The present work was submitted to the Faculty of Raw Materials and Environmental Engineering

Assessment of wind energy resources of Mongolia

Bachelor Thesis

by
Naranzul Bayasgalan

Supervisor 1 /	**Prof. Dr. Gantuya Ganbat**
Supervisor 2 /	**MSc. Odontungalag Dorjsuren**

Ulaanbatar/Nalaikh,

Statutory Declaration

Bayasgalan, Naranzul
Last Name, First Name

15348178697716
Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

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Ulaanbaatar, Mongolia
05/16/2022
Place, Date

Б Наранзул
Signature

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Acknowledgement

I would like to express my profound gratitude and appreciation to the many people who have supported me during my research project. First and foremost, I would like to extend my sincerest thanks to my first supervisor, Prof. Gantuya, and my second supervisor, Mrs. Odontungalag, for their unwavering support, invaluable guidance, and insightful feedback. Their expertise, patience, and encouragement have been instrumental in shaping my research project and helping me achieve my academic goals.

Furthermore, I would like to express my heartfelt appreciation to my colleagues, family and friends, whose unwavering support, understanding, and encouragement have sustained me during this academic journey. Their belief in my abilities and their constant encouragement have been a source of strength and motivation during challenging times.

Abstract

This study assessed the wind energy potential in Mongolia by analyzing wind speed data collected from 69 stations across the country. The data was categorized by region and analyzed using the Weibull distribution to determine the monthly mean wind speed and wind power density. Additionally, the study evaluated the potential reductions in the usage of CO2, water, and coal that could be achieved through the selection of wind turbines. To visualize the results, maps of wind power density and mean wind speed were created using a GIS program. Overall, this study provides valuable insights into the potential of wind energy as a sustainable and environmentally-friendly energy source in Mongolia. Wind speed data were collected from 69 Wind Measurement Towers (WMTs) over the course of one year. The WMTs recorded wind speed measurements every three hours throughout the day at a height of 10 meters. The Gobi areas and east Mongolia have potential wind speed to build wind farms compared to Khangai and West Mongolia.

1. Introduction

1.1 Background

The primary objective of sustainable development is to secure a future where upcoming generations can enjoy a quality of life that is equal to or better than the current standards. Sustainable development encompasses a wide range of areas, including the integration of renewable energy sources, ensuring energy security, establishing effective pricing and policy mechanisms, and adopting smart grid technologies. Central to the concept of sustainable development is the utilization of renewable energy derived from naturally replenishing resources that are available within a human timescale. Examples of such resources include solar power, wind energy, hydropower, and geothermal heat, among others [1]. The utilization of renewable energy offers numerous benefits and substituting it for fossil fuels can significantly contribute to environmental preservation. By 2030, affordable electricity generated from renewable sources has the potential to meet around 65 percent of the global electricity demand. This transition can lead to the decarbonization of approximately 90 percent of the power sector by 2050, resulting in a substantial reduction in carbon emissions and serving as a crucial measure to combat climate change [2]. Renewable energy sources generated 38% of the Global Electricity in 2021. Nowadays, most countries are trying to increase the usage of renewable energy. For example, 98.4% of Norway's energy comes from renewable sources [3].

Wind energy is regarded as the most environmentally friendly and sustainable form of renewable energy compared to other sources. In recent times, Mongolia has been increasingly tapping into this natural resource and placing a significant emphasis on its utilization. The wind resource distribution in the country is primarily influenced by the interaction between the westerly jet stream, a fast-moving air current at high altitudes, and prominent topographic features like mountain ranges in western and central Mongolia. Currently, almost all districts and settlements in Mongolia, totaling 329 districts and approximately 326 settlements, are connected to the power grid, resulting in a remarkable 98% electricity access rate. Additionally, five districts are supplied with electricity generated from renewable sources. According to the Energy Sector Development Policy 2015-2030, Mongolia's total installed capacity as of June 2015 is estimated to be 1082 MW. However, a significant portion of Mongolia's electricity generation capacity relies on coal-fired thermal power plants, accounting for 85% of the overall capacity [5]. Wind and solar energy are considered more cost-effective than fossil fuels, and their affordability continues to improve with each passing year. By increasing the utilization of wind and solar energy, Mongolia can reduce its reliance on coal for power generation, leading to substantial positive environmental impacts. Therefore, it is crucial for Mongolia to prioritize the development of renewable energy sources.

1.2 Objective of the study

The aim of this study is to conduct basic research in order to achieve specific objectives that are in line with the current knowledge and practical needs of the field.

1. Study the information of natural resources of Mongolia and other countries and review literatures on renewable energy of Mongolia, specifically on wind resources and wind energy
    - Review of literature on other papers related to assessment of wind energy
    - Types of renewable energy resources, its advantages
    - Overview of renewable energy resources of Mongolia

2. Investigate the wind turbines and explain types of its
    - Do wind turbine selection
    - Study wind turbine types, classification and process
3. Collect data, conduct calculation based on methodology and analysis
    - Find Weibull parameters (k and c) using one year data of wind speed
    - Calculate amount of CO_2 , coal and water that can be prevented
    - Find and differentiate mean wind speed data at 10m and 80m height in different locations
4. Create spatial maps using the GIS program for wind energy potentials of several locations of Mongolia.
    - Find seasonal mean wind speed and create maps at 10m height

2. State of the art

2.1 Sustainable development

In recent decades, the progress of humanity has led to not only conflicts and socio-economic instability but also a growing concern over climate change and natural disasters. Human actions have endangered the peaceful existence of future generations and posed a threat to the survival of the planet, resulting in significant damage and negative impacts on the environment. The idea of sustainable development is built upon the principles of development, needs, and the well-being of future generations. At its core, sustainable development emphasizes the importance of maintaining a balance among three key pillars of sustainability: [6]

1. *Environmental sustainability*: is defined as the responsibility to conserve natural resources and to maintain and not jeopardize the needs of future generations. According to the United Nations (UN) World Commission on Environment and Development, environmental sustainability is about acting in a way that ensures future generations have the natural resources available to live an equal, if not better, way of life as current generations [7]. Environmental sustainability encompasses various practices such as eliminating the use of plastic bags to maintain the cleanliness of oceans and soil, recycling waste materials like paper, plastic, and glass, planting trees to prevent desertification, and reducing water consumption in daily activities. Giving due importance to environmental sustainability is crucial as its neglect can have detrimental effects on the health and well-being of future generations.

2. *Economic sustainability:* Conserving natural and financial resources in order to establish long-term financial stability is known as economic sustainability. A system that is sustainable can last for a very long time and have negative impacts. In finance, this can entail limiting global resource use to preserve their availability for use by future generations in building wealth and financial stability [8]. Examples of economic sustainability include the promotion of alternative energy sources, sustainable agriculture, and initiatives focused on recycling and pollution reduction. By reducing reliance on fossil fuels and encouraging the adoption of renewable energy sources, carbon emissions and associated pollution can be reduced. This, in turn, can lead to various economic benefits such as lower consumer taxes, decreased environmental impact costs, and improved energy equity for low-income individuals. These factors collectively contribute to increased economic output.

3. *Social Sustainability:* refers to the act of guaranteeing equal availability of essential resources such as clean water, food, and air. It also involves establishing fair employment systems that prevent worker exploitation for financial benefits. Since social, economic, and environmental sustainability are interconnected, when companies achieve social sustainability, they often accomplish it in economic and environmental aspects as well. Health and safety, wellness, equity, diversity, human rights, and empowerment are among the various aspects encompassed by social sustainability.

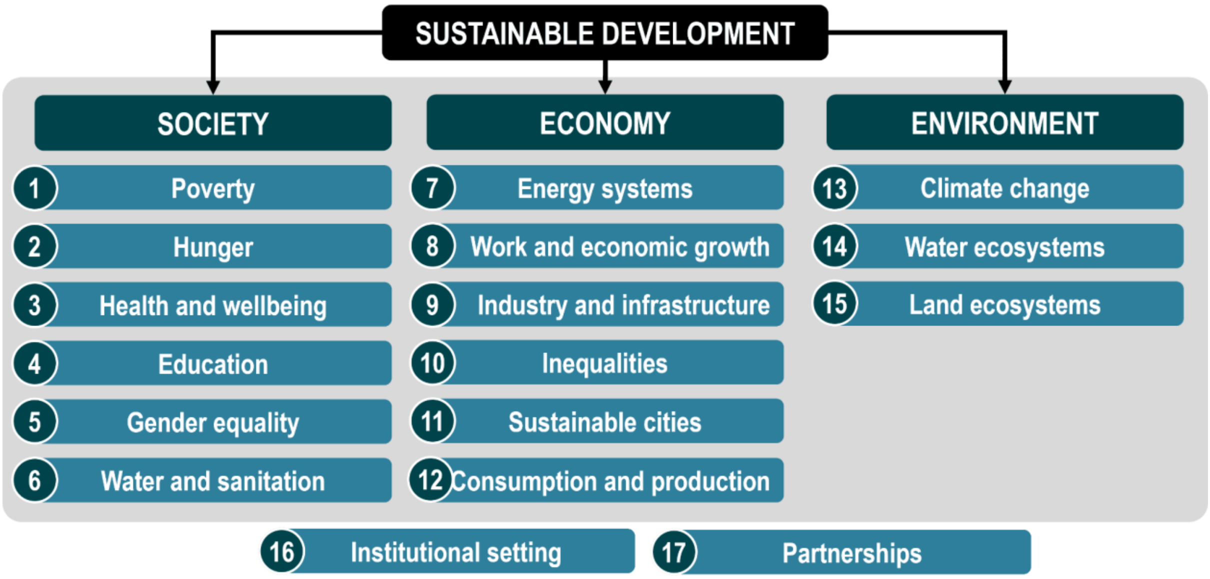

Figure 1: Sustainable Development Diagram

2.2 Renewable energy and types

Although harnessing natural resources and processes for transportation, lighting, heating, and other uses has been practiced for a long time, renewable energy, also known as clean energy, is often perceived as a relatively recent technological advancement [9].

The advantages of renewable energy are numerous and affect the economy, environment, national security, and human health:

- Reducing carbon dioxide emissions and air pollution from energy production
- Increasing world energy dependence
- Creating job of renewable energy industries
- Enhancing reliability and resilience of main power grid
- Stable cost [10]

These sorts of clean, useful energy can be produced from renewable natural resources such biomass, geothermal energy, sunlight, water, and wind.

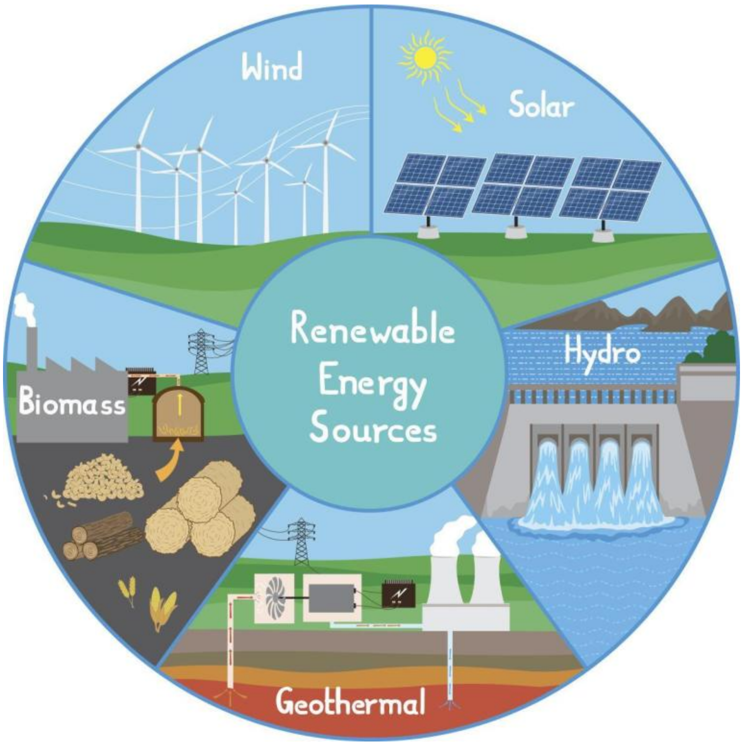

Figure 2: Types of Renewable Energy Sources

2.2.1 Bioenergy

It is a type of renewable energy produced from recently living organic elements called biomass, which can be used to create products, heat, power, and transportation fuels. A flexible renewable energy source is biomass. It may be transformed into liquid transportation fuels, such as diesel, jet fuel, and gasoline, that are comparable to fossil fuels. Bioenergy technologies make it possible to recycle carbon from waste streams and biomass to create sustainable energy, bioproducts, and fuels with fewer emissions for automobiles, trucks, airplanes, and ships [11].

2.2.2 Geothermal energy

It harnesses the thermal energy that is available from the Earth's interior. Geothermal reservoirs can be heated using wells or other methods. Hydrothermal reservoirs are those that are naturally sufficiently hot and permeable, whereas enhanced geothermal systems are those that are naturally adequately hot but improved by hydraulic stimulation (EGS). After reaching the surface, fluids of different temperatures can be used to produce electricity or used more directly for tasks requiring thermal energy, such as district heating or the utilization of lower-temperature heat from shallow wells for geothermal heat pumps used for heating or cooling. Geothermal power facilities often give steady output when producing electricity [12].

There are two main types of geothermal energy:

1. Direct use geothermal energy: This involves using the heat directly for heating buildings, greenhouses, and industrial processes, without the need for electricity generation.
2. Geothermal power generation: This involves using the heat to generate electricity by using geothermal power plants. Geothermal power plants use steam or hot water from underground to drive turbines and generate electricity.

Geothermal energy possesses several distinct advantages as a renewable energy source. Its reliability sets it apart from solar and wind power, as it remains unaffected by weather conditions and offers a consistent and dependable energy supply. Furthermore, geothermal energy boasts an exceptional environmental profile, emitting minimal greenhouse gases and eliminating the need for fuel combustion. In terms of cost-effectiveness, geothermal power plants exhibit low operational expenses once constructed, making them a financially viable long-term energy solution. Nevertheless, geothermal energy faces specific challenges, including its limited availability in regions with suitable geological conditions, the significant upfront investment required for constructing power plants, and potential environmental concerns such as greenhouse gas emissions and land subsidence. Recognizing and addressing these aspects is crucial for maximizing the potential benefits of geothermal energy while mitigating its limitations.

2.2.3 Hydropower

It's time to rediscover and restore hydropower, a traditional source of clean energy. It can be produced by either huge stations or tiny plants, and it can help drain swampy land and irrigate crops. Even for domestic use, it has enormous potential. Since the water cycle will continue to function, hydroelectric energy is renewable in this sense. It also contributes significantly to the fight against climate change by assisting in the avoidance of fossil fuel consumption and lowering CO_2 emissions as well as the creation of greenhouse gasses and particulate matter, hence reducing pollution and the greenhouse effect. One of the advantages of hydropower is its cheapest energy source [13].

There are several types of hydropower:

1. Conventional hydropower: This is the most common form of hydropower and involves the construction of a dam to create a reservoir, which then drives turbines to generate electricity.

2. Pumped-storage hydropower: This involves using excess energy to pump water uphill to a reservoir, where it can be stored and then released to generate electricity during periods of high demand.
3. Run-of-river hydropower: This involves diverting a portion of a river's flow through a turbine to generate electricity without the need for a dam or reservoir [14].

2.2.4 Solar energy

Solar energy is that produced by the Sun’s light – photovoltaic energy – and its warmth – solar thermal – for the generation of electricity or the production of heat. Inexhaustible and renewable, since it comes from the Sun, solar energy is harnessed using panels and mirrors. Photovoltaic solar cells convert sunlight directly into electricity by the so-called photovoltaic effect, by which certain materials are able to absorb photons (light particles) and liberate electrons, generating an electric current. On the other hand, solar thermal collectors use panels or mirrors to absorb and concentrate the Sun’s heat, transferring it to a fluid and conducting it through pipes to use it in buildings and installations, and also for electricity production (solar thermoelectric) [15].

2.2.5 Wind energy

By turning the kinetic energy of moving air into the electrical, wind is used to generate power. Wind drives the rotor blades of contemporary wind turbines, which transform kinetic energy into rotational energy. A shaft transmits this rotational energy to the generator, which generates electrical energy [16]. One of the world's fastest-growing energy sources is wind energy because it has several benefits. Researchers are attempting to resolve technical and socio-economic issues in support of a future with decarbonized power in order to further enhance the potential of wind energy and the benefits it provides to communities [17].

Wind energy offers numerous unique advantages as a renewable energy source. Firstly, it is renowned for its clean and sustainable nature, devoid of greenhouse gas emissions or air pollution, thereby mitigating environmental impact. Moreover, the cost-effectiveness of wind energy has witnessed remarkable improvements in recent times, rendering it an economically viable option for various residential and commercial applications. The abundant and widespread availability of wind resources further distinguishes this form of energy, presenting ample opportunities for harnessing its potential in numerous regions across the globe. Additionally, the scalability of wind energy is a remarkable characteristic, enabling its flexible adaptation to meet the energy demands of both small-scale communities and large-scale developments. This adaptability contributes to its versatility and applicability in diverse settings, solidifying its position as a vital contributor to the global renewable energy landscape.

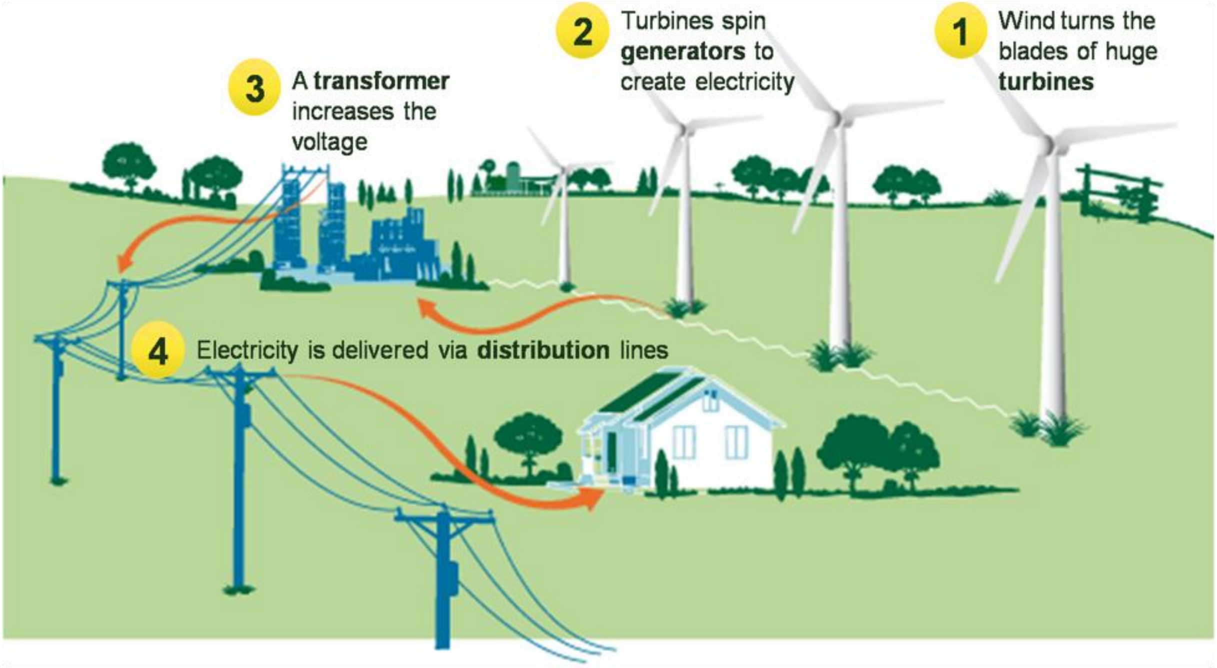

Figure 3: Process of wind energy conversion

2.3 Renewable energy sources in Mongolia

Mongolia possesses considerable prospects for renewable energy, encompassing wind, solar, and hydropower. Particularly, the expansive Gobi Desert holds a substantial renewable energy capacity of 2.6TW. Currently, renewable sources contribute merely 7% to Mongolia's power generation capacity. However, the government has established targets to elevate this figure to 20% by 2023 and 30% by 2030, illustrating a resolute dedication to fostering a sustainable energy framework.

2.3.1 Wind Power

Mongolia possesses the potential to emerge as a prominent producer of wind power, with the vast expanse of the Gobi Desert in southern Mongolia serving as an optimal location for wind energy generation. With average wind speeds ranging between 7 and 9 meters per second, the Gobi Desert offers ideal conditions for harnessing this renewable resource.

Approximately 10% of Mongolia's land area exhibits high suitability for large-scale renewable energy projects, boasting a power density varying from 40 to 600 watts per square meter. If fully tapped into, this abundant resource has the capability to generate over 1100 gigawatts of installed capacity, presenting significant opportunities for sustainable energy production.

Areas classified as possessing excellent wind power resources are estimated to harbor a wind power potential of approximately 1,113,300 megawatts of electricity. These remarkable figures underscore the immense prospects for wind power development in Mongolia and highlight the nation's potential to become a prominent player in the global wind energy landscape [18].

2.3.2 Solar energy

Mongolia experiences a significant number of sunny days, ranging from approximately 270 to 300 days per year, with an average duration of sunlight spanning between 2,250 to 3,300 hours. The annual solar energy availability averages at 1,400 kilowatt-hours per square meter, while the solar intensity fluctuates between 4.3 to 4.7 kilowatt-hours per square meter per day [18].

2.3.3 Hydropower

Mongolia boasts an extensive network of 3,800 streams and rivers, unlocking a significant potential for hydropower generation. These water bodies hold the capability to produce an impressive 6,417.7 megawatts of power, translating to an annual electricity production of 56.2 billion kilowatt-hours. The theoretical capacity for hydropower is estimated at 6.2 gigawatts, with more than 1 gigawatt already identified for development. This abundance of untapped hydropower resources highlights Mongolia's potential to leverage this renewable energy source for sustainable electricity generation [18]. Despite the challenging climate and limited water resources in Mongolia, the progress of hydropower projects has been constrained. However, the Mongolian government has demonstrated proactive measures in advancing renewable energy development. These efforts encompass the implementation of incentives to encourage renewable energy initiatives and the establishment of a dedicated Renewable Energy Fund aimed at fostering the growth of renewable energy sources. Furthermore, strategic partnerships with international organizations have been forged to provide support and collaborate on renewable energy projects within Mongolia. These collaborative endeavors reflect a steadfast commitment to promoting sustainable energy practices and driving the transition towards a greener and more resilient energy sector in the country.

Figure 4: One type of wind turbines

2.4 Wind Turbine

The utilization of wind energy to harness mechanical power has a rich history spanning thousands of years. Dating back to as early as 5000 B.C., the ancient Egyptians employed wind energy to propel boats along the Nile River. Similarly, American colonists relied on windmills as vital tools for grinding grain, pumping water, and powering sawmills for wood cutting. In the present era, modern wind turbines serve as the contemporary counterparts to these historical windmills, efficiently converting the kinetic energy present in wind into clean and renewable electricity. This evolution signifies the ongoing advancement in utilizing wind as a sustainable resource for generating power and highlights the remarkable journey from ancient civilizations harnessing wind's force to the sophisticated technology employed in today's wind turbines [19].

2.4.1 Types of wind turbines

Horizontal-axis turbines (HAWT)

Horizontal-axis wind turbines (HAWTs) are the conventional image associated with wind turbines, typically featuring three blades and operating in an "upwind" configuration, where the turbine pivots at the top of the tower to face into the wind. HAWTs dominate the wind energy industry and offer numerous advantages. Firstly, they exhibit superior efficiency in harnessing wind energy compared to other turbine types, such as vertical-axis wind turbines (VAWTs). Secondly, HAWTs provide scalability, accommodating the energy requirements of both small and large communities. Lastly, HAWTs are well-established and renowned for their proven reliability and durability.

Nevertheless, challenges accompany HAWTs. Noise generation, especially at high wind speeds, can pose concerns for nearby residents. The visual impact on the surrounding landscape, particularly in scenic areas, is another aspect to consider. Additionally, HAWTs are sensitive to changes in wind direction, which may limit their effectiveness in certain regions.

In summary, HAWTs operate with blades rotating in a horizontal plane, perpendicular to the wind direction. Their superior energy production efficiency compared to VAWTs, combined with adaptability to various wind speeds and locations, solidifies their prominence in the wind energy sector. However, careful consideration of challenges such as noise, visual impact, and wind direction sensitivity is necessary during project planning and implementation.

Vertical-axis wind turbines (VAWT)

Vertical-axis wind turbines (VAWTs) feature a vertical rotor shaft with blades rotating around it. These turbines possess the advantage of being able to harness wind from any direction and generally exhibit smaller size and quieter operation compared to HAWTs. However, VAWTs are less effective in energy production than HAWTs and have lower prevalence in the wind energy industry. Both HAWTs and VAWTs are available in a range of sizes, catering to diverse applications, from small-scale turbines capable of powering individual homes or buildings to large-scale turbines capable of supplying electricity to entire communities or cities [20].

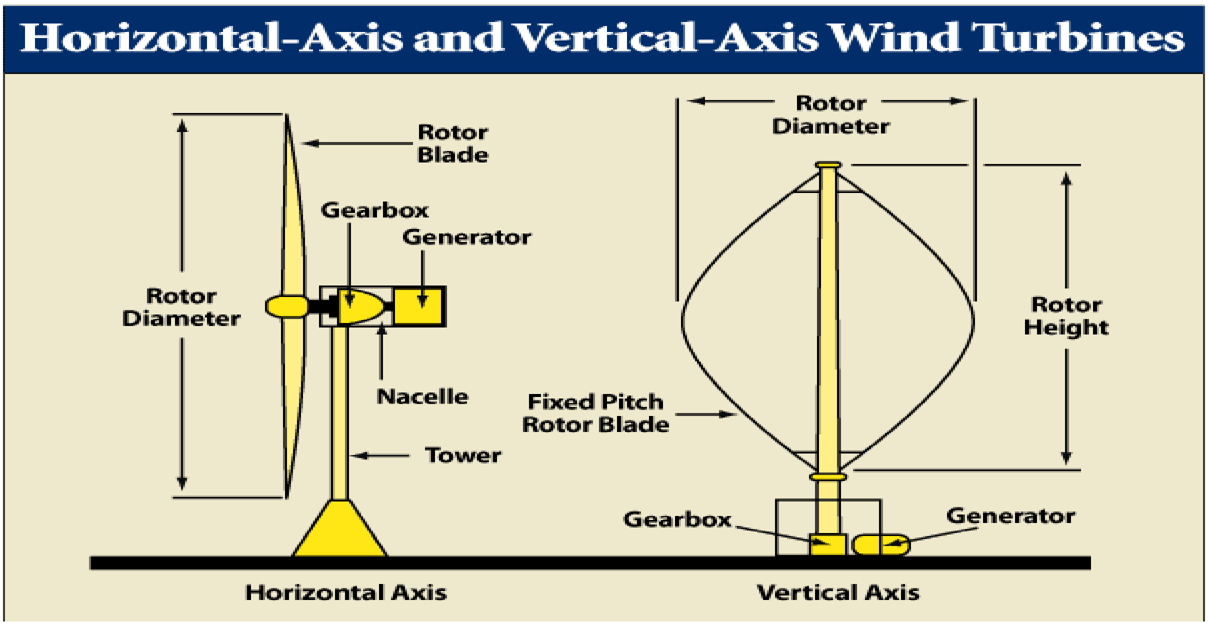

Figure 5: Difference between HAWT and VAWT   Source: American wind association

2.4.2 Classes of wind turbines

Wind turbine manufacturers design their turbines based on specific Wind Classes to ensure reliable operation and optimal energy capture. Wind Class 3 turbines are built for average wind speeds up to 7.5 m/s and feature larger rotors to maximize energy extraction from lower wind speeds. Wind Class 2 turbines, the most common type, are designed for windier sites up to 8.5 m/s. Wind Class 1 turbines are tailored for challenging conditions with average wind speeds above 8.5 m/s, utilizing smaller rotors and heavier-duty designs, albeit at a higher cost.

Turbulence intensity, a measure of wind turbulence at a site, is another factor influencing wind class. Complex topography can induce turbulence, leading to varying loads on turbines and accelerated wear. In extreme cases of excessive turbulence, turbine manufacturers may decline to supply turbines due to concerns about reliable long-term operation. While wind monitoring is typically crucial for Class 2 and Class 1 sites to determine wind speed and turbulence intensity accurately, Class 3 sites may not require it as manufacturers have confidence in acceptable turbine loads (although some site owners still prefer monitoring for income certainty) [21].

Wind turbines in 3 (A, B, C) categories according to the ability to withstand the erosion of the area distributed (regardless of the age of the equipment).

IEC category	I	II	III
Standard wind speed at height of the rotor (m/s)	50	42.5	37.5
Mean wind speed at height of the rotor	10	8.5	7.5
3 second extreme wind (in 50 years)	70	59.5	52.5
Class A wind intensity (above 15 m/s)	16%		
Class B wind intensity (above 15 m/s)	14%		
Class A wind intensity (above 15 m/s)	12%		

Table 1: IEC category of wind turbine classes

3. Assessment of wind energy

Assessing the potential of wind energy is crucial in deciding whether a wind energy project is feasible and worth investing in. This process involves analyzing factors that impact wind power generation such as wind speed, direction, and terrain. It's important to have accurate assessments to make sure wind energy projects are economically viable and produce maximum energy output.

Over the years, there has been significant research on wind energy potential assessment, resulting in various methodologies and tools to estimate the wind energy potential of a given region. These include models based on statistical analysis, numerical weather prediction models, and Geographic Information Systems (GIS)-based approaches.

Studies have shown that wind energy potential assessments can vary significantly depending on the methodology and data used. Therefore, it is essential to use reliable and accurate data and models to obtain a realistic estimate of the wind energy potential. Additionally, wind energy potential assessments should consider the potential impact of environmental factors such as topography, vegetation cover, and proximity to human settlements.

3.1 Assessment of wind energy in Iran

The article titled "Assessment of wind energy in Iran: A review" written by P. Alamdari, O. Nematollahi, and M. Mirhosseini gives a detailed examination of the current situation and possibilities of wind energy in Iran. The authors discuss the significant wind energy resources present in Iran that could help fulfill the country's energy demand, reduce reliance on fossil fuels, and lower greenhouse gas emissions. They also analyze previous studies on the assessment of wind energy potential in Iran and identify the critical factors that could affect the development of wind energy in the country, such as regulatory policies, technical and financial feasibility, as well as environmental and social concerns.

During the course of this research, data was gathered for a period of one year, specifically from January 1, 2007, to December 31, 2007, with measurements taken every 10 minutes. The data was collected using a data logger that had three velocity sensors at 10m, 30m, and 40m heights, as well as two direction sensors at 30m and 37.5m.

The authors focus on the use of GIS technology and statistical analysis methods to analyze wind speed data and create wind resource maps. The authors used data from 68 stations in coastal regions of India to calculate the average wind speed using the Weibull probability distribution. This technique allowed the authors to determine the k and c parameters for each station and create wind resource maps for the region. The authors also provided detailed information on the standard deviation of wind speeds at different heights and the average wind speed at different heights.

In conclusion, the paper by Kumar, Singh, and Pandey provides a comprehensive literature review of wind resource assessment techniques in coastal regions of India. The authors' use of GIS technology and statistical analysis methods to analyze wind speed data provides valuable insights into the potential for wind energy development in the region [22].

3.2 Wind energy and assessment of wind energy potential in Turkey

The study conducted by Cumali İlkiliç entitled "Assessment of Wind Energy Potential in Turkey" aims to evaluate the potential of wind energy in Turkey and provide insights into the country's energy policies. The paper reviews relevant literature on wind energy and its potential, as well as the current state of wind energy in Turkey.

The study analyzed the wind energy potential of different regions in Turkey by using hourly time series wind data from the Electrical Power Resources Survey and Development Administration (EIEI) in 2010. The paper also discussed the exploitation of wind energy in Turkey, with a review of wind energy applications. Overall, the study provides an assessment of wind energy in Turkey as of May 2010.

The purpose of this study was to demonstrate that wind power is a crucial source of energy for Turkey due to its significant wind energy resources that can help meet the country's energy demand. The Aegean, Marmara, Southeast Anatolia, and East-Mediterranean regions of Turkey are considered to have more promising wind power potential than other regions, particularly the coastal areas of Gökçeada Island and Bandirma. As of 2008, Turkey had 433.35 MW of available wind energy capacity, which increased to 1503.35 MW by the end of 2010 [23].

3.3 Wind energy potential assessment for the site of Inner Mongolia in China

This study conducted in Iran aimed to determine the wind energy potential of Zabol district as an alternative to fossil fuel energy, after hydropower. Wind speed values collected over a ten-year period (2002-2011) from the district's meteorological station were analyzed to calculate the wind energy potential.

The aim of this paper was to evaluate the wind energy potential of Zabol district in Iran using Weibull and Rayleigh distributions, and to create graphs based on mean wind speed for each year and annual capacity factor versus wind turbine models at heights of 40m and 50m, with the goal of selecting the best wind turbine from various models, conducting economic evaluation, and calculating the energy cost index.

The results showed that the average wind speed in the region is approximately 6.5 m/s with the highest wind speeds occurring in warm seasons and the lowest in cold seasons. The fastest winds were recorded between 3 a.m. and 9 a.m. Using Weibull and Rayleigh distributions, the assessment of wind energy potentiality was carried out. The yearly total power density and wind energy density were calculated to be 424 W/m² and 3720 kW.h/m² respectively, indicating that Zabol city is a suitable area for wind turbine establishment in class 6. The wind rose diagram revealed that the dominant wind direction with the highest contribution in the region blows between 112.5 to 135 degrees. Finally, the performance of various turbine models was evaluated based on the Zabol wind speed data [24].

3.4 Calculation of solar and wind energy resources with spatial accuracy using regional atmospheric dynamic models and evolution of its environmental effects

The objective of this research was to determine the statistical features of wind speed in Bulgan soum by analyzing wind data from 2006 to 2015, collected eight times daily. The study also aimed to compare the power generation capabilities of a 1.5MW wind turbine in Bulgan soum with those in the nearby stations of Dalanzadgad and Tsogt-Ovoo. The findings revealed that Bulgan soum has higher wind speeds during winter, resulting in a more stable and significant power capacity compared to the other two stations. Additionally, the Weather Research and Forecasting (WRFv.3.6) Model was used to simulate wind speed, direction, and solar radiation at four-dimensional dimensions. The study also included a unique spatially continuous assessment of wind speed at 10m, in addition to the traditional pointwise validation of modeled data.

This research conducted a comparative analysis of monthly mean wind speed among three locations and generated maps depicting wind energy at 80m height for a single turbine (with a horizontal resolution of 9km). The results indicate that Bulgan soum exhibits significant potential for constructing wind turbines, as evidenced by the statistical analysis of wind speed data.

Furthermore, this study conducted a comparative analysis of wind speed at 10m and 80m heights. The results indicate that the mean wind speed at 80m height was utilized in all calculations presented in this paper [25].

4. Materials and Method

4.1 Methodology

Wind speed depending on height

Wind velocity can change with height due to various factors such as the surface roughness, topography, and atmospheric stability. The power law describes the relationship between wind speed and height, indicating that wind speed increases as height above the ground increases. The power law formula is used to calculate the wind speed at a given height based on the wind speed and height at another point, as well as the power law exponent that is dependent on the surface roughness and atmospheric stability.

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^{\alpha} \quad \text{(Equation 1)}$$

- V is the wind speed at height h (in meters per second)
- V_0 is the wind speed at height h_0 (in meters per second)
- h is the height at which V is measured (in meters)
- h_0 is the height at which V_0 is measured (in meters)
- α is the power law exponent, which depends on the surface roughness and atmospheric stability

Weibull distribution

The Weibull distribution is commonly used to model wind speed data. Using the average wind speed (V) and the mean square deviation (σ), the Weibull distribution parameters c and k can be calculated using the following formulas:

$$k = \left(\frac{\sigma}{\underline{v}}\right)^{-1.086} \qquad (1 \le k \le 10) \quad \text{(Equation 2)}$$

$$c = \frac{\underline{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad \text{(Equation 3)}$$

Mean square deviation of wind speed:

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n} \quad (v_i - \underline{v})^2 \text{ (Equation 4)}$$

The probability density function of the Weibull distribution is written in the form below.

$$F(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} \quad \text{(Equation 5)}$$

- k-distribution shape parameter
- c-proportion parameter (approximate value of wind speed)
- v-probability of wind speed.

Calculation of wind resources or specific wind power:The amount of total wind power is determined by the flow of air passing through area A in time t.

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3 \text{ (Equation 6)}$$

- ρ-air density
- v-wind speed
- Avt-volume of wind passing through area A (wind direction is perpendicular to area A). Therefore, Avtρ is equal to the mass of air passing through area A.

Air density is determined by the following equation for dry air.

$$\rho = \frac{P}{RT} \text{ (Equation 7)}$$

- P-air pressure Pa
- R-general gas constant, 287J/kg K in dry air,
- T-air temperature, K (°C+273)

Wind power is the kinetic energy of the horizontal flow of air passing through per unit time.

$$W = \frac{E}{t} = \frac{1}{2}A\rho v^3 \quad \text{(Equation 8)}$$

According to the above, wind energy potential is basically expressed in 3 degrees of wind speed.

However, the wind energy perpendicular to the air flow per unit area is called the specific power of the wind energy, the unit is W/m2.

$$WPD = \frac{1}{2}\rho v^3 \quad \text{(Equation 9)}$$

If the air density per unit area is standard or 1.25 kg/m3 (this is the air density at sea level), the specific power

$$WPD = 0.625v^3 \quad \text{(Equation 10)}$$

Under the condition based on the sum of Weibull probability density functions, the monthly specific power (WRD) of wind power is calculated as below, the unit is [W/m2].

$$WRD = W_{personal\ power} = \frac{1}{2}\rho \sum_{v=0}^{25} \quad v^3F(v) \quad \text{(Equation 11)}$$

Calculation of wind power capacity:

The power output of the wind turbine at a given wind speed is expressed in the form below.

$$Wa = \frac{1}{8}\xi\, A\, \rho v^3, \quad \text{[Вт] (Equation 12)}$$

- ξ-coefficient of wind turbine efficiency. It can be found using the formula below. $\xi = c_p\ \eta_{meh}\eta_{el}$ = 0.38
- cp - coefficient of wind use is 0.45,
- η_{meh} - efficiency coefficient of the mechanical part of the structure is 0.9
- η_{el}- the coefficient of efficiency of electricity of the structure is equal to 0.95 respectively.
- A= πR2 – area covered by fan rotation.
- R- the length of the radius of the fan. [25]

Calculation of the monthly and annual amount of wind power:

Depending on the wind speed in the area, the monthly and annual average power of the wind passing through the total area of the flag of the selected wind turbines in a unit period is calculated using the formula below, the unit is [W] [25].

$$W_{monthly\ average\ power} = 0.25\,\xi\, A\, W_{power} \quad \text{(Equation 13)}$$

$$W_{yearly\ average\ power} = \frac{1}{12}\sum_{1}^{12} * W_{monthly\ average\ power} \quad \text{(Equation 14)}$$

Using the value of the power curve corresponding to the given wind speed of the wind turbines, calculating the monthly and annual amount of electricity produced by the wind turbines:

How much electricity can be produced from wind energy, the monthly average power of the selected wind turbines was calculated using the formula below, the unit is [W*h].

$$W_{monthly\ total\ electricity} = \sum_{v=0}^{20} * F(v) * P(v) \quad \text{(Equation 15)}$$

$$W_{yearly\ electricity} = \sum_{1}^{12} * W_{monthly\ total\ electricity} \quad \text{(Equation 16)}$$

- F(v) – Density value of the Weibull distribution for a given wind speed v for a given month
- P(v) – The power value corresponding to the wind speed v for a given SCC
- t – is the sum of hours corresponding to the total number of days in the month [25].

Calculating the environmental benefits of using the electricity produced by wind turbines:

The use of wind turbine-generated electricity offers environmental advantages when compared to generating the same amount of power from fossil fuels. When fossil fuels like coal, oil, and gas are burned for electricity generation, they release harmful pollutants such as carbon dioxide, sulfur dioxide, and nitrogen oxide into the air. These emissions contribute to problems like air pollution, acid rain, and climate change.

On the other hand, wind-generated electricity produces no emissions or pollutants, making it a clean and renewable energy source. By opting for wind energy instead of fossil fuels, we can significantly reduce our carbon footprint and minimize the negative environmental effects associated with traditional energy sources [25].

$$Coal_{month} = 0{,}89\text{кг} * W_{monthly\ electricity} \quad \text{(Equation 17)}$$

$$Coal_{year} = \sum_{1}^{12} * Coal_{month} \quad \text{(Equation 18)}$$

$$Water_{month} = 9.5\text{л} * W_{monthly\ electricity} \quad \text{(Equation 19)}$$

$$Water_{year} = \sum_{1}^{12} * Water_{\text{cap}} \quad \text{(Equation 20)}$$

$$CO2_{month} = 1.11\text{кг} * W_{monthly\ electricity} \quad \text{(Equation 21)}$$

$$CO2_{year} = \sum_{1}^{12} * CO2_{month} \quad \text{(Equation 22)}$$

4.2 Study Area

Wind speed data is an important meteorological parameter that can provide valuable insights into weather patterns and climate trends. The wind data from 69 WMTs which record wind speed data every 3 hours, were used. Wind speed was measured every three hours of a day and estimated at 10 m height. All stations were plotted on this map and categorized by their region of provinces.

4.2.1 Geography and climate of regions of Mongolia

In this section, the climate of all regions of Mongolia were included and after analyzing wind power, this information will be needed on how it affects wind power. When assessing the wind energy potential in Mongolia, it is important to consider the unique climates of each region. Mongolia has a diverse range of climates across its different regions, and each climate has a varying effect on wind energy generation. For instance, areas with high elevations and strong winds, such as the mountainous regions of the Altai and Khangai Mountains, have the greatest potential for wind energy generation. On the other hand, regions like the Gobi Desert, with low wind speeds and arid climates, have lower wind energy potential. In addition, factors like temperature, humidity, and precipitation can also impact the performance of wind turbines. The cold and dry climate of Mongolia may lead to icing on turbine blades, which can affect their efficiency and performance. Therefore, when assessing wind energy potential in Mongolia, a thorough understanding of the climate of each region is necessary to optimize the design and operation of wind farms.

Mongolia has 4 regions which are Khangai, Central, West and East regions.

- West region: The provinces highlighted in green on the map belong to the West region of Mongolia. These provinces include Bayan-Ulgii, Hovd, Uvs, Gobi-Altai and Zavkhan.
- East region: The provinces highlighted in blue on the map belong to the East region of Mongolia. These provinces include Dornod, Sukhbaatar, and Khentii.
- Khangai region: The provinces highlighted in pink on the map belong to the Khangai region of Mongolia. This region includes Arkhangai, Uvurkhangai, Bayankhongor, Bulgan, Orkhon and Khuvsgul.
- Central region: The provinces highlighted in yellow on the map belong to the Central region of Mongolia. This region includes Ulaanbaatar, Tuv, Selenge, Darkhan-Uul, Dornogobi, Umnugobi and Dundgobi.

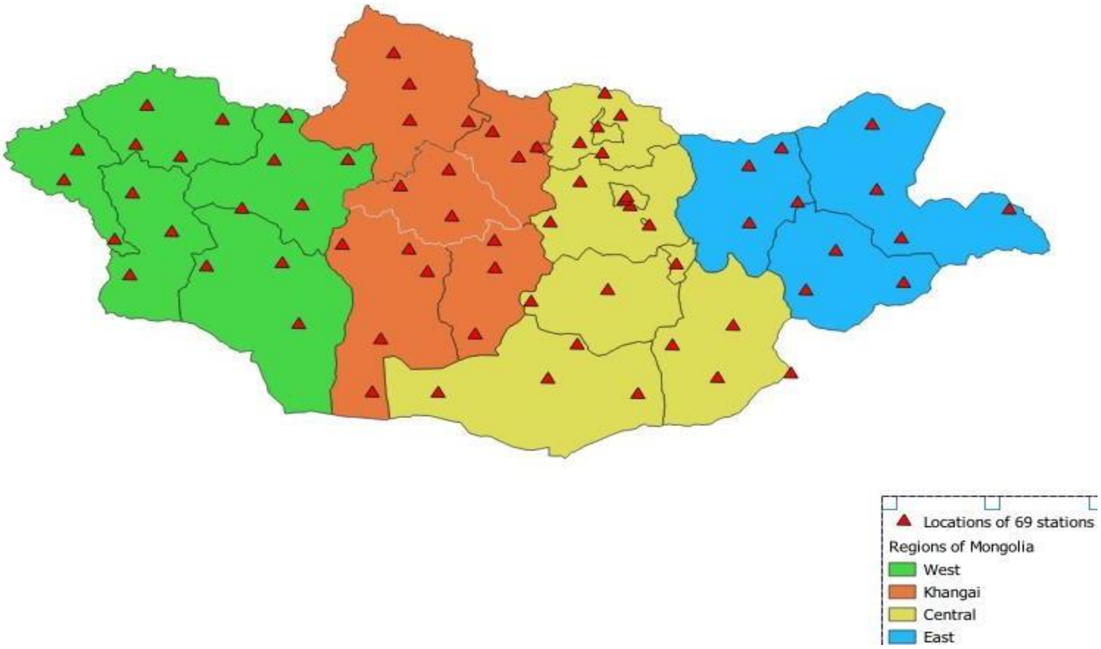

Figure 6: Map of 69 stations divided their regions

4.2.1.1 West Mongolia

West Mongolia is a region of remarkable beauty and diversity, characterized by a wide range of climatic and geographical features. The region is located at an elevation of over 1,500 meters above sea level and is dominated by the Altai Mountains, which rise to over 4,000 meters in height. The climate in West Mongolia is characterized by extreme temperature variations and low levels of precipitation, with average annual temperatures ranging from –10°C to 12°C depending on the altitude and location [26].

In meteorology, a rainy day is defined as any day during which a minimum of 0.1 mm of precipitation per square meter occurs, including rain, snow, hail, or dew. It is not necessary for precipitation to fall throughout the entire day. July is the month with the highest number of rain days, with eight, while January has the least amount of rain days [27].

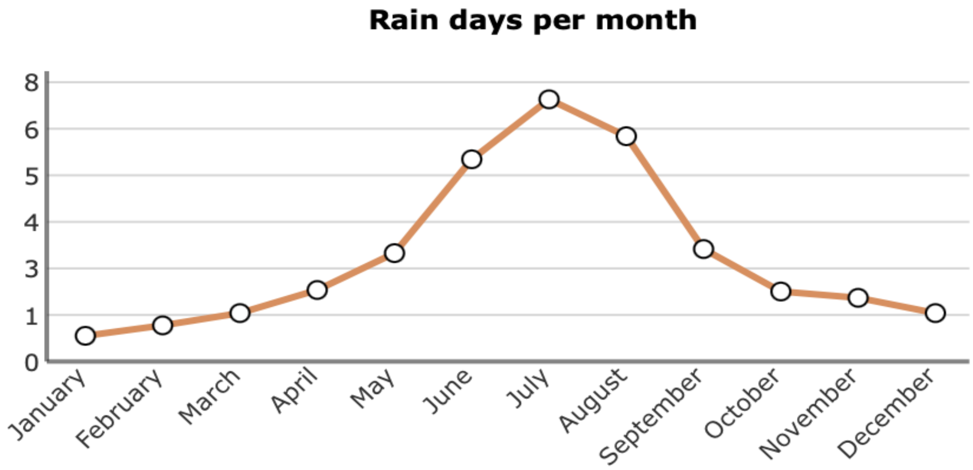

Figure 7: Rainy days per month of west Mongolia

Overall, West Mongolia is a fascinating and unique region that offers a wealth of opportunities for adventure, exploration, and discovery.

4.2.1.2 East Mongolia

The climate of east Mongolia is classified as continental, with large temperature fluctuations between summer and winter. The summers are short and warm, with temperatures averaging around 20-25°C (68-77°F) in July and August. However, temperatures can occasionally reach as high as 35°C (95°F) during heatwaves.

In contrast, the winters are long and extremely cold, with temperatures often dropping below -30°C (-22°F) in January and February. The cold temperatures are accompanied by strong winds, which can make the already frigid conditions feel even more severe.

Precipitation in the region is generally low, with most of it falling during the summer months. The annual rainfall in east Mongolia ranges from around 200-400 mm (8-16 inches) in the north, to around 400-600 mm (16-24 inches) in the south. Snowfall is common in the winter months, with some areas receiving over 1 meter (3 feet) of snow each year [28].

4.2.1.3 Khangai region of Mongolia

With significant temperature differences between summer and winter, the Khangai region has a subarctic climate. The summers are brief and chilly, with typical highs in July and August of 10–20°C (50–68°F). The freezing and long winters, in contrast, frequently see temperatures below -30°C (-22°F) in January and February.

In comparison to other regions of Mongolia, the Khangai region experiences relatively significant precipitation, with lower elevations experiencing an average annual rainfall of 400–600 mm (16–24 inches). Even more precipitation falls on the region's steep terrain, with some regions receiving over 1,000 mm (39 inches) of rain annually. The majority of the precipitation falls as rain during the summer and snow during the winter [29].

4.2.1.3 Central region of Mongolia

The region experiences predominantly cold and frosty weather, with winter temperatures consistently below freezing. The optimal time for travel is between April and September when temperatures are relatively warmer. Winter sports enthusiasts will find ideal conditions from November to March. The hours of sunshine indicate the duration when the sun is unobstructed by clouds, fog, or mountains. May boasts the highest sunshine hours per day, with an average of 10 hours, while December has the least. A rain day is defined as a day with precipitation of at least 0.1 mm per square meter, which can include rain, snow, hail, or dew. July has the highest number of rain days with 9, while January has the fewest [30].

4.2.2 Wind turbine selection

Vesta v110 2mW is chosen for some assumptions. Here is the detailed information of this type of wind turbine. The V110-2.0 MW® IEC IIIA turbine is highly dependable and has a strong track record of availability and performance. It offers the advantage of making low-wind sites, which were previously considered impractical, viable for increased productivity. By utilizing a 110 m rotor, this turbine can harness the available wind even at extremely low speeds of just 3 m/s. Its impressive rotor-to-generator ratio, supported by 54 m blades, results in a significant capacity and yield, particularly in locations with low to medium wind conditions.

Features:

- Vestas OptiStop pitch control strategy included to reduce loads and enable a lighter structure
- Select products from the Vestas PowerPlus™ range are added to maximize output

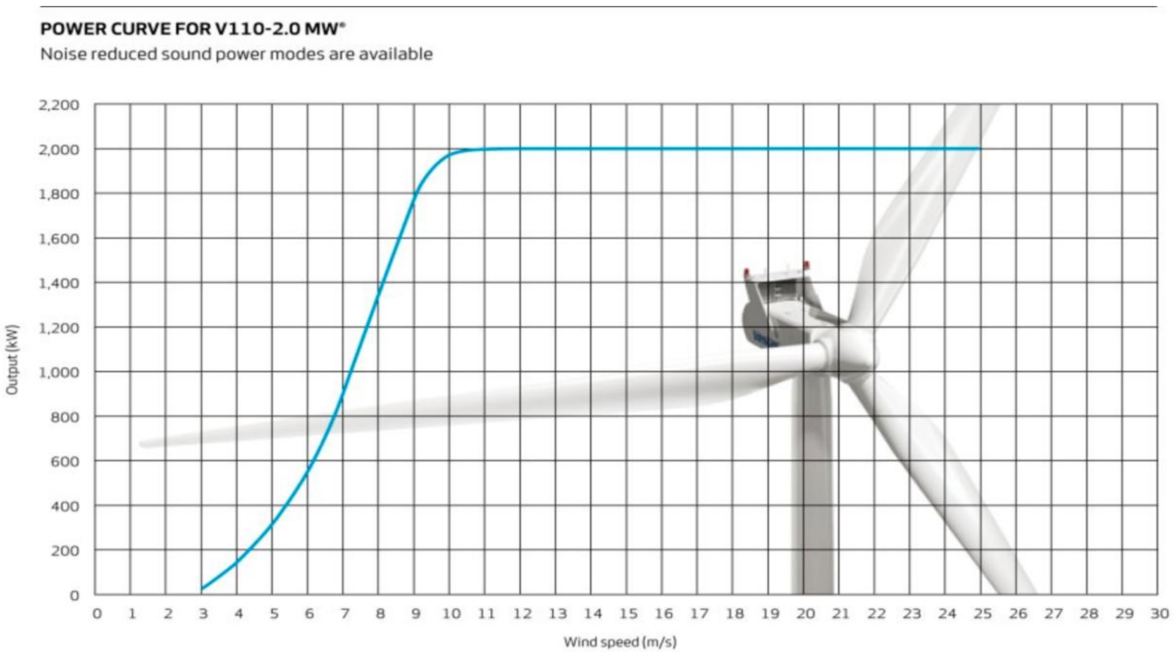

Figure 8: Power curve for V110- 2MW

Options available for the V110-2.0M

- High Wind Operation
- Power Mode (site specific)
- Condition Monitoring System
- Smoke Detection
- Vestas Shadow Flicker Control System
- Low Temperature Operation to -30˚C
- Aviation Lights
- Aviation Markings on the Blades
- Vestas InteliLight™
- Vestas Bat Protection System [31]

Figure 9: Photo of Vesta V110-2MW Source: Vestas

5. Results

5.1 Comparing wind speed

This section presents the grouping of all stations into four categories based on their region and the monthly mean wind speed (m/s) at two different heights (10m and 80m), as shown in tables 1 and 2. The analysis includes a comparison of the mean wind speed of each station within its region, as well as a seasonal comparison to determine which station experiences the highest mean wind speed.

5.1.1 West Mongolia

Twelve months were analyzed by season. In general, December, January, and February are considered winter months. Based on the findings presented in Table 2, it can be observed that during the winter and spring seasons, the mean wind speed is highest at Index 214, 266, 237, and 277, which are situated in the Gobi-Altai, Arkhangai, and Bayan-Ulgii regions.

	average wind speed at 10m height											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
212	1.2	1.7	2.1	3.3	3.4	3.0	2.5	2.5	2.7	2.4	2.2	1.4
213	0.3	0.8	1.3	2.7	2.8	2.6	2.0	2.0	2.1	1.3	1.1	0.2
214	3.9	5.5	5.1	4.5	4.7	4.4	3.8	3.1	4.1	3.4	5.2	3.3
215	3.8	4.4	4.4	4.1	4.7	4.4	3.7	3.3	3.8	3.4	3.8	2.6
216	1.7	2.9	4.0	5.2	5.4	5.0	4.3	4.4	4.0	3.3	3.7	2.0
217	1.0	1.9	1.9	1.7	2.0	1.8	1.1	1.2	2.0	0.9	1.4	0.7
218	1.2	2.4	2.9	2.8	3.0	3.0	2.3	2.1	2.6	1.9	2.2	1.2
219	2.6	3.8	3.8	3.8	4.4	4.1	3.6	3.9	3.3	3.5	3.4	2.5
221	1.2	1.7	1.9	2.7	3.5	3.0	2.1	2.5	2.2	1.6	1.8	1.0
224	2.0	2.7	3.5	3.9	4.0	1.6	1.0	1.0	1.1	0.8	1.3	0.5
225	2.0	2.0	2.3	3.4	4.1	3.1	2.2	2.3	2.7	2.3	1.9	1.6
229	3.9	2.9	2.6	3.0	3.8	3.7	1.7	2.3	2.6	2.3	2.7	2.5
230	3.3	3.3	3.7	3.8	4.3	3.6	2.9	2.9	3.1	3.1	2.9	2.9
237	4.5	5.3	4.7	4.9	5.9	4.3	3.2	3.6	3.8	3.8	4.4	3.8
263	2.4	2.7	3.0	3.5	3.8	3.3	3.2	2.5	2.7	2.7	2.7	2.3
264	1.0	2.1	2.8	2.8	4.1	3.3	3.2	2.5	2.5	1.5	2.2	0.8
265	1.3	1.8	2.5	3.0	3.6	3.2	2.9	1.9	2.1	2.4	1.5	1.4
266	4.3	5.2	5.4	5.5	6.3	5.8	4.5	4.5	5.3	4.4	5.2	3.5
272	1.8	1.8	2.5	2.9	3.6	3.4	2.8	2.7	2.7	2.2	2.0	1.8
277	4.7	5.8	5.1	5.5	6.2	4.5	2.5	3.1	5.0	3.2	4.7	3.1
282	3.2	3.1	3.1	3.2	3.6	2.7	2.2	2.2	2.3	2.2	2.4	2.1
325	2.5	3.1	3.5	4.0	5.8	4.9	4.0	4.6	3.1	3.3	2.5	2.2

Table 2: Monthly wind speed data at 10m height of West Mongolia

Conversely, during the summer season, Index 325, 216, and 266, located in Gobi-Altai and Uvs Aimag, exhibit the highest mean wind speed compared to the other stations.Similarly, in autumn, Index 277, 266, and 237 record the highest mean wind speeds across various regions.

The information gathered at an altitude of 80 meters indicates that Index 266 records the highest wind speed of 9 m/s in May. Additionally, this station displays more stable and comparatively higher mean wind speeds than the other stations located in Tonkhil soum of Gobi-Altai, throughout all seasons.

Overall, the Gobi-Altai Aimag region experiences the highest wind speeds in West Mongolia.

	mean wind speed at 80m height											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
212	2.4	3	3.8	5	5.5	5	4.4	4	4.7	4	4.0	3
213	0.9	1.8	2.6	4.7	4.8	4.5	3.7	3.7	3.8	2.7	2.3	0.6
214	6.2	8.2	7.6	6.9	7.2	6.8	6.1	5.2	6.5	5.6	7.8	5.5
215	6.0	6.8	6.8	6.4	7.1	6.8	5.9	5.4	6.0	5.6	6.0	4.5
216	3.3	4.9	6.3	7.7	7.9	7.5	6.7	6.8	6.3	5.4	6.0	3.6
217	2.1	3.5	3.6	3.3	3.7	3.4	2.4	2.5	3.7	1.9	2.8	1.6
218	2.5	4.3	5.0	4.8	5.1	5.0	4.1	3.8	4.5	3.6	4.0	2.5
219	4.6	6.1	6.1	6.1	6.8	6.5	5.9	6.2	5.5	5.7	5.6	4.4
221	2.4	3.3	3.5	4.7	5.8	5.0	3.8	4.4	3.9	3.0	3.4	2.2
224	3.7	4.7	5.8	6.2	6.4	3.1	2.2	2.2	2.4	1.8	2.7	1.3
225	3.7	3.6	4.1	5.6	6.5	5.2	3.9	4.2	4.7	4.1	3.6	3.1
229	6.2	4.9	4.5	5.1	6.1	5.9	3.3	4.1	4.5	4.2	4.7	4.4
230	5.5	5.5	6.0	6.1	6.7	5.8	5.0	4.9	5.2	5.2	4.9	5.0
237	7.0	7.9	7.2	7.5	8.6	6.7	5.4	5.9	6.0	6.0	6.9	6.0
263	4.3	4.7	5.0	5.7	6.1	5.4	5.3	4.5	4.7	4.7	4.7	4.1
264	2.1	3.9	4.8	4.8	6.4	5.5	5.3	4.4	4.4	3.0	4.0	1.9
265	2.6	3.4	4.4	5.1	5.8	5.3	4.9	3.6	3.9	4.2	3.0	2.8
266	6.7	7.8	8.0	8.1	9.0	8.4	6.9	7.0	7.9	6.8	7.7	5.7
272	3.3	3.4	4.4	4.9	5.8	5.6	4.8	4.7	4.6	3.9	3.7	3.5
277	7.2	8.5	7.7	8.1	8.9	7.0	4.3	5.2	7.5	5.4	7.1	5.1
282	5.3	5.2	5.2	5.4	5.8	4.7	4.0	4.0	4.2	3.9	4.3	3.8
325	4.5	5.2	5.7	6.3	8.4	7.4	6.3	7.0	5.2	5.5	4.4	4.0

Table 3: Monthly mean speed at 80m height of West Mongolia

5.1.2 East Mongolia

Index 314 located in Dornod Aimag exhibits the highest mean wind speed amongst all other indices, exceeding 4 m/s in all seasons. Conversely, Table 4 reveals that indices 254, 257, and 317 have the lowest wind speeds in the eastern region, particularly in the months of October, November, and December. The wind speed at an 80m height reaches up to 9.2 m/s in index 314, which surpasses the wind speed in the west region. Notably, indices 302, 304, and 305 located in Khentii and Sukhbaatar demonstrate higher wind speeds than others and maintain stable wind speeds exceeding 3.3 m/s during the spring season.

An analysis of the wind resource potential in Mongolia indicates that the eastern region generally possesses a greater wind resource than the west region. Furthermore, all wind measurement stations across both regions display considerable wind capacity in all seasons, indicating the presence of an abundant wind resource throughout the country. Notably, Dornod Aimag, situated in the east region, is found to exhibit stable wind speeds throughout all months of the year, thereby underscoring its potential as a highly favorable location for wind energy development in East Mongolia.

	mean wind speed at 10m height m/s											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
254	2.4	2.7	3.2	3.3	3.3	2.5	2.1	2.1	2.3	2.5	2.3	2.3
256	4.4	3.8	4.9	5.9	5.8	3.7	2.5	2.6	3.0	2.2	2.1	3.0
257	3.3	3.1	3.7	4.1	4.8	3.6	2.0	1.8	2.1	1.8	1.7	1.7
259	3.8	3.9	4.3	4.9	4.9	4.0	3.1	3.3	3.3	3.8	3.5	3.9
302	5.5	5.3	5.3	6.0	6.2	4.6	3.4	3.8	4.0	4.6	4.9	5.6
304	4.5	4.1	4.7	6.2	6.3	4.5	3.7	4.3	3.9	4.3	4.4	4.7
305	4.0	4.4	5.3	5.8	5.6	4.7	3.7	4.2	3.9	4.0	4.4	4.1
313	4.3	4.5	5.2	5.3	5.5	4.2	2.9	3.3	3.9	4.2	4.2	4.0
314	6.2	5.7	5.9	6.5	6.5	5.1	4.1	4.3	4.0	5.1	5.7	5.9
317	3.3	3.4	3.8	3.7	3.5	2.3	1.2	1.9	2.3	2.7	2.9	2.8
352	3.5	3.6	3.8	4.4	4.2	3.1	2.2	3.0	2.5	3.1	3.6	4.0

Table 4: Monthly mean speed at 10m height of East Mongolia

	mean wind speed at 80m height m/s											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
254	4.3	4.6	5.3	5.5	5.5	4.5	3.8	3.8	4.1	4.4	4.1	4.2
256	6.8	6.1	7.4	8.6	8.4	6.0	4.3	4.6	5.0	3.9	3.9	5.0
257	5.4	5.2	6.0	6.4	7.3	5.9	3.7	3.4	3.9	3.4	3.2	3.3
259	6.1	6.2	6.6	7.4	7.4	6.3	5.2	5.4	5.5	6.0	5.8	6.2
302	8.1	7.9	7.9	8.7	8.8	7.0	5.6	6.1	6.4	7.0	7.4	8.2
304	6.9	6.5	7.2	8.9	9.0	6.9	5.9	6.7	6.2	6.7	6.9	7.1
305	6.3	6.8	7.9	8.5	8.2	7.2	6.0	6.5	6.2	6.3	6.8	6.5
313	6.7	7.0	7.8	7.9	8.1	6.6	4.9	5.5	6.1	6.6	6.5	6.3
314	8.9	8.3	8.6	9.2	9.2	7.7	6.4	6.7	6.3	7.7	8.3	8.6
317	5.4	5.5	6.0	6.0	5.7	4.1	2.5	3.6	4.1	4.6	4.9	4.8
352	5.8	5.8	6.1	6.8	6.6	5.2	4.0	5.0	4.4	5.2	5.8	6.4

Table 5: Monthly mean speed at 80m height of Eastern Mongolia

5.1.3 Khangai region of Mongolia

Table 6 provides a wealth of insights into the mean wind speeds observed at various measurement stations across Mongolia. Among the stations, index 329, situated in Jinst soum, Bayankhongor Aimag, stands out as displaying the highest mean wind speed, particularly during the months of January to May, where it exceeds 6 m/s. Conversely, index 203, located in Galuut soum, Bayankhongor Aimag, demonstrates the lowest wind speeds, hovering around 3 m/s for most of the year. Interestingly, both areas displaying the highest and lowest mean wind speeds are located in Bayankhongor Aimag, highlighting the regional variability in wind patterns across the country. The observed discrepancy in wind speeds can be attributed to the surrounding topography, as Galuut soum is encircled by numerous mountains, which impedes wind flow and results in lower wind speeds.

	mean wind speed at 10m height m/s											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
203	1.7	1.9	2.4	3.6	4.0	3.1	2.3	1.9	2.2	1.7	1.5	0.9
207	3.5	3.8	3.8	3.7	3.8	2.8	2.3	2.4	2.5	2.4	3.6	3.4
229	3.9	2.9	2.6	3.0	3.8	3.7	1.7	2.3	2.6	2.3	2.7	2.5
230	3.3	3.3	3.7	3.8	4.3	3.6	2.9	2.9	3.1	3.1	2.9	2.9
231	2.6	2.8	2.4	3.1	4.0	2.7	2.2	1.9	2.1	1.6	1.9	1.6
232	2.2	2.2	2.2	2.6	2.6	2.1	2.1	2.0	2.3	2.3	1.9	2.2
236	2.4	2.6	2.7	3.0	3.2	2.7	2.2	2.4	2.1	2.2	2.5	2.3
237	4.5	5.3	4.7	4.9	5.9	4.3	3.2	3.6	3.8	3.8	4.4	3.8
239	2.6	2.6	3.1	3.5	3.9	3.3	2.6	3.1	2.6	2.9	2.6	2.5
275	3.6	4.0	3.7	4.2	5.9	4.3	3.0	3.5	3.6	2.3	2.9	2.4
282	3.2	3.1	3.1	3.2	3.6	2.7	2.2	2.2	2.3	2.2	2.4	2.1
284	1.2	1.4	1.9	3.3	4.4	3.3	2.2	2.4	2.4	1.7	1.3	1.0
285	2.1	2.1	2.9	3.5	3.8	2.7	2.1	2.2	2.2	1.9	2.2	1.5
287	4.4	4.4	4.1	4.6	5.3	4.1	2.9	3.4	3.4	2.8	3.3	3.6
288	2.4	2.4	3.7	4.4	4.8	4.3	3.1	3.6	3.5	3.2	3.1	2.4
329	6.3	6.8	6.2	6.2	7.3	6.0	4.4	5.4	5.1	4.4	5.7	5.2
338	3.0	3.8	4.4	4.3	5.1	4.4	3.1	3.1	3.3	2.8	3.3	2.7
366	2.7	2.6	3.2	3.1	3.4	2.3	2.2	2.4	1.8	2.5	2.2	1.8

Table 6: Monthly mean speed at 10m height of Khangai region of Mongolia

Overall, the study findings reveal that, except for index 329, most wind measurement stations demonstrate lower mean wind speeds compared to east and west Mongolia. This observation points to the significant influence of location and topography on wind speed, with the Gobi and was regions featuring relatively flat terrains and fewer mountains exhibiting comparatively lower wind speeds.

	mean wind speed at 10m height m/s											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
203	3.2	3.5	4.2	5.8	6.3	5.2	4.2	3.5	4.0	3.3	2.9	2.0
207	5.7	6.1	6.1	5.9	6.1	4.7	4.1	4.3	4.4	4.3	5.8	5.6
229	6.2	4.9	4.5	5.1	6.1	5.9	3.3	4.1	4.5	4.2	4.7	4.4
230	5.5	5.5	6.0	6.1	6.7	5.8	5.0	4.9	5.2	5.2	4.9	5.0
231	4.5	4.9	4.2	5.2	6.3	4.7	3.9	3.6	3.8	3.0	3.5	3.1
232	4.0	4.0	4.0	4.5	4.6	3.9	3.8	3.6	4.2	4.1	3.6	3.9
236	4.2	4.5	4.7	5.1	5.4	4.6	4.0	4.3	3.8	4.0	4.5	4.1
237	7.0	7.9	7.2	7.5	8.6	6.7	5.4	5.9	6.0	6.0	6.9	6.0
239	4.5	4.6	5.1	5.7	6.3	5.4	4.5	5.2	4.5	4.9	4.5	4.3
275	5.8	6.3	5.9	6.6	8.5	6.7	5.1	5.7	5.9	4.2	4.9	4.3
282	5.3	5.2	5.2	5.4	5.8	4.7	4.0	4.0	4.2	3.9	4.3	3.8
284	2.5	2.8	3.6	5.4	6.8	5.4	4.0	4.3	4.3	3.2	2.7	2.1
285	3.9	3.9	4.9	5.7	6.0	4.7	3.8	4.0	4.0	3.5	3.9	2.9

287	6.8	6.8	6.5	7.1	7.9	6.4	5.0	5.5	5.6	4.9	5.5	5.9
288	4.3	4.2	6.0	6.8	7.3	6.7	5.2	5.8	5.7	5.3	5.2	4.3
329	9.0	9.5	8.9	8.9	10.1	8.7	6.8	7.9	7.7	6.8	8.3	7.7
338	5.1	6.1	6.8	6.7	7.7	6.9	5.2	5.2	5.4	4.9	5.4	4.6
366	4.7	4.5	5.3	5.2	5.6	4.1	4.0	4.2	3.4	4.5	4.0	3.4

Table 7: Monthly mean speed at 80m height of Khangai region of Mongolia

5.1.3 Central region of Mongolia

Analysis of Table 8 indicates that the central region of Mongolia exhibits a markedly different mean wind speed when compared to the other regions. Specifically, index 339, situated in the Gobi area of Umnugobi, Dornogobi, Dundgobi, and Gobisumber Aimag, displays the highest wind speeds in all seasons, with winter recording the highest mean wind speed of 9.6 m/s. Interestingly, the central region experiences higher wind speeds in winter, whereas in most other regions, spring and summer exhibit higher wind speeds compared to autumn and winter. This high wind speed during winter in the Gobi area can make the harshness of the already low temperatures worse, while the hot and arid summer exacerbates the aridity of the region.

	mean wind speed at 10m height m/s											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
236	2.4	2.6	2.7	3.0	3.2	2.7	2.2	2.4	2.1	2.2	2.5	2.3
240	2.6	2.6	3.1	3.5	3.9	3.3	2.6	3.1	2.6	2.9	2.6	2.5
241	1.9	2.8	3.3	4.0	4.0	3.4	2.5	3.1	2.7	2.3	2.5	2.0
242	1.3	1.7	2.7	3.8	3.4	2.5	2.0	2.0	2.2	1.6	1.7	1.2
243	2.4	2.7	3.2	3.3	3.3	2.5	2.1	2.1	2.3	2.5	2.3	2.3
247	1.5	2.7	3.9	5.3	5.0	4.6	3.6	3.7	3.5	3.1	2.9	2.0
286	4.1	3.1	4.0	4.5	5.2	3.4	2.1	3.1	2.6	2.7	3.4	3.0
290	3.6	3.4	4.2	5.1	6.3	5.3	3.7	4.2	4.0	3.5	3.5	3.0
291	1.7	2.2	3.4	4.0	4.9	4.2	2.9	3.5	2.9	2.9	2.2	1.4
292	1.1	1.5	2.0	2.6	2.9	2.8	2.3	2.5	2.3	1.8	1.1	0.4
294	2.9	2.5	4.2	5.3	5.8	5.0	2.9	3.5	3.4	2.3	2.4	2.1
298	4.7	4.3	5.3	6.6	6.5	6.1	4.7	4.9	4.6	4.3	4.4	4.2
336	2.9	4.1	4.6	5.6	5.4	4.6	3.7	3.9	3.4	3.0	3.2	2.1
339	10.1	9.3	7.3	6.9	7.6	6.3	4.4	5.1	5.6	6.4	10.3	9.4
341	4.8	4.4	5.1	6.8	7.1	6.0	4.5	5.0	4.2	3.8	4.6	3.9
347	5.1	5.3	5.2	5.6	5.4	4.8	4.5	4.6	4.0	3.8	4.4	3.6
348	6.1	5.5	4.7	6.0	6.2	5.1	3.8	5.0	4.2	3.4	5.9	5.5
354	4.0	3.2	4.0	5.3	5.4	4.6	2.6	3.4	2.9	3.3	4.3	4.3
358	3.1	3.5	3.8	4.4	4.4	3.9	3.1	3.3	3.0	2.8	3.4	3.6
373	3.8	3.9	4.1	4.8	5.5	4.3	3.4	3.8	3.7	3.3	3.3	2.7
374	3.8	4.4	4.2	4.6	5.8	4.8	4.0	4.3	4.3	3.4	3.9	3.4
385	4.7	4.9	4.8	5.3	5.6	4.5	3.7	4.1	3.8	3.6	5.4	5.3

386	5.6	5.8	6.0	6.5	7.2	5.7	4.3	4.6	4.3	4.2	5.6	5.7

Table 8: Monthly mean speed at 10m height of Central Mongolia

In contrast, Ulaanbaatar, Selenge, and Tuv Aimag have the lowest wind speeds, with spring and summer exhibiting higher wind speeds compared to the other seasons. These areas are characterized by urbanization and lower elevations, which could contribute to the observed differences in wind speed. Overall, these results highlight the significant influence of location on wind speed, and the Gobi region's unique wind patterns in Mongolia.

	mean wind speed at 80m height m/s											
Index	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
236	4.2	4.5	4.7	5.1	5.4	4.6	4.0	4.3	3.8	4.0	4.5	4.1
240	4.5	4.6	5.1	5.7	6.3	5.4	4.5	5.2	4.5	4.9	4.5	4.3
241	3.6	4.8	5.5	6.4	6.4	5.6	4.4	5.1	4.7	4.1	4.5	3.7
242	2.7	3.3	4.6	6.1	5.6	4.4	3.7	3.7	4.0	3.1	3.2	2.5
243	4.3	4.6	5.3	5.5	5.5	4.5	3.8	3.8	4.1	4.4	4.1	4.2
247	3.0	4.6	6.2	7.9	7.5	7.0	5.8	5.9	5.7	5.2	4.9	3.6
286	6.5	5.2	6.3	6.9	7.7	5.6	3.8	5.2	4.5	4.6	5.5	5.0
290	5.6	6.6	7.6	9.0	7.8	6.0	6.6	6.3	5.7	5.7	5.1	3.2
291	3.2	4.0	5.6	6.4	7.4	6.5	4.9	5.7	4.9	5.0	4.0	2.9
292	2.3	3.0	3.7	4.6	5.0	4.7	4.1	4.4	4.2	3.5	2.3	1.0
294	4.9	4.5	6.6	7.9	8.4	7.5	4.9	5.7	5.6	4.2	4.2	3.8
298	7.1	6.7	7.9	9.4	9.2	8.8	7.2	7.4	7.1	6.7	6.8	6.6
336	5.0	6.4	7.1	8.2	8.0	7.1	6.0	6.2	5.6	5.0	5.4	3.8
339	13.0	12.2	10.1	9.6	10.4	9.0	6.9	7.6	8.2	9.1	13.2	12.3
341	7.3	6.8	7.7	9.5	9.9	8.7	6.9	7.5	6.6	6.1	7.1	6.2
347	7.6	7.8	7.7	8.2	8.0	7.3	6.9	7.1	6.4	6.1	6.8	5.9
348	8.8	8.1	7.1	8.7	8.9	7.6	6.1	7.5	6.6	5.6	8.6	8.1
354	6.4	5.4	6.4	7.9	8.0	7.0	4.6	5.6	5.0	5.5	6.6	6.6
358	5.2	5.7	6.1	6.9	6.8	6.2	5.2	5.4	5.1	4.8	5.6	5.8
373	6.1	6.2	6.4	7.3	8.1	6.7	5.6	6.1	6.0	5.4	5.5	4.7
374	6.0	6.8	6.6	7.0	8.5	7.3	6.3	6.6	6.7	5.6	6.2	5.6
385	5.6	7.2	7.4	7.3	7.9	8.2	7.0	5.9	6.4	6.0	5.9	7.9
386	8.2	8.4	8.6	9.2	10.0	8.3	6.7	7.1	6.7	6.6	8.2	8.3

Table 9: Monthly mean speed at 80m height of Central Mongolia

5.2 Monthly wind power density

Table 10 presents a list of stations in Mongolia with the highest wind power density in their respective regions, indicating that these locations are favorable for the installation of wind turbines to generate electricity efficiently. Specifically, Gobisumber, Dornogobi, Umnugobi, Bayankhongor, Gobi-Altai, Khentii, Sukhbaatar, and Dornod stand out as regions with the most potential to install wind turbines, specifically the Vesta V110 2mW model, which requires a wind speed range of 3-25 m/s. These stations exhibit stable wind speeds throughout every season and are able to meet the wind turbine's requirements.

According to research, coal power stations can generate electricity worth anywhere from 400 to 1000 homes per year for each MW of capacity. If we consider the Sainshand Wind Park project and assume that 25 wind turbines are installed, each generating 1MW per year, a total of 25 MW of electricity can be generated by one station. Given that on average, one MW can supply electricity to 500 households, one station can provide power to approximately 12,500 households in one year.

Wind power density (MW)													
Central region of Mongolia													
Index	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**Total**
298	0.08	0.07	0.11	0.19	0.17	0.15	0.08	0.09	0.08	0.06	0.07	0.06	**1.19**
339	0.22	0.18	0.10	0.09	0.11	0.07	0.03	0.04	0.05	0.07	0.23	0.19	**1.39**
347	0.12	0.14	0.13	0.16	0.15	0.11	0.09	0.10	0.07	0.06	0.09	0.06	**1.27**
348	0.14	0.10	0.07	0.13	0.14	0.09	0.04	0.08	0.05	0.03	0.12	0.10	**1.11**
385	0.10	0.11	0.11	0.14	0.16	0.09	0.06	0.07	0.06	0.06	0.14	0.13	**1.23**
386	0.11	0.12	0.13	0.16	0.20	0.12	0.06	0.07	0.06	0.06	0.11	0.11	**1.30**
Khangai region of Mongolia													
237	0.08	0.11	0.08	0.09	0.14	0.07	0.03	0.05	0.05	0.05	0.07	0.05	**0.88**
329	0.15	0.18	0.14	0.15	0.21	0.14	0.06	0.10	0.09	0.06	0.12	0.09	**1.50**
West region of Mongolia													
214	0.05	0.12	0.09	0.07	0.08	0.07	0.05	0.03	0.06	0.04	0.10	0.03	**0.78**
215	0.06	0.09	0.09	0.08	0.10	0.09	0.06	0.05	0.06	0.05	0.06	0.03	**0.83**
266	0.07	0.11	0.12	0.13	0.17	0.14	0.08	0.08	0.11	0.07	0.11	0.04	**1.23**
East region of Mongolia													
304	0.07	0.06	0.08	0.16	0.17	0.07	0.05	0.07	0.05	0.07	0.07	0.08	**1.00**
305	0.06	0.08	0.13	0.16	0.14	0.10	0.06	0.07	0.06	0.07	0.08	0.07	**1.07**
302	0.11	0.10	0.10	0.14	0.15	0.07	0.04	0.05	0.05	0.07	0.09	0.12	**1.09**
314	0.15	0.12	0.13	0.17	0.17	0.10	0.06	0.06	0.05	0.10	0.12	0.13	**1.35**

Table 10: List of highest wind power density area of Mongolia

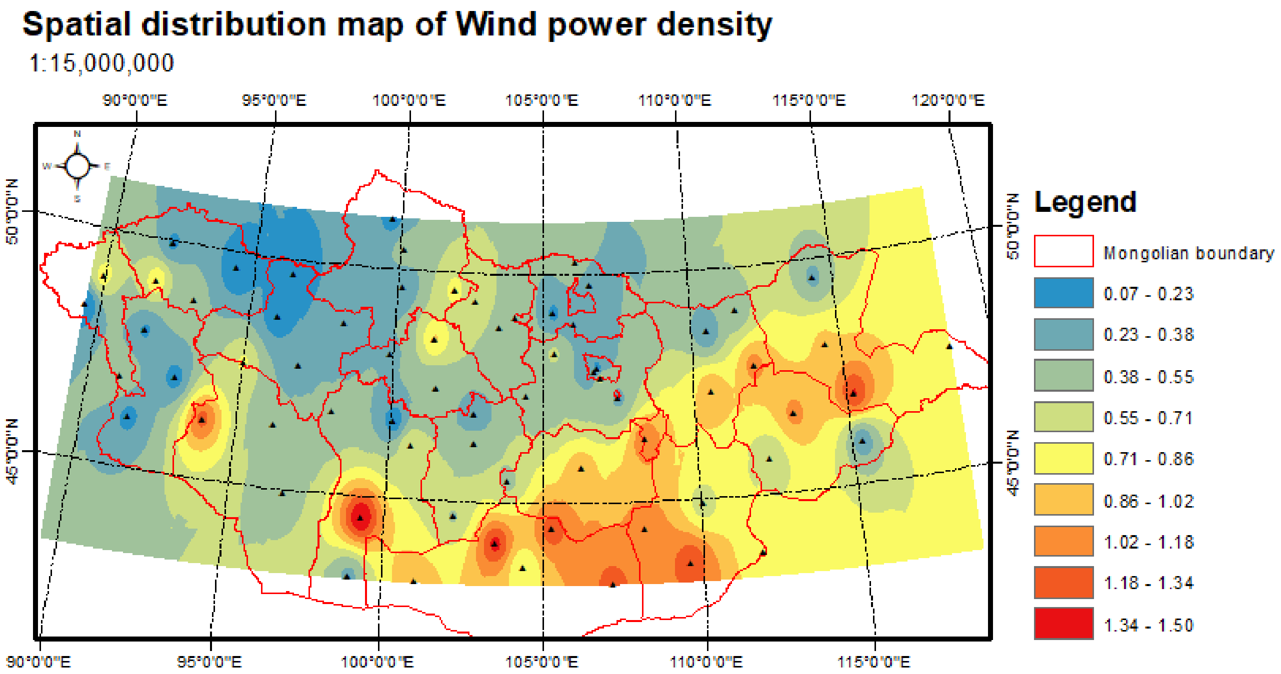

Figure 10: Wind power density of Mongolia based on 69 stations (MW)

6. Environmental effects

Wind power is a comparatively eco-friendly energy source with fewer negative effects on the environment than other forms of energy. Wind turbines do not emit pollutants that could harm air or water quality, except for infrequent cases, and do not necessitate the usage of water for cooling. By potentially reducing the need for fossil fuels in electricity generation, wind turbines can also lower the total carbon dioxide emissions and air pollution. [29] By employing equation 17-22, the quantities of CO2, water, and coal used in the process of energy production were estimated for wind turbines. While the calculated values may not be entirely precise, they do provide a general impression of the potential reductions in these parameters achieved by the implementation of wind turbines. This analysis offers valuable insights into the benefits of wind power in terms of reducing the environmental impact of energy production. Table 11 presents data on the quantities of CO2, water, and coal usage that can significantly impact the environment in a negative manner. The information contained within this table serves to highlight the importance of implementing sustainable energy solutions that minimize the consumption of these resources, reduce pollution, and contribute to a cleaner, healthier environment.

Index	Coal(kg)	water (L)	CO2 (kg)
236	2040.2	21777.2	2544.5
240	2235.9	23866.3	2788.6

241	1469.7	15688.0	1833.0
242	726.8	7758.2	906.5
243	939.6	10029.9	1171.9
247	2395.6	25570.6	2987.7
286	1774.8	18944.2	2213.5
290	2847.5	30394.4	3551.3
291	1133.2	12095.7	1413.3
292	456.8	4875.5	569.7
294	1470.8	15699.8	1834.4
298	4781.6	51039.5	5963.6
336	1652.9	17643.2	2061.5
339	3398.6	36277.6	4238.8
341	3812.2	40692.5	4754.6
347	5395.5	57592.0	6729.2
348	4722.5	50408.9	5889.9
354	2604.1	27796.6	3247.8
358	3064.4	32710.3	3821.9
373	2987.5	31888.7	3725.9
374	4057.2	43307.0	5060.1
385	5212.9	55643.0	6501.4
386	5058.2	53991.8	6308.5

Table 11: Amount of reduction of CO2, water and coal usage of Central Mongolia

6.1 Spatial maps based on calculation

GIS, short for Geographic Information System, refers to software that combines the capabilities of a map and a database, enabling individuals to generate, control, and analyze data, with a specific emphasis on spatial information.

Four maps were generated using ArcGIS, incorporating seasonal data from multiple stations at a height of 10 meters. These maps facilitate an efficient analysis of variations in wind intensity across different areas, enabling the identification of regions with higher wind activity compared to others.

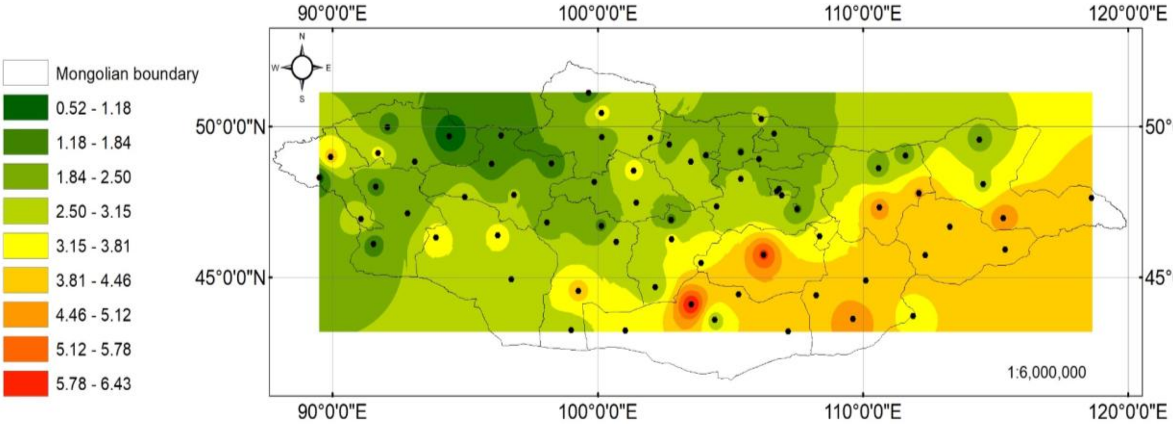

Figure 11: Mean wind speed of Mongolia in winter at 10m height (m/s)

The utilization of a GIS program proves invaluable and user-friendly when analyzing stations and regions, identifying areas with the highest mean wind speed, and assessing wind power density for the purpose of establishing wind farms, all from a single map image. The ability to segregate and evaluate these stations based on their geographical location and seasonal variations in mean wind speed allows for a clear and easily comprehensible differentiation of their wind energy potential, making it readily accessible and understandable to a wider audience.

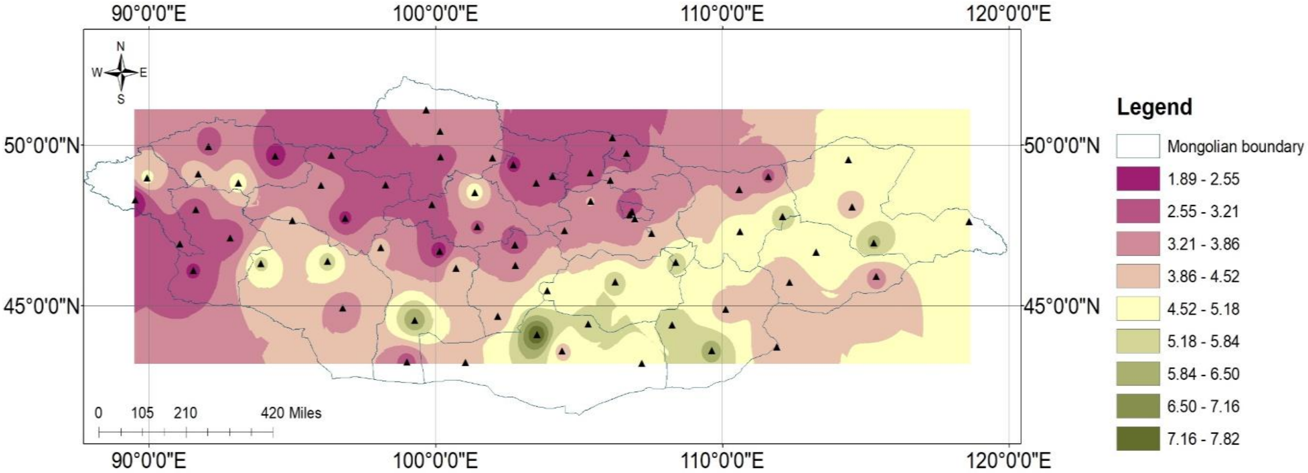

Figure 12: Mean wind speed of Mongolia in spring at 10m height (m/s)

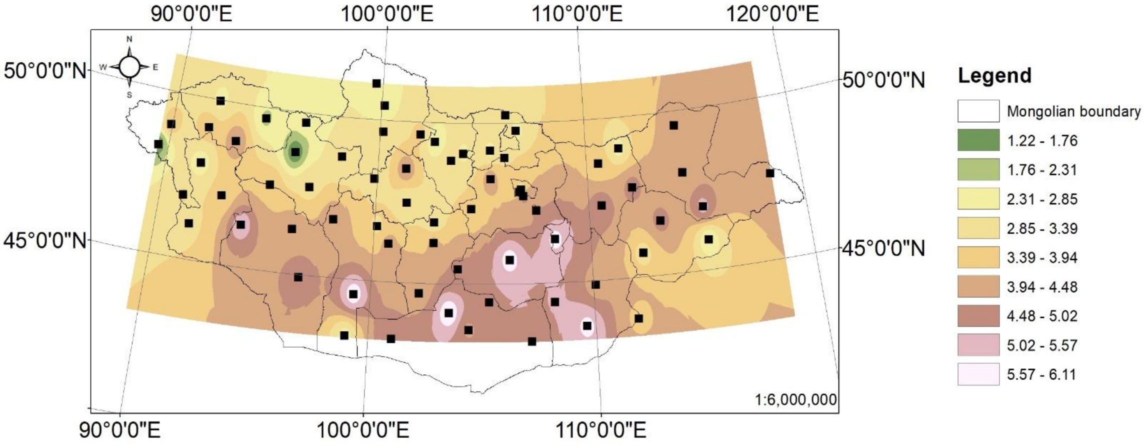

Figure 13: Mean wind speed of Mongolia in summer at 10m height (m/s)

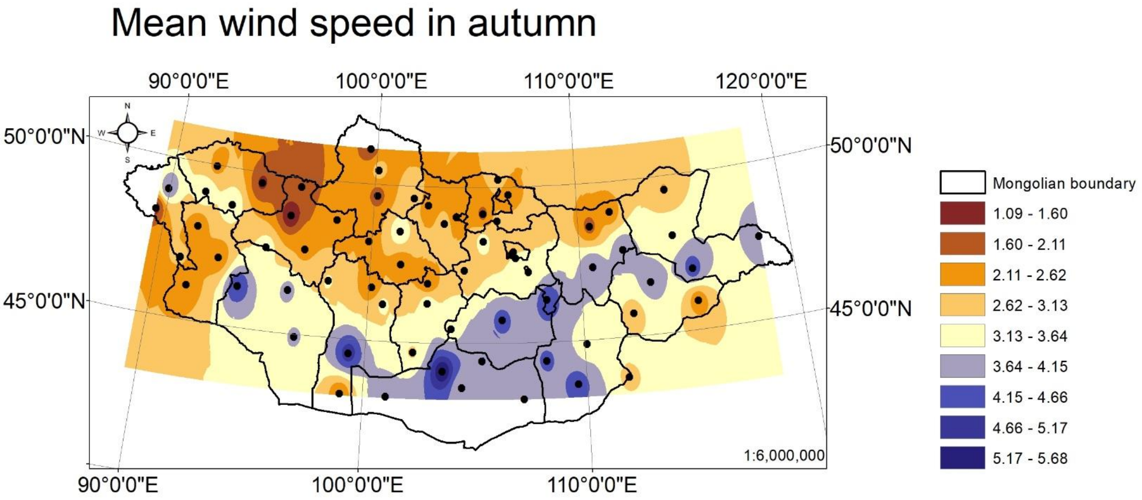

Figure 14: Mean wind speed of Mongolia in autumn at 10m height (m/s)

7. Discussion

Based on the data presented in Table 10, specifically index 339 located in Bulgan soum of Umnugobi Aimag, it is evident that this region experiences consistently stable wind speeds, making it highly suitable for the installation of wind turbines. However, prior to the construction of wind farms, it is imperative to conduct more precise measurements and assessments in this area to ensure accurate evaluation of its wind energy potential.

Considering the power generation capacity, Bulgan soum has the capability to generate 1.4 MW of power in one year. By installing 25 wind turbines with a capacity of 2 MW each, the total power generation in Bulgan soum could be significantly increased to 35 MW per year. These estimates are based on the findings presented in Figure 10, which indicate that the southern and eastern areas of the soum exhibit higher wind potential compared to other regions. The observed disparities in wind intensity can be attributed to variations in elevation height, where higher elevations correspond to higher wind speeds due to reduced obstructions.

Furthermore, it is noteworthy that the Khangai region displays the lowest wind speeds in comparison to other regions. This disparity can be attributed to the presence of elevated mountains and dense vegetation, such as trees, which act as obstacles, hindering the flow of wind and limiting its speed. Consequently, wind speeds are not sufficiently accelerated in such areas due to these physical barriers.

In Mongolia, stable winter wind conditions are uncommon, as indicated in Figure 11, where only a few areas exhibit wind speeds exceeding 5 m/s during the winter season. This underscores the need for thorough assessment and consideration of seasonality when evaluating the feasibility of wind energy projects in the region.

The article titled "Assessment of wind energy in Iran: A review" by Alamdari.P and Nematollahi.O provides valuable insights into wind energy assessment in Iran, and a comparison with Mongolia reveals some similarities and differences in terms of mean wind speeds at a height of 10 meters. Similar to Iran, Mongolia also experiences mean wind speeds ranging from 3 m/s to 5 m/s; however, there are notable distinctions between the two countries.

In Iran, the mean wind speeds tend to be stable across most areas, indicating a consistent wind resource. Conversely, Mongolia exhibits less stability in wind speeds, with some regions experiencing speeds below 3 m/s for a significant portion of the year, while other areas maintain relatively high wind speeds throughout the year, including the winter season. These variations highlight the diverse wind climate in Mongolia, which necessitates a more comprehensive analysis to accurately assess the wind energy potential.

Although analyzing only 69 stations and utilizing one year of data may be limited in terms of a comprehensive evaluation, it can provide initial insights and an approximate understanding of the wind energy potential in Mongolia.

8. Conclusion

In simpler terms, Mongolia has great potential for wind energy projects. By developing more wind farms, Mongolia can reduce its reliance on coal and benefit both economically and environmentally. Learning from other countries' experiences in renewable energy can help Mongolia transition to a sustainable and eco-friendly energy sector, ensuring a better future for its people and the planet.

Although Mongolia currently has a limited number of wind farms, there are still numerous locations in the country with untapped potential for wind energy development. However, it should be noted that constructing wind farms in certain areas can be challenging due to various factors. Therefore, it is crucial to conduct thorough and precise research and assessments for each potential location to accurately determine its feasibility for wind farm construction.

In conclusion, wind energy is a clean, abundant, and cost-effective alternative to fossil fuels. By using wind power, we can reduce harmful emissions, support sustainable development, and create a more environmentally friendly energy system. Wind energy has great potential to contribute to a greener and more resilient future. It's crucial that we continue to support its expansion and integration into our global energy sources.

Appendices

№	Latitude	Longitude	Name	Aimag	Soum	Height of station	ZipCode
1	49.97	92.08	Ulaangom	Uvs	Ulaangom	936	212
2	49.66	94.40	Baruunturuun	Uvs	Baruunturuun	1232	213
3	48.98	89.94	Ulgii	Bayan-Ulgii	Ulgii	1715	214
4	49.10	91.73	Umnugobi	Uvs	Umnugobi	1591	215
5	48.83	93.11	Zavkhan	Uvs	Zavkhan	1050	216
6	48.30	89.52	Yalalt	Bayan-Ulgii	Altai	2148	217
7	48.00	91.63	Jargalant	Khovd	Khovd	1406	218
8	51.11	99.67	Renchinlkhumbe	Khuvsgul	Renchinlkhumbe	1583	203
9	50.44	100.15	Khatgal	Khuvsgul	Khatgal	1668	207
10	48.16	99.88	Tariat	Arkhangai	Tariat	2061	229
11	49.61	101.98	Tarialan	Arkhangai	Tarialan	1218	230
12	49.64	100.17	Murun	Khuvsgul	Murun	1291	231
13	49.39	102.71	Khutga	Bulgan	Khutga	946	232
14	49.04	104.09	Erdenet	Orkhon	Bayan-Undur	1305	236
15	50.24	106.17	Sukhbaatar	Selenge	Sukhbaatar	620	240
16	49.55	114.40	Dashbalbar	Dornod	Dashbalbar	704	256
17	48.08	114.54	Choibalsan	Dornod	Choibalsan	747	259
18	47.63	118.62	Khalkhgol	Dornod	Khalkhgol	687	313
19	46.96	115.30	Matad	Dornod	Matad	901	314
20	48.91	106.09	Baruunkharaa	Selenge	Bayangol	811	241
21	49.14	105.40	Orkhon	Selenge	Orkhon	756	242
22	49.75	106.66	Yeroo	Selenge	Yeroo	673	243
23	48.26	105.41	Ugtaal	Tuv	Ugtaal	1161	247
24	47.33	104.49	Erdenesant	Tuv	Erdenesant	1364	286
25	47.65	95.00	Durvuljin	Zavkhan	Durvuljin	1389	219
26	49.70	96.36	Bayantes	Zavkhan	Bayantes	1424	221
27	48.75	96.00	Tsetsen-Uul	Zavkhan	Tsetsen-Uul	1933	224
28	47.71	106.95	Zuunmod	Tuv	Zuunmod	1532	290
29	49.02	111.61	Dadal	Khentii	Dadal	993	254
30	48.62	110.60	Binder	Khentii	Binder	1052	257
31	47.79	112.11	Bayan-Ovoo	Khentii	Bayan-Ovoo	926	302
32	47.31	110.62	Undurkhaan	Khentii	Undurkhaan	1035	304
33	48.76	98.26	Tosontsengel	Zavkhan	Tosontsengel	1721	225
34	48.53	101.37	Erdenemandal	Arkhangai	Erdenemandal	1511	237
35	48.82	103.52	Bulgan	Bulgan	Bulgan	1221	239
36	46.81	98.09	Bayanbulag	Bayankhongor	Bayanbulag	2259	275

37	47.47	101.46	Tsetserleg	Arkhangai	Tsetserleg	1685	282
38	46.70	100.14	Galuut	Bayankhongor	Galuut	2127	284
39	46.90	102.77	Khujirt	Uvurkhangai	Khujirt	1661	285
40	47.84	106.76	Nisekh	Ulaanbaatar	Khan-Uul district	1296	291
41	47.92	106.85	Takhilt	Ulaanbaatar	Songinokhairkhan district	1301	292
42	47.26	107.54	Maanit	Tuv	Bayan	1429	294
43	46.35	108.37	Choir	Govisumber	Sumber	1290	298
44	46.67	113.28	Baruun-Urt	Sukhbaatar	Baruun-Urt	981	305
45	45.91	115.37	Erdenetsagaan	Sukhbaatar	Erdenetsagaan	1076	317
46	45.73	112.36	Bayandelger	Sukhbaatar	Bayandelger	1102	352
47	45.46	103.90	Saikhan-Ovoo	Dundgobi	Saikhan-Ovoo	1317	336
48	44.10	103.54	Saikhan	Umnugobi	Bulgan	1301	339
49	45.74	106.26	Mandalgobi	Dundgobi	Saintsagaan	1395	341
50	44.42	105.32	Tsogt-Ovoo	Umnugobi	Tsogt-Ovoo	1295	347
51	44.40	108.25	Mandakh	Dornogobi	Mandakh	1308	348
52	44.88	110.12	Sainshand	Dornogobi	Sainshand	938	354
53	43.71	111.90	Zamiin-Uud	Dornogobi	Zamiin-Uud	964	358
54	43.58	104.42	Dalanzadgad	Umnugobi	Dalanzadgad	1466	373
55	43.23	101.04	Gurvantes	Umnugobi	Gurvantes	1729	374
56	43.20	107.19	Khanbogd	Umnugobi	Khanbogd	1114	385
57	46.17	100.71	Bayankhongor	Bayankhongor	Bayankhongor	1860	287
58	46.93	91.08	Duchinjil	Bayan-Ulgii	Bulgan	1951	263
59	47.11	92.84	Zereg	Khovd	Zereg	1151	264
60	46.09	91.55	Baitag	Khovd	Bulgan	1189	265
61	46.26	102.79	Arvaikheer	Uvurkhangai	Arvaikheer	1815	288
62	44.55	99.27	Jinst	Bayankhongor	Shinejinst	2223	329
63	44.67	102.18	Bogd	Uvurkhangai	Bogd	1521	338
64	46.30	93.91	Tonkhil	Gobi-Altai	Tonkhil	2200	266
65	47.73	96.85	Uliastai	Zavkhan	Uliastai	1776	272
66	46.38	96.24	Altai	Gobi-Altai	Altai	2180	277
67	43.24	99.01	Enkhiingol	Bayankhongor	Shinejinst	979	366
68	44.92	96.75	Tooroi	Gobi-Altai	Tsogt	1181	325
69	43.60	109.64	Khuvsgul	Dornogobi	Khuvsgul	998	386

Wind power density (MW)													
Index	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**Total**
203	0.01	0.01	0.01	0.03	0.04	0.02	0.01	0.01	0.01	0.01	0.00	0.00	**0.16**
207	0.05	0.06	0.06	0.05	0.06	0.03	0.02	0.02	0.02	0.02	0.05	0.05	**0.49**
212	0.00	0.01	0.01	0.03	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.00	**0.20**
213	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	**0.07**
214	0.05	0.12	0.09	0.07	0.08	0.07	0.05	0.03	0.06	0.04	0.10	0.03	**0.78**
215	0.06	0.09	0.09	0.08	0.10	0.09	0.06	0.05	0.06	0.05	0.06	0.03	**0.83**
216	0.00	0.02	0.03	0.06	0.07	0.06	0.04	0.04	0.03	0.02	0.03	0.01	**0.42**
217	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	**0.07**
218	0.00	0.02	0.03	0.03	0.03	0.03	0.02	0.01	0.02	0.01	0.01	0.00	**0.21**
219	0.03	0.07	0.07	0.07	0.10	0.08	0.06	0.07	0.05	0.05	0.05	0.03	**0.73**
221	0.00	0.01	0.01	0.02	0.04	0.03	0.01	0.02	0.01	0.01	0.01	0.00	**0.16**
224	0.01	0.01	0.02	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.10**
225	0.01	0.01	0.01	0.04	0.06	0.03	0.01	0.01	0.02	0.01	0.01	0.01	**0.24**
229	0.06	0.03	0.02	0.03	0.06	0.05	0.01	0.02	0.02	0.02	0.02	0.02	**0.35**
230	0.06	0.06	0.08	0.09	0.11	0.07	0.05	0.04	0.05	0.05	0.04	0.05	**0.76**
231	0.02	0.03	0.02	0.03	0.06	0.02	0.01	0.01	0.01	0.01	0.01	0.01	**0.23**
232	0.05	0.05	0.05	0.07	0.07	0.04	0.04	0.04	0.05	0.05	0.03	0.05	**0.58**
236	0.04	0.04	0.05	0.06	0.07	0.05	0.03	0.04	0.03	0.03	0.04	0.03	**0.51**
237	0.08	0.11	0.08	0.09	0.14	0.07	0.03	0.05	0.05	0.05	0.07	0.05	**0.88**
239	0.03	0.03	0.05	0.07	0.09	0.06	0.03	0.05	0.03	0.04	0.03	0.03	**0.54**
240	0.03	0.03	0.05	0.07	0.09	0.06	0.03	0.05	0.03	0.04	0.03	0.03	**0.55**
241	0.01	0.03	0.04	0.06	0.06	0.04	0.02	0.03	0.02	0.02	0.02	0.01	**0.36**
242	0.00	0.01	0.02	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.00	**0.19**
243	0.02	0.02	0.03	0.04	0.04	0.02	0.01	0.01	0.02	0.02	0.02	0.02	**0.26**
247	0.01	0.02	0.05	0.12	0.10	0.08	0.04	0.05	0.04	0.03	0.03	0.01	**0.58**
254	0.03	0.04	0.05	0.06	0.06	0.03	0.02	0.02	0.02	0.03	0.02	0.03	**0.41**
256	0.04	0.03	0.05	0.08	0.07	0.03	0.01	0.01	0.02	0.01	0.01	0.02	**0.36**
257	0.02	0.02	0.03	0.04	0.06	0.03	0.01	0.01	0.01	0.01	0.00	0.01	**0.24**
259	0.07	0.07	0.09	0.12	0.13	0.08	0.04	0.05	0.05	0.07	0.06	0.07	**0.89**
263	0.03	0.04	0.05	0.07	0.08	0.06	0.05	0.03	0.04	0.04	0.04	0.03	**0.54**
264	0.00	0.01	0.02	0.02	0.04	0.03	0.02	0.01	0.01	0.00	0.01	0.00	**0.17**
265	0.00	0.01	0.02	0.03	0.04	0.03	0.02	0.01	0.01	0.02	0.00	0.00	**0.19**
266	0.07	0.11	0.12	0.13	0.17	0.14	0.08	0.08	0.11	0.07	0.11	0.04	**1.23**
272	0.01	0.01	0.02	0.03	0.05	0.04	0.03	0.03	0.02	0.01	0.01	0.01	**0.28**
275	0.03	0.04	0.04	0.05	0.11	0.05	0.02	0.03	0.04	0.01	0.02	0.01	**0.47**
277	0.03	0.04	0.04	0.05	0.11	0.05	0.02	0.03	0.04	0.01	0.02	0.01	**0.47**
282	0.04	0.04	0.04	0.05	0.06	0.03	0.02	0.02	0.02	0.02	0.02	0.02	**0.39**
284	0.00	0.00	0.01	0.02	0.05	0.02	0.01	0.01	0.01	0.00	0.00	0.00	**0.14**
285	0.01	0.01	0.03	0.04	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.00	**0.24**

286	0.05	0.03	0.05	0.06	0.09	0.03	0.01	0.03	0.02	0.02	0.03	0.02	**0.44**
287	0.07	0.07	0.06	0.08	0.11	0.06	0.03	0.04	0.04	0.03	0.04	0.05	**0.68**
288	0.02	0.01	0.04	0.07	0.08	0.06	0.03	0.04	0.04	0.03	0.03	0.02	**0.46**
290	0.03	0.05	0.08	0.14	0.09	0.04	0.05	0.05	0.04	0.04	0.02	0.01	**0.64**
291	0.01	0.01	0.03	0.04	0.06	0.04	0.02	0.03	0.02	0.02	0.01	0.00	**0.28**
292	0.00	0.00	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	**0.12**
294	0.02	0.01	0.04	0.07	0.08	0.06	0.02	0.02	0.02	0.01	0.01	0.01	**0.36**
298	0.08	0.07	0.11	0.19	0.17	0.15	0.08	0.09	0.08	0.06	0.07	0.06	**1.19**
302	0.11	0.10	0.10	0.14	0.15	0.07	0.04	0.05	0.05	0.07	0.09	0.12	**1.09**
304	0.07	0.06	0.08	0.16	0.17	0.07	0.05	0.07	0.05	0.07	0.07	0.08	**1.00**
305	0.06	0.08	0.13	0.16	0.14	0.10	0.06	0.07	0.06	0.07	0.08	0.07	**1.07**
313	0.06	0.07	0.10	0.11	0.11	0.06	0.02	0.03	0.05	0.06	0.06	0.05	**0.79**
314	0.15	0.12	0.13	0.17	0.17	0.10	0.06	0.06	0.05	0.10	0.12	0.13	**1.35**
317	0.03	0.03	0.04	0.04	0.04	0.01	0.00	0.01	0.01	0.02	0.02	0.02	**0.29**
325	0.01	0.02	0.03	0.04	0.09	0.06	0.04	0.05	0.02	0.03	0.01	0.01	**0.43**
329	0.15	0.18	0.14	0.15	0.21	0.14	0.06	0.10	0.09	0.06	0.12	0.09	**1.50**
336	0.02	0.04	0.06	0.09	0.08	0.06	0.03	0.04	0.03	0.02	0.02	0.01	**0.51**
338	0.03	0.05	0.07	0.06	0.10	0.07	0.03	0.03	0.03	0.02	0.03	0.02	**0.54**
339	0.22	0.18	0.10	0.09	0.11	0.07	0.03	0.04	0.05	0.07	0.23	0.19	**1.39**
341	0.07	0.06	0.08	0.15	0.17	0.11	0.06	0.07	0.05	0.04	0.06	0.04	**0.96**
347	0.12	0.14	0.13	0.16	0.15	0.11	0.09	0.10	0.07	0.06	0.09	0.06	**1.27**
348	0.14	0.10	0.07	0.13	0.14	0.09	0.04	0.08	0.05	0.03	0.12	0.10	**1.11**
352	0.05	0.05	0.06	0.08	0.07	0.03	0.02	0.03	0.02	0.04	0.05	0.06	**0.55**
354	0.05	0.03	0.05	0.10	0.10	0.07	0.02	0.03	0.02	0.03	0.06	0.06	**0.62**
358	0.05	0.06	0.07	0.11	0.10	0.08	0.05	0.05	0.04	0.04	0.06	0.06	**0.76**
366	0.03	0.03	0.05	0.04	0.06	0.02	0.02	0.02	0.01	0.03	0.02	0.01	**0.35**
373	0.05	0.06	0.06	0.09	0.13	0.07	0.04	0.05	0.05	0.04	0.04	0.02	**0.71**
374	0.06	0.09	0.08	0.10	0.17	0.11	0.07	0.08	0.08	0.05	0.06	0.05	**0.99**
385	0.10	0.11	0.11	0.14	0.16	0.09	0.06	0.07	0.06	0.06	0.14	0.13	**1.23**
386	0.11	0.12	0.13	0.16	0.20	0.12	0.06	0.07	0.06	0.06	0.11	0.11	**1.30**

References

1. Environmental and Sustainable Development [Internet]. [cited 2022]. Available from: https://ncert.nic.in/textbook/pdf/keec109.pdf
2. United Nations. Renewable energy – powering a safer future [Internet]. United Nations. United Nations; Available from: https://www.un.org/en/climatechange/raising-ambition/renewable-energy
3. Renewable energy production in Norway [Internet] [cited 2022]. Available from:https://www.regjeringen.no/en/topics/energy/renewable-energy/renewable-energy production-in-norway/id2343462/
4. Elliott D, Schwartz M, Scott G, Haymes G, Heimiller D, George R. *Wind Resource Atlas of Mongolia.* National Renewable Energy Laboratory; 2001.
5. Chen Y, Gönül G, Tumenjargal M. *Mongolia Renewable Readiness Assessment.* International Renewable Energy Agency; 2016.
6. Klarin T. The Concept of Sustainable Development: From its Beginning to the Contemporary Issues. Zagreb International Review of Economics and Business [Internet]. 2018 May 1;21(1):67–94. Available from: https://doi.org/10.2478/zireb-2018-0005
7. BDO Sustainability Movement [Internet]. www.bdo.global. Available from: https://www.bdo.global/en-gb/microsites/bdo-sustainability/bdo-sustainability-movement
8. What Is Economic Sustainability? (With Examples and Tips) [Internet]. Indeed Career Guide. Available from: https://www.indeed.com/career-advice/career-development/what-is-economic-sustainability
9. Renewable Energy: The Clean Facts. Renewable Energy: The Clean Facts [Internet]. NRDC. 2019. Available from: https://www.nrdc.org/stories/renewable-energy-clean-facts#sec-types
10. Office of Energy Efficiency & Renewable Energy. Renewable Energy [Internet]. Energy.gov. 2022. Available from: https://www.energy.gov/eere/renewable-energy
11. Office of Energy Efficiency & Renewable Energy. Bioenergy Basics [Internet]. Energy.gov. 2018. Available from: https://www.energy.gov/eere/bioenergy/bioenergy-basics

12. IPCC. Renewable energy sources and climate change mitigation: special report of the Intergovernmental Panel on Climate Change. Choice Reviews Online. 2012 Jul 1;49(11):49–630949–6309.
13. enel. All the advantages of hydroelectric energy [Internet].www.enelgreenpower.com. Available from: https://www.enelgreenpower.com/learning-hub/renewable-energies/hydroelectric-energy/advantages
14. Bojek P. Hydroelectricity – Analysis [Internet]. IEA. 2022. Available from: https://www.iea.org/reports/hydroelectricity
15. Acciona. What are the benefits of solar energy? | ACCIONA | Business as unusual [Internet].www.acciona.com. 2020. Available from: https://www.acciona.com/renewable-energy/solaenergy/?_adin=02021864894
16. ENEL Green Power. All the benefits of wind power [Internet]. www.enelgreenpower.com. Available from: https://www.enelgreenpower.com/learning-hub/renewable-energies/wind-energy/advantages-wind-energy
17. IRENA. Wind energy [Internet]. www.irena.org. 2022. Available from: https://www.irena.org/Energy-Transition/Technology/Wind-energy
18. Energy – Invest in Mongolia | Ministry of Economy and Development [Internet]. Available from: https://investmongolia.gov.mn/energy/
19. Department of Energy. How a Wind Turbine Works [Internet]. Energy.gov. 2014. Available from: https://www.energy.gov/articles/how-wind-turbine-works
20. How Do Wind Turbines Work? [Internet]. Energy.gov. Available from: https://www.energy.gov/eere/wind/how-do-wind-turbines-work#size
21. What is the wind class of a wind turbine? - Renewables First [Internet]. Renewables First - The Renewable Energy Company. Available from: https://www.renewablesfirst.co.uk/home/renewable-energy-technologies/windpower/windpower-learning-centre/what-is-the-wind-class-of-a-wind-turbine/
22. Alamdari P, Nematollahi O, Mirhosseini M. Assessment of wind energy in Iran: A review. Renewable and Sustainable Energy Reviews. 2012 Jan;16(1):836–60.
23. 1.İlkiliç C. Wind energy and assessment of wind energy potential in Turkey. Renewable and Sustainable Energy Reviews. 2012 Feb;16(2):1165–73.
24. 1.Wu J, Wang J, Chi D. Wind energy potential assessment for the site of Inner Mongolia in China. Renewable and Sustainable Energy Reviews. 2013 May;21:215–28.

25. D.Odontungalag, D.Dulamsuren. *Calculation of solar and wind energy resources with spatial accuracy using regional atmospheric dynamic models and evolution of its environmental effects.* Metropolitan Air Pollution Control Department ;
26. Mongolian Tourism Board. Mongolia Travel Guide. [Internet]. [cited 2023 Apr 23]. Available from: https://www.mongolia.travel/
27. Climate: Western (Altai Mountains) in Mongolia [Internet]. Worlddata.info. [cited 2023 May 10]. Available from: https://www.worlddata.info/asia/mongolia/climate-western-altai-mountains.php
28. Sainjargal, D., & Chimeddorj, B. (2019). Geospatial analysis of potential wind energy resources in eastern Mongolia. Journal of Renewable Energy, 2019, 1-11. doi: 10.1155/2019/4070960
29. Harris CD, Lattimore O. Mongolia | Culture, History, & People. In: Encyclopædia Britannica [Internet]. 2018. Available from: https://www.britannica.com/place/Mongolia
30. Climate: Central Mongolia [Internet]. Worlddata.info. [cited 2023 May 10]. Available from: https://www.worlddata.info/asia/mongolia/climate-central.php
31. V110-2.0 MW^{TM} [Internet]. www.vestas.com. Available from: https://www.vestas.com/en/products/2-mw-platform/V110-2-0-mw