RESEARCH ARTICLE

Renewable Energy Potential Assessment for Remote Areas of Akmola Region

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Abstract

Fossil fuels, including oil, gas, and coal, have been an energy center for the global economy; however, they present huge environmental and health risks for society. This study aims to calculate the potential of renewable energy sources for the remote areas of the Akmola region. A calculation was conducted using formulas from Omni Calculator, 60Hertz Energy. Data was extracted from Global Wind and Global Solar Atlas. The study calculates power output of small wind turbines and solar panels. The findings indicate that a combination of small wind turbines and solar panels is the most reliable energy source for
remote areas. The results suggest that a balanced approach of wind and solar energy is the most effective energy source. Future researchers should calculate power output of extreme wind panels.

Keywords: Renewable Energy, solar panels, sustainability

1 Introduction

1.1 Renewable energy

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind, for example, are such sources that are constantly being replenished. Renewable energy sources are plentiful and all around us. Fossil fuels - coal, oil and gas - on the other hand, are non-renewable resources that take hundreds of millions of years to form. Fossil fuels, when burned to produce energy, cause harmful greenhouse gas emissions, such as carbon dioxide. Generating renewable energy creates far lower emissions than burning fossil fuels. Transitioning from fossil fuels, which currently account for the lion's share of emissions, to renewable energy is key to addressing the climate crisis.[1]

1.2 Environmental crisis

Fossil fuels including oil,gas, coal, have been an energy center for global economy, however, it presents huge environmental and health risk for the society When fossil fuels are burned, they release nitrogen oxides into the atmosphere, which contribute to the formation of smog and acid rain. The most common nitrogen-related compounds emitted into the air by human activities are collectively referred to as nitrogen oxides.[2] The exhaust of nitrogen oxides lead to air pollution and harm our ecosystem. When fossil fuels are burned, they release large amounts of carbon dioxide, a greenhouse gas, into the air. Greenhouse gases trap heat in our atmosphere, causing global warming. Already the average global temperature has increased by 1C. Warming above 1.5°C risks further sea level rise, extreme weather, biodiversity loss and species extinction, as well as food scarcity, worsening health and poverty for millions of people worldwide. The Intergovernmental Panel on Climate Change (IPCC) has found that emissions from fossil fuels are the dominant cause of global warming. In 2018, 89% of global CO2 emissions came from fossil fuels and industry. Coal is a fossil fuel, and is the dirtiest of them all, responsible for over 0.3C of the 1C increase in global average temperatures. This makes it the single largest source of global temperature rise. Oil releases a huge amount of carbon when burned -

approximately a third of the world's total carbon emissions. There have also been a number of oil spills in recent years that have a devastating impact on our ocean's ecosystem. Natural gas is often promoted as a cleaner energy source than coal and oil. However, natural gas is still a fossil fuel and accounts for a fifth of the world's total carbon emissions.[3] Water pollution occurs when sulfur dioxide dissolves into water and creates sulfuric acid. This produces acid rain and can lead to the acidification of freshwater sources like lakes and streams. When these bodies of water become too acidic, life cannot survive in them. Acid rain can also affect local crops and soil acidity levels. [4]

1.3 Energy sources in Kazakhstan

Kazakhstan is the largest landlocked country in the world with plentiful natural resources and is also one of the largest oil and gas exporters in the world . Kazakhstan is facing serious environmental problems due to CO2 emissions from fossil fuel energy consumption [5]. Kazakhstan relied on fossil fuels for 87% of its electricity in 2023, falling only slightly from 90% in 2015. Its per capita emissions were more than two and a half times higher than the global average. Kazakhstan's largest clean electricity source is hydro (8%). Wind and solar are starting to play a role, reaching 5% of Kazakhstan's electricity in 2023 [6]

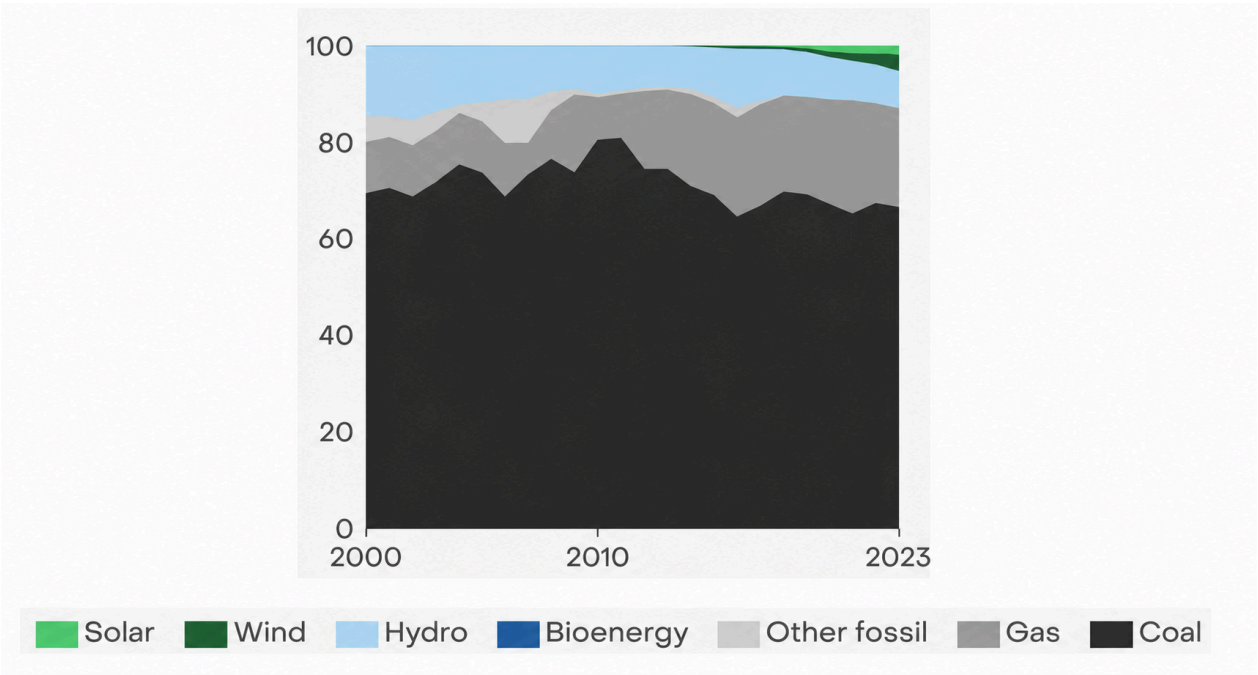


Fig. 1. Energy Sources of Kazakhstan

The graph shows approximately 90% of sources of energy in Kazakhstan were non-renewable; therefore it would be beneficial to use renewable energy resources (wind, solar, geothermal, wave and biomass energy) because of their availability and cleanliness.

1.4 Solar energy in Kazakhstan

Available solar energy varies throughout the day due to the relative motion of the sun and cloud cover. At noon, in clear weather, solar irradiance can reach 1000 W/m^2 , whereas, under dense clouds, it may fall to less than 100 W/m^2 even at midday. The amount of solar energy also depends on the angle and orientation of the solar panel, decreasing as the distance from the south increases. Methods for producing electricity and heat from solar radiation include:

- Photovoltaics – generating electricity using photovoltaic cells.
- Solar thermal energy – heating a surface that absorbs solar rays, followed by the distribution and use of heat (e.g., focusing solar radiation on a vessel with water for heating systems or steam power generators).

Commercial photovoltaic cells have a rated output expressed in Peak Power Watts (WP), which indicates their maximum power under standard test conditions—solar radiation of 1000 W/m^2 and a cell temperature of 25°C. However, in real-world applications, these conditions are rarely met. Despite

Kazakhstan's northern latitude, the country's solar energy resources are stable and viable due to favorable climatic conditions. According to research from the Ministry of Industry and New Technologies of Kazakhstan, the solar energy potential in the southern regions reaches 2500–3000 hours of sunshine per year, generating 1.3–1.8 billion kWh per square meter annually. At least 50% of Kazakhstan's total land area (2,724,902 km^2) is available for installing photovoltaic panels or solar heaters. This translates to a potential solar energy generation of 1700 TWh per year. Given that the efficiency of photovoltaic panels does not exceed 30%, the estimated technical potential of solar energy in Kazakhstan is approximately 500 TWh per year.[7]

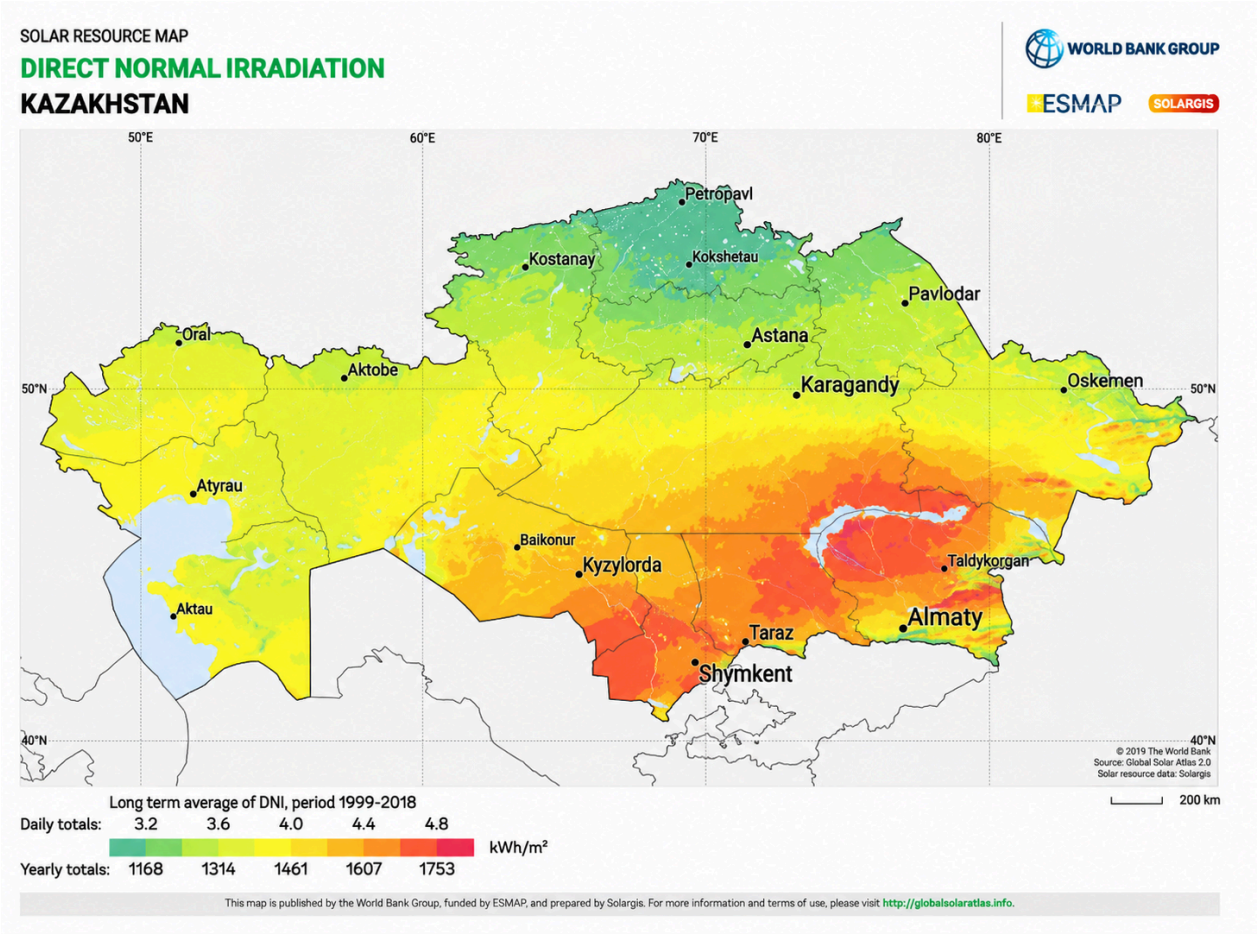


Fig. 2. Distribution map of Normal Irradiation in Kazakhstan

Map illustrates the distribution of solar energy potential across the country based on long-term data from 1999 to 2018. The map categorizes solar radiation levels using a color scale ranging from low (blue/green) to high (orange/red), indicating variations in available solar energy.

1.5 Wind energy in Kazakhstan

Bladed wind turbines (horizontal-axis) begin producing electricity at a wind speed of 3 m/s and shut down when wind speeds exceed 25 m/s. The maximum power output is reached at a wind speed of 15 m/s. The output power is proportional to the cube of the wind speed, meaning that if the wind speed doubles from 5 m/s to 10 m/s, the power output increases by a factor of eight. For areas with low wind speeds, vertical-axis wind turbines (also known as rotary or carousel turbines) are the most efficient design. Unlike horizontal-axis turbines, vertical-axis turbines can start generating electricity with wind speeds as low as 1 m/s. These turbines are increasingly popular because many consumers live inland, where wind speeds typically range between 3 and 12 m/s. In these conditions, vertical-axis turbines operate with greater efficiency. Vertical wind turbines also offer several additional advantages: they are nearly silent, require minimal maintenance, and have a service life exceeding 20 years. Recent developments in braking systems ensure stable operation even under strong gusts of wind, reaching speeds of up to 60 m/s. Kazakhstan and the Russia are jointly developing, manufacturing, and implementing complex energy systems (CESs) based on wind rotor turbines with capacities ranging

from 2 kW to 20 kW. These systems are equipped with solar inverters, batteries, smart chargers, and protective components to meet the energy demands of autonomous facilities, ensuring a reliable power supply for consumers.[7]

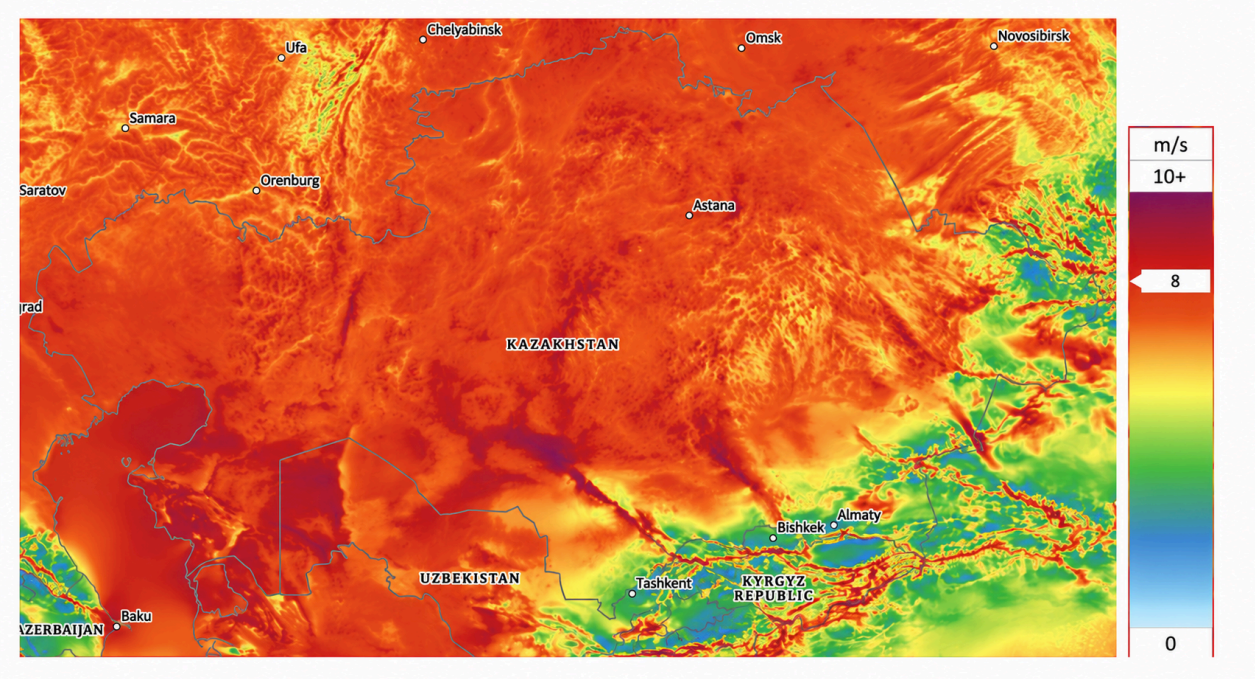


Fig. 3. Distribution map of wind energy resources in the territory of Kazakhstan (Global Wind Atlas)

The map illustrates wind speed distribution across the region, with color variations indicating different levels of wind energy potential. The red and orange areas represent regions with higher wind speeds, while the green and yellow areas indicate lower wind energy availability. Wind energy resources on the territory of Kazakhstan have a constant value ranging from 6 to 10 m/s.

2 Methods

2.1 Data analysis

Based on energy reliance and the diversity of solar irradiance in different parts of Kazakhstan, this study divides the country into three zones (Figure). Zone 1 has a large amount of oil and natural gas resources, while Zone 2 has vast coal-producing plants. Zone 3, with its high solar irradiance and wind potential, is the most dominant in the renewable energy field. This study specifically focuses on Region 7 in Zone 2.

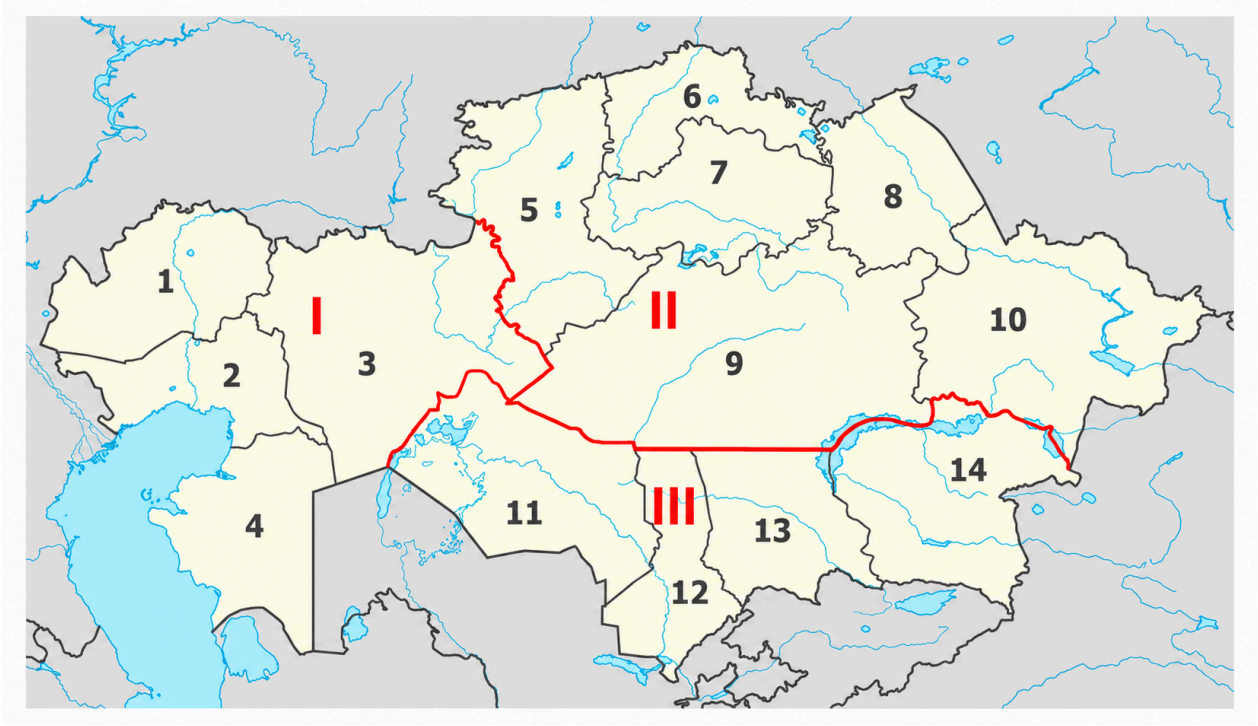


Fig. 4. Power generation zones in Kazakhstan. Source: authors' development. Note: I (Western Zone): 1—West Kazakhstan Region; 2—Atyrau Region; 3—Aktobe Region; 4—Mangystau Region; II (Northern Zone): 5—Kostanay Region; 6—North Kazakhstan Region; 7—Akmola Region; 8—Pavlodar Region; 9—Karagandy Region; 10—East Kazakhstan Region; III (Southern Zone): 11—Kyzylorda Region; 12—South Kazakhstan Region; 13—Zhambyl Region; 14—Almaty Region.[8]

The aim of this study is to assess the potential of renewable energy in remote areas of Akmola region. If properly assessed and utilized, the wind and solar energy potential in remote areas of Northern Kazakhstan can provide a sustainable and cost-effective alternative to traditional energy sources, reducing reliance on fossil fuels and improving energy accessibility for rural communities. To tackle above mentioned hypotheses, the potential of solar and wind energy has been calculated. Wind speed (V) is a basic parameter to decide on the location of a wind farm, however, the simulation of the wind speed in the long run is difficult due to the fluctuating direction, energy, and density of wind flow. [9]The annual average wind speed data of various locations obtained from Global Wind Atlas[10].

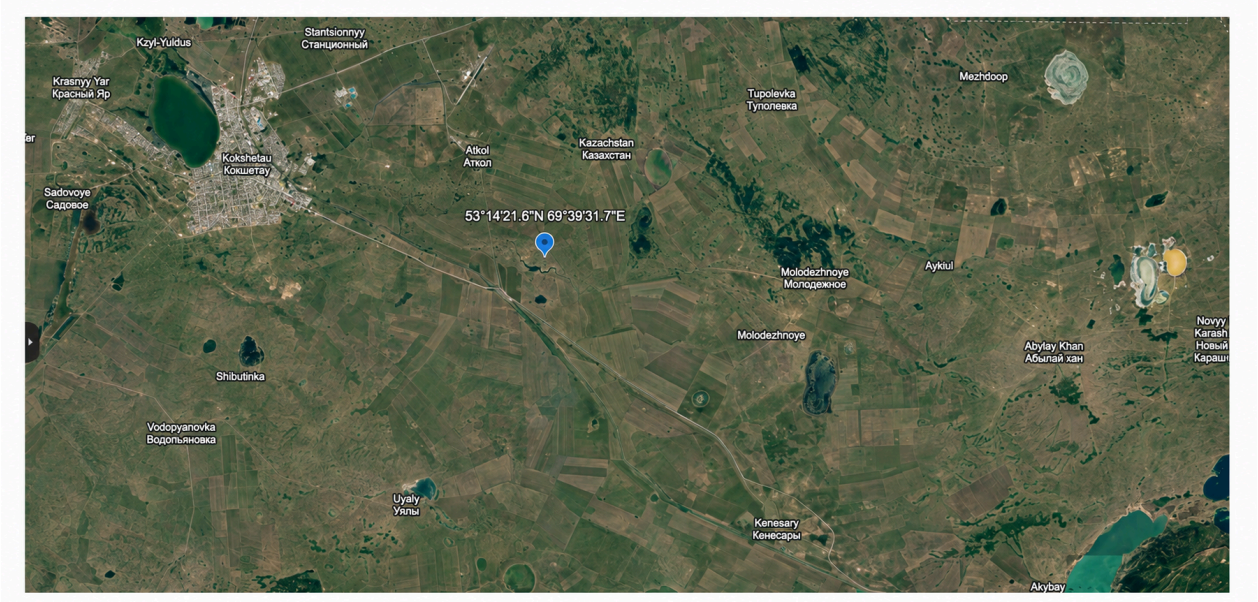


Fig. 5. Coordination Point on Map

The coordinates 53° 14 '21"N 69° 39' 31"E point to Kokshetau, North Kazakhstan, a region with significant potential for renewable energy projects due to its climate and geography. Given research on renewable energy potential assessment for remote areas and solar energy production in Burabay, these coordinates could be analyzed for their wind and solar energy capabilities.

2.2 Calculation Methods

Wind panel

To accurately estimate wind turbine power, Omni Calculator's Wind Turbine Calculator [11] has been used for research purposes, the calculator was created by Bogna Szyk who has a Master's of Civil engineering and they were confirmed with the PhD professor Dominik Czernia. To calculate wind turbine power, you need to estimate two values: the available wind power and the efficiency of the wind turbine. Multiplying these two values produces an estimate of the output power of the wind turbine. Below you can find the whole procedure:

Sweep area of turbine

Before finding the wind power, you need to determine the swept area of the turbine according to the following equations: Since wind turbines capture wind energy based on the area their blades sweep, this formula is essential for calculating the total wind power available to the turbine. The larger the blade length (L), the greater the energy potential.

$$A = \pi \times L^2$$

Formula of Sweep Area, where:
- L: Blade length — the radius of the horizontal-axis turbine;
- π: Pi number
- A: Swept area — the area of the horizontal-axis turbine;

Calculate the available wind power.

$$P_{wind} = 0.5 \times \rho \times v^3 \times A$$

Formula of Wind Power Availability, where:
- P_{wind}: Total power in the wind (Watts)
- ρ: Air density (typically 1.225 kg/m^3 at sea level under

standard conditions)
- A: Swept area of the turbine blades (m^2)
- v: Wind speed in meters per second (m/s)

Finding the efficiency of the turbine:

$$\mu = (1 - k_m) \times (1 - k_e) \times (1 - k_{e,t}) \times (1 - k_t) \times (1 - k_w) \times C_p$$

Formula of Turbine Efficiency, where:
- C_p: Turbine efficiency (it must be lower than the Betz limit (59.3%), and is typically between 30-40%);
- k_w: Wake losses caused by neighboring turbines and terrain topography, typically 3% to 10%;
- k_m: Mechanical losses of the blades and gearbox, typically 0% to 0.3%;
- k_e: Electrical losses of the turbine, typically 1% to 1.5%;
- $k_{e,t}$: Electrical losses during transmission to the grid, typically 3% to 10%;
- k_t: Fraction of time the turbine is unavailable because of failure or maintenance, typically 2% to 3%;
- μ: Actual turbine efficiency.

Calculating the output power:

$$P_{output} = \mu \times P_{wind}$$

Formula of Power Output, where:
- P_{output}: Total output power in watts (W);
- μ: Actual turbine efficiency;
- P_{wind}: Total available wind power in watts (W).

Calculate daily power:

$$P_{daily} = P \times H \times \eta$$

Formula of Daily Power, where:
- P_{daily}: Daily energy output in kilowatt hours (kWh);
- P: Solar panel wattage;
- H: Peak sunlight hours;
- η: Panel efficiency.

Estimate annual energy production:

$$P_{annual} = P_{daily} \times 365$$

Formula of Annual Energy Production, where:
- P_{annual}: Annual energy production in kilowatt hours (kWh);
- P_{daily}: Average daily energy output in kilowatt hours (kWh);
- 365: Number of days in a year.

Consider system loss and efficiency degradation:

$$P = P_{annual} \times S_{loss} \times D_{annual}$$

Formula of Power Output, where:
- P: Output after accounting for system losses and efficiency degradation;
- P_{annual}: Annual output before these adjustments;
- S_{loss}: System loss factor;
- D_{annual}: Efficiency degradation factor.

3 Results

Wind Turbines

Remote areas often lack financial resources, making the construction of large, expensive wind turbines seem impractical. The cost of such turbines varies from $100,000 to 5$ million, according to different sources. For research purposes, sample wind turbines have been selected for their convenience and affordability. The sample wind turbines include Windmax HY400 500W, Eco-Worthy 400W, Primus Wind Power Air 40, Automaxx Windmill DB-400, and Pikasola 400W. These are all small wind turbines commonly used for residential, off-grid, and small-scale renewable energy applications. Calculation results are represented in Table 1:

Table 1. Numerical data used to calculate the total power of each wind turbine.

Wind Turbines	Blade Length	Wind Speed	Efficiency	Total Power	Price
Windmax HY400 500W	1.7 m	8 m/s	~35%	~2182 kWh/year	~$550
Eco-Worthy 400W	1.5 m	8 m/s	~30%	~1456 kWh/year	~$280
Primus Wind Power Air 40	1.3 m	8 m/s	~27%	~985 kWh/year	~$1.100
Automaxx Windmill DB-400	1.4 m	8 m/s	~30%	~1269 kWh/year	~$450
Pikasola 400W	1.4 m	8 m/s	~30%	~1269 kWh/year	~$300

For research purposes, five wind turbines have been analyzed. The Windmax HY400 500W has a blade length of 1.7 m, an efficiency of approximately 35%, and a price of around $550, generating about 2,182 kWh per year. The Eco-Worthy 400W has a blade length of 1.5 m, an efficiency of approximately 30%, and a price of around 280, producing about 1,456 kWh per year. The Primus Wind Power Air 40 features a 1.3 m blade length, an efficiency of about 27%, and a price of around $1,100, yielding approximately 985 kWh annually. The Automaxx Windmill DB-400 has a 1.4 m blade length, an efficiency of approximately 30%, and costs approximately 450, generating about 1,269 kWh per year. Similarly, the Pikasola 400W also has a blade length of 1.4 m, an efficiency of approximately 30%, and a price of around $300, producing around 1,269 kWh per year. For all wind turbines, the most ideal tower height is 10–12 m, and the average wind speed used for calculations is 8 m/s.

Solar panel

Remote areas often lack financial resources, making the installation of large, expensive solar panels impractical. The cost of high-capacity solar panel systems varies from $1,000 to 10,000$, depending on the energy needs and system size. For research purposes, budget-friendly and efficient solar panels have been selected as samples.

Table 2. Solar panels comparison

Solar Panels	Wattage	Type	Efficiency	Power Output	Price
Renogy 200W Flexible Solar Panel RV Kit	200W	Monocrystalline	~21%	~292 kWh/year	~$519.99
Renogy 12V 250W Bifacial Solar Panel	250W	Bifacial Monocrystalline	~22%	~365 kWh/year	~$269.99
Rockpals 500W Power Station with Solar Panel	500W	Portable Solar Kit	~20%	~730 kWh/year	~$500
Hyundai 410W Solar Panel	410W	Monocrystalline	~21.3%	~598 kWh/year	~$280
Solarland SLP200S-12U Monocrystalline Panel	200W	Monocrystalline	~20%	~292 kWh/year	~$300

The chosen solar panels include the Renogy 200 Watt Flexible Solar Panel RV Kit, Renogy 12V 250W Bifacial Solar Panel, Rockpals 500W Power Station with Solar Panel, Hyundai 410W Solar Panel, and Solarland SLP200S-12U Monocrystalline 200W Solar Panel. These panels are commonly used for residential, off-grid, and small-scale renewable energy applications. Calculation results, represented in Graph 1, show the numerical data used to determine the total energy output and cost-effectiveness of each solar panel. The Renogy 200W Flexible Solar Panel RV Kit, priced at approximately $519.99, is designed for off-grid applications, offering flexibility and durability. The Renogy 12V 250W Bifacial Solar Panel, priced at 269.99$, features bifacial technology to enhance efficiency by capturing sunlight on both sides. The Rockpals 500W Power Station with Solar Panel, which integrates a solar power system and a battery pack, costs around $500 and is ideal for portable power needs. The Hyundai 410W Solar Panel, part of a bulk purchase set, cost 280$ per panel and is designed for high output. Lastly, the Solarland SLP200S-12U Monocrystalline 200W Solar Panel provides a balance between affordability and efficiency. For optimal performance, all solar panels require proper positioning and exposure to direct sunlight, ensuring maximum energy generation.

4 Discussion

5 Conclusion

Among the countries of Central Asia, Kazakhstan was the first to begin its transition to carbon-free energy. Since the early 2000s, there have been several initiatives (e.g., the Wind Power Market Development Initiative), programs (e.g., the Kazakhstan Climate Change Mitigation Program), and numerous studies that aimed to reduce the country's GHG emissions by developing the production and distribution of wind power[13]. Kazakhstan is the largest landlocked country in the world with plentiful natural resources and is also one of the largest oil and gas exporters in the world . Kazakhstan is facing serious environmental problems due to CO2 emissions from fossil fuel energy consumption [2]. The research aimed to properly assess and utilize the wind and solar energy potential in remote areas of Northern Kazakhstan show if it can provide a sustainable and cost-effective alternative to traditional energy sources, reducing reliance on fossil fuels and improving energy accessibility for rural communities. The study focused on the budget-friendly,small-scale energy project to determine their potential. The analysis included five wind panels and five solar panels, calculating their efficiency, power output, and cost-effectiveness.The results show that using single energy source is not efficient, however , combining wind and solar energy can prove reliable source of energy The findings indicated that wind turbines with longer blade lengths have a higher power output and better efficiency. Nevertheless, the price differed greatly, with some models costing more than others even if they produced the same quantity of energy. Similar price and efficiency differentiation can be seen with solar panels, while some less expensive types produced results that were on par with those of more expensive models.These findings were in line with predictions and provided credence to the idea that a hybrid

strategy that combines solar and wind energy can increase energy sustainability and accessibility in rural areas. Research has its own limitations. It has a small sample size of ten energy products, which may not fully show their full potential. Moreover, the research has evaluated standard environmental conditions without assuming factors like seasonal variations, maintenance needs, and unexpected weather patterns that could affect efficiency. The financial side was simplified without calculating the cost of installation and maintenance costs. Future research should expand databases by conducting more projects. Also, it should consider factors such as maintenance costs and conduct a long-term evaluation process. Expanding the research field should also include discussions on batteries and solutions for storing energy.

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