440 tons annually, contributing to Azerbaijan's green energy transition and long-term climate goals. The findings are of great importance in unlocking the country's renewable energy potential and will make the Khizi region a key player in the use of renewable energy sources, positively impacting Azerbaijan's energy strategy and environmental sustainability.

REFERENCES

1. Ahmadov, N. (2024) Renewable Energy in Azerbaijan: Opportunities and Obstacles // International Confe-rence on Smart Environment and Green Technologies, Cham: Springer Nature Switzerland, 219–226.
2. Aliyev, R.N. (2015) Alternative Energy and Ecology. Baku: Teknur, 368 p. (in Azerbaijani).
3. Allan, R.P., Arias, P.A., Berger, S., Canadell, J.G., Cassou, C., Chen, D., et al. (2023) Summary for policymakers // In: Climate Change 2021: The Physical Science Basis, Cambridge University Press, 3–32. https://doi.org/10.1017/9781009157896
4. Bandoc, G., Prăvălie, R., Patriche C., Degeratu M. (2018) Spatial assessment of wind power potential at global scale // Journal of Cleaner Production, № 200, p. 1065–1086. https://doi.org/10.1016/j.jclepro.2018.07.288
5. Blazy, R., Łabuz, R. Potential ecological effects of wind farm location in Małopolska region // Frontiers in Energy Research, Vol. 12, 2025, Article 1504371. https://10.3389/fenrg.2024.1504371
6. Duranay, Z.B., Güldemir, H., Coşkun, B. (2024) The Role of Wind Turbine Siting in Achieving Sustainable Energy Goals // Processes, Vol. 12(12), 2900. https://doi.org/10.3390/pr12122900
7. State Statistical Committee of Azerbaijan (2024) Energy of Azerbaijan. Baku: Statistical Bulletin, 164 p. (In Aze).
8. Gardashov, E., Gardashov, R. (2024) Analytical expression for wind power distribution and turbine capacity factor // International Journal of Sustainable Energy, Vol. 43(1), 2390447. https://doi.org/10.1080/14786451.2024.2390447
9. Geographical Atlas of the Republic of Azerbaijan (2018). Baku Cartography Factory, 207 p. (in Azerbaijani).
10. Hajizade, O. (2024) Green Economic Potential of Baku and Absheron-Khizi Regions // Polish Journal

of Environmental Studies, Vol. 33(5), https://doi.org/10.15244/pjoes/183794

11. Hashimov, A.M., Rahmanov, N.R., Mahmudova, A.Z., Morillo, J.M.B. (2023) Voltage stability distribution in renewable-integrated system // IJTPE, Issue 55, Vol. 15(2).

12. IEA (2023). Azerbaijan Energy Profile // Paris: IEA. URL:https://www.iea.org/reports/azerbaijan-energy-profile. (Accessed 09.11.2024).

13. Imamverdiyev, N.S. (2023) Geospatial analysis of wind indicators for optimal wind farm sites // Journal of Geography & Environmental Management, Vol. 71(4). https://doi.org/10.26577/JGEM.2023.v71.i4.03

14. Ismayilov, M.A., Aliyev, A.M., Abbasov, S.H. (2025) Assessment of onshore wind potential using Weibull analysis // SOCAR Proceedings, № 1, 122–129. https://doi.org/10.5510/OGP20250101051

15. Murdock, H.E., Gibb, D., Andre, T., Sawin, J.L., Brown A., Ranalder L., et al. (2023) Renewables 2023: Global Status Report, 379 p.

16. Mustafayev F., Kulawczuk P., Orobello C. Renewable Energy Status in Azerbaijan: Solar and Wind Potentials // Energies, Vol. 15(2), 2022, Article 401. https://doi.org/10.3390/en15020401

17. NASA MERRA-2, POWER Data Access Viewer // URL: https://power.larc.nasa.gov/data-access-viewer (Accessed 01.12.2024).

18. Negru, N., Radu, S.M., Soica, A. (2024) Economic reintegration potential of tailings dump land using wind turbines // 9th International Conference on Mathematics and Computers in Sciences and Industry, IEEE, 16–21. https://10.1109/MCSI63438.2024.00011

19. Salamov, O., Mamedova, L., Aliyev, F., Gasimova, S. (2021) Wind energy resources in Absheron peninsula // Colloquium-journal, № 27(114), p. 40–50. https://doi.org/10.24412/2520-6990-2021-27114-40-50

20. Şahin, G., Koç, A., Doğan, S.Ş., van Sark, W. (2024) Wind energy potential and site selection in Igdir // Sustainability, Vol. 16(20), 2024, 8775. https://doi.org/10.3390/su16208775

21. Global Wind Atlas: Azerbaijan – Khizi District. URL: https://globalwindatlas.info (Accessed 29.10.2024).

22. Atilgan Turkmen, B, Germirli Babuna, F. (2024) Life Cycle Environmental Impacts of Wind Turbines: A Path to Sustainability with Challenges. Sustainability. 16(13):5365. https://doi.org/10.3390/su16135365

XIZI RAYONUNUN KÜLƏK ENERJİSİ POTENSİALININ COĞRAFİ QİYMƏTLƏNDİRİLMƏSİ: TEXNİKİ VƏ İQTİSADİ TƏHLİL

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Xülasə. Məqalə Xızı rayonunun külək resurslarından enerji istehsalında istifadə imkanlarının öyrənilməsinə həsr olunmuşdur. Tədqiqatda ərazi-coğrafi xüsusiyyətlər və resurs mövcudluğu elektrik stansiyalarının yerləşdirilməsinin əsas təyinediciləri kimi vurğulanır. Tədqiqatın məlumat bazası meteoroloji stansiyaların ölçmələri, Qlobal Külək Atlası və NASA Power məlumatları kimi müxtəlif mənbələrdən əldə edilmiş məlumatların təhlilinə əsaslanır. Rayonun külək enerjisi potensialı meteoroloji göstəricilər əsasında qiymətləndirilmiş, torpaqdan istifadə, ətraf mühitə təsir və enerji tələbatı kimi amillər nəzərə alınmaqla, perspektivli sahələr Coğrafi İnformasiya Sistemləri (CİS) vasitəsilə müəyyən edilmişdir. Toplanmış məlumatlar riyazi modellər, CİS təhlilləri, iqtisadi təhlillər və kartoqrafik üsullardan istifadə etməklə işlənmişdir. Külək elektrik stansiyalarının (KES) tikintisi üçün optimal sahələr orta külək sürəti, külək istiqaməti və uzunmüddətli dəyişkənliyi və ildaxili dalğalanmaları əks etdirən mövsümi külək rejimi daxil olmaqla əsas külək parametrləri əsasında müəyyən edilmişdir. Nəticədə, Xızı rayonunun külək enerjisi potensialı CİS əsaslı mikrozonlaşdırma və 1981-2022-ci illər meteoroloji məlumatlarından istifadə etməklə qiymətləndirilmişdir. Seçilmiş ərazi 250 km² sahəni əhatə edir və bu sahədə 40 turbin üçün nəzərdə tutulmuş 20 quraşdırma zonası inşa edilə bilər. Burada potensial külək enerjisi istehsalının 295,7 GWh ola biləcəyi, bu isə Azərbaycanın 2030-cü il üçün bərpa olunan enerji məqsədlərinin 12%-ni təşkil edə biləcəyi müəyyən edilmişdir.

Açar sözlər: Bərpa olunan enerji mənbələri, külək enerjisi, CİS təhlili, enerji potensialı, elektrik stansiyaları.