E-ISSN : 3062-3391

Eurasian Journal of Theoretical and Applied Sciences (EJTAS)
Volume 1, Issue 3, 2025, Page No: 18-28
Website: https://eurasian-journals.com/index.php/etjas/index

Wind Energy: an overview of the physical basics and the current types of technology

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Received: May 24, 2025	Accepted: July 29, 2025	Published: September 02, 2025

Abstract:
In recent years, the need for renewable energy has become a primary topic of discussion among all countries worldwide. This is especially true because the use of fossil fuels, such as natural gas and crude oil, has led to more environmental pollution, and the availability of these fuels is also decreasing. Renewable energy is a type of energy that originates from natural sources, and it requires specialized technology to be utilized in a manner that produces clean energy. Wind energy is one of the most commonly used renewable energy sources, and it has been used for many years. This article will explain why wind forms on the Earth's surface, the factors that influence how much energy can be taken from the wind, the effects of wind energy on the environment, and the different types of turbines used in wind power plants. These turbines are designed to collect the energy in the wind and turn it into mechanical energy, and then, through an electric generator attached to the turbine, they create electrical energy

Keywords: Wind speed, Wind turbines, Wind power curve, Wind power plant.

الملخص
في السنوات الأخيرة، أصبحت الحاجة إلى الطاقة المتجددة موضوعًا رئيسيًا للنقاش بين جميع دول العالم. ويتجلى ذلك بشكل خاص في تزايد التلوث البيئي نتيجة استخدام الوقود الأحفوري، كالغاز الطبيعي والنفط الخام، وتناقص توفر هذه الأنواع من الوقود. الطاقة المتجددة هي نوع من الطاقة ينبع من مصادر طبيعية، ويتطلب استخدامها تقنيات متخصصة لإنتاج طاقة نظيفة. تُعد طاقة الرياح من أكثر مصادر الطاقة المتجددة شيوعًا، وقد استُخدمت لسنوات عديدة. تشرح هذه المقالة أسباب تشكل الرياح على سطح الأرض، والعوامل التي تؤثر على كمية الطاقة التي يمكن استخلاصها منها، وتأثيرات طاقة الرياح على البيئة، وأنواع التوربينات المختلفة المستخدمة في محطات طاقة الرياح. صُممت هذه التوربينات لجمع طاقة الرياح وتحويلها إلى طاقة ميكانيكية، ثم تُنتج طاقة كهربائية من خلال مولد كهربائي متصل بالتوربين.

الكلمات المفتاحية: سرعة الرياح، توربينات الرياح، منحنى طاقة الرياح، محطة طاقة الرياح.

1. Introduction

Wind energy has been used by people for over three thousand years to grind grain, sail boats, and pump water using windmills [5, 8]. In 1888, Charles Brush built the first big wind turbine that could generate electricity, which had a wind rose shape and 12 kW generators. The first modern wind turbine designed for electricity was made in Denmark in 1890 [8]. In the 1890s, the Lewis Electric Company in New York sold generators that could be added to old windmills. From the 1920s to the 1950s, there were wind turbines with propeller shapes and two or three blades that converted wind into electricity. In the 1940s and 1960s, electrification in the US and Europe caused a drop in the use of these wind systems [9]. During the energy crisis in the 1970s, better materials and technology made wind turbines more cost-effective, energy-independent, and better for the environment [5]. Wind is created when air moves because of differences in atmospheric pressure. Wind moves from areas with high pressure to areas with low pressure. The bigger the pressure difference, the faster the wind, and the more energy can be captured by wind turbines. The movement of wind is affected by many factors. The most important factors are the uneven heating of the Earth by the sun, the geography of the land like hills, water, and forests, and the Coriolis Effect caused by the Earth's rotation [1, 4, 5, and 10]. Wind energy is a type of solar energy, and its speed depends on where you are, the landscape, and the season. Because of this, some places are better for generating wind energy [4, 7].

1.1 **Uneven Solar Heating**

The first reason for uneven heating is that the Earth is perpendicular to the sun's rays at the equator but parallel at the poles. The equator gets the most solar energy per area, and this energy reduces as you move toward the poles. This uneven heating creates a temperature difference from the equator to the poles and a pressure difference from the poles to the equator. Hot air, which is less dense, rises at the equator and moves toward the poles, while cold, denser air flows from the poles to the equator along the Earth's surface. Without considering the Earth's rotation and the Coriolis Effect, air circulation in each hemisphere forms a single cell, known as the meridional circulation. Second, the Earth's axis is tilted about 23.5 degrees from the ecliptic plane. This tilt causes seasonal changes as the Earth orbits the sun. Third, the Earth has different types of surfaces, like vegetation, rocks, sand, water, ice, and snow. These surfaces absorb and reflect sunlight differently, leading to hot areas like deserts and cold areas like icy lakes, even at the same latitude. Fourth, the Earth's topography, with mountains, valleys, and hills, causes different solar radiation on the sunny and shady sides [4]

1.2 Coriolis effect

The Earth's rotation plays a big role in how wind moves and how fast it moves. This is because of something called the Coriolis force, which is created by the Earth's spinning. In the northern part of the world, this force makes winds turn to the right, and in the southern part, winds turn to the left. The strength of the Coriolis force depends on where you are on the Earth; it is not strong at all near the equator but is strongest at the poles. Also, the amount that wind is turned depends on how fast it is blowing; slow winds are turned only a little, but strong winds are turned more. When looking at big air movements, the combination of pressure differences caused by uneven sunlight and the Coriolis force from Earth's spin causes one big air cell to split into three separate cells in each half of the world: the Hadley cell, the Ferrel cell, and the Polar cell, as shown in Figure 1. Each of these cells has its own way of moving air. In the Northern Hemisphere, the Hadley cell is between the equator and 30 degrees north, and it affects tropical and subtropical climates. Hot air rises at the equator and moves toward the North Pole in the upper part of the air. This moving air is turned by the Coriolis force, creating the northeast trade winds. At about 30 degrees north, the Coriolis force gets so strong that it balances the force from pressure differences. This causes the winds to turn west. The air that builds up in the upper part of the atmosphere forms a high-pressure area near the 30 degrees north line, and then falls back to the Earth's surface. It splits into two parts: one goes back to the equator to complete the Hadley cell loop, and the other moves along the Earth's surface toward the North Pole to start the Ferrel cell, which is between 30 and 60 degrees north. The air continues to move toward the North Pole along the Earth's surface until it meets cold air coming from the North Pole at about 60 degrees north. Because of the Coriolis force, this moving air turns to create westerly winds. The Polar cell is between the North Pole and 60 degrees north. Cold air sinks at the North Pole and moves along the Earth's surface toward the equator. Near 60^0 north, the Coriolis Effect causes the air to move southwest [4].

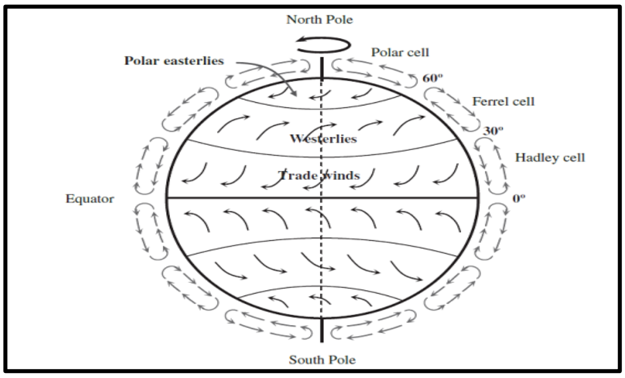


Figure 1. Idealized atmospheric circulations [4].

1.3 Local geography

The roughness on the Earth's surface comes from both natural features and man-made objects. Friction and obstacles near the surface usually slow down the wind, and this creates something called wind shear. The way wind speed increases with height depends on the local landscape, terrain, and climate. The biggest increases in wind speed happen over the roughest areas. A good estimate is that wind speed increases by about 10% each time the height doubles. Also, certain geographic features can greatly boost wind speed. For example, wind blowing through mountain passes can create fast-moving wind streams called mountain jets [4].

2. Wind energy characteristics

The terms wind energy or wind power refers to using the wind to produce mechanical power or electricity. Wind turbines take the kinetic energy in the wind and turn it into mechanical power. This mechanical power can be used for certain tasks, like grinding grain or pumping water. A generator can also turn this mechanical power into electricity [1]. Three main factors affect how much energy a turbine can get from the wind: wind speed, air density, and the size of the swept area [4, 9].

2.1 Wind power

Kinetic energy exists whenever an object of a certain mass is moving, either by translation or rotation. When air is moving, the kinetic energy in the wind can be calculated using the formula:

$$E=\frac{1}{2}\, m\overline{u^2} \quad (1)$$

Where m is the mass of the air and u is the average wind speed over a certain period. The wind power can be found by taking the derivative of the kinetic energy with respect to time, which is:

$$Pw = \frac{d\,Ek}{dt} \quad (2)$$

However, only a small part of wind power can be turned into electrical power. When wind passes through a wind turbine and turns the blades, the wind mass flow rate is:

$$\dot{m} = \rho A\bar{u} \quad (3)$$

Where ρ is the air density and A is the swept area of the blades, as shown in Fig. 3. Substituting (3) into (2), the available wind power (Pw) can be written as:

$$Pw= \frac{1}{2}\,\rho A\overline{u^3} \quad (4)$$

Looking at equation (4), it's clear that to get more wind power, you need higher wind speed, longer blades to increase the swept area, and higher air density. Since wind power is proportional to the cube of the wind speed, even a small change in wind speed can lead to a big change in wind power [4, 6, and 9].

2.2 Blade swept area

As shown in Figure 2, the blade swept area can be calculated from the formula:

$$A= \pi\,[\ (1+r)^2 - r^2\ ] = \pi\,(1+ 2r^2) \quad (5)$$

r represents the radius of the circle swept by the rotating blades

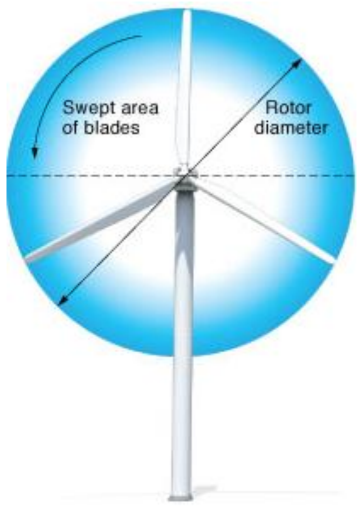


Figure 2. Swept area of wind turbine blades [4]

Where L is the length of the wind blades and r is the radius of the hub. So, if you double the length of the blades, the swept area can increase by up to four times. When L is much larger than 2r, the swept area is approximately πL^2.

3. Air density

Another important factor that directly influences wind power generation is the density of the air.

This can be calculated using the equation of state:

$$\rho=\frac{P}{RT} \tag{6}$$

Where P is the local air pressure, R is the gas constant (287 J/Kg.K for air), and T is the air temperature in Kelvin. The hydrostatic equation says that when there is no vertical movement, the difference in pressure between two heights is due to the weight of the air layer:

$$dp = -\rho g\, dz \tag{7}$$

Where g is the acceleration due to gravity. Combining Equations (6) and (7) gives:

$$\frac{dp}{p} = -\frac{g}{RT}dz \tag{8}$$

The acceleration due to gravity g decreases with height above the Earth's surface z:

$$g= g_0\left(1 - \frac{4z}{D}\right) \tag{9}$$

Where (g_0) is the acceleration due to gravity at the ground and (D) is the diameter of the Earth.

However, the change in g with height can be ignored because D is much larger than 4z. Also, temperature decreases with height. Assuming that the change in temperature with height is constant (dT/dz = c), it can be derived that:

$$P= P_0\left(\frac{T}{T_0}\right)^{-g/cR} \tag{10}$$

Where (P_0) and (T0) are the air pressure and temperature at the ground, respectively. Combining Equations (6) and (10) gives:

$$\rho=\rho_0\left(\frac{T}{T_0}\right)^{-g/cR} =\rho_0\left(1+\frac{cz}{T_0}\right)^{-g/cR} \tag{11}$$

This equation indicates that the density of air decreases nonlinearly with height above the sea level. [4]. Typical values of wind power classes, along with their corresponding power densities and mean wind speeds, are presented in Table 1 by the National Renewable Energy Laboratory (NREL) of the United States of America (USA). These values are measured at 50 m above ground, according to NREL's wind power density-based classification. Wind speed corresponding to each class is the mean wind speed based on the Rayleigh probability distribution of equivalent mean wind power density at 1500 m elevation above sea level. Data adopted from <https://www.nrel.gov/gis/data-wind.html>. [12]

Table 1. Wind Power Classification [12].

Wind Power Class	Resource Potential	Wind Power Density (W m^{-2})	Wind Speed (m s^{-1})
1	Poor	0 - 200	0.0 - 5.9
2	Poor	0 - 200	0.0 - 5.9
3	Fair	300 - 400	6.7 - 7.4
4	Good	500 - 600	7.4 - 7.9
5	Excellent	500 - 600	7.9 - 8.4
6	Outstanding	600 - 800	8.4 - 9.3
7	Superb	> 800	> 9.3

3. Wind power parameters

3.1 Power coefficient.

The process of turning wind energy into electricity happens in two main steps. In the first step, the wind's kinetic energy is turned into mechanical energy that makes the shaft of a wind generator turn. But there are several aerodynamic losses in wind turbine systems, like blade-tip, blade-root, profile, and wake rotation losses, which make the actual power coefficient, Cp, much lower than the theoretical maximum. Usually, Cp ranges from 30 to 45%. The power coefficient Cp measures how well the first step converts wind energy to mechanical energy. It is the ratio of the mechanical power actually captured by the blades to the total wind power available, as shown in Equation (12) [4,9,12]:

$$Cp = \frac{Pme,out}{Pw} = \frac{Pme,out}{(\frac{1}{2})\rho A\overline{u^3}} \quad (12)$$

3.2 Total power conversion coefficient and effective power output.

In the second step, the mechanical energy captured by the blades is turned into electrical energy using wind generators. The efficiency of this step depends on several factors.

a. Gearbox efficiency ηgear. The power losses in a gearbox can be broken into two types: load-dependent and no-load losses. Load-dependent losses include gear tooth friction and bearing losses. No-load losses include oil churning, windage, and shaft seal losses. Planetary gearboxes, which are often used in wind turbines, have higher power transmission efficiency compared to conventional gearboxes.
b. Generator efficiency ηgen. This is related to all the electrical and mechanical losses in the wind generator, such as copper, iron, load, windage, friction, and other miscellaneous losses.
c. Electric efficiency ηele. This covers all the electric power losses that happen in the converter, switches, controls, and cables. Therefore, the total power conversion efficiency from wind to electricity, ηt , is the product of these parameters, like this:

$$\eta t = Cp\ \eta gear\ \eta gen\ \eta ele \quad (13)$$

The actual power output that a wind turbine delivers to the electricity grid becomes:

$$Peff = Cp\ \eta gear\ \eta gen\ \eta elePw = \eta tPw = (\frac{1}{2})\rho A\overline{u^3} \quad (14)$$

3.3 **Lanchester-Betz.**

The Betz limit is the highest possible efficiency for a wind turbine, first proposed by physicist Albert Betz in 1919. Betz found that this limit is 59.3%, which means most of the wind's kinetic energy about 59.3% can be converted into electricity to spin the turbine. But in reality, turbines can't reach the Betz limit. Common efficiency levels are between 35 and 45%. If a turbine were 100% efficient, the wind would have to stop completely as it hit the blades, which isn't possible in practice [4, 12].

3.4 **Wind Speed Power Curve.**

Wind speed plays a big role in how much electricity a turbine produces. Higher wind speeds generate more power because stronger winds make the blades spin faster. Faster spinning means more mechanical power and more electrical power from the generator. The relationship between wind speed and power for a typical wind turbine is shown in figure 3.

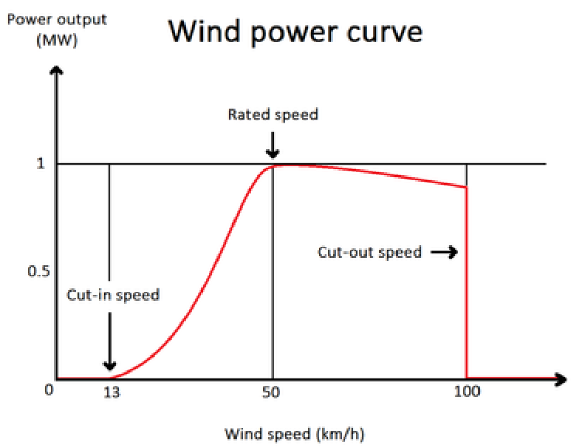


Figure 3 Wind power curve [4].

Turbines are designed to operate within a specific range of wind speeds. The limits of the range are known as the cut-in speed and cut-out speed. The cut-in speed is the point at which the wind turbine can generate power. Between the cut-in speed and the rated speed, where the maximum output is reached, the power output will increase cubically with wind speed. For example, if wind speed doubles, the power output will increase 8 times. This cubic relationship is what makes wind speed such an important factor for wind power. This cubic dependence does cut out at the rated wind speed. This leads to the relatively flat part of the curve in Fig. 3, so the cubic dependence is observed during the speeds below 15 m/s (54 kph). The cut-out speed is the point at which the turbine must be shut down to avoid damage to the equipment. The cut-in and cut-out speeds are related to the turbine design and size and are decided on before construction.

3.5 Tip Speed Ratio, often called TSR, is very important in how wind turbines are designed.
If the blades spin too slowly, most of the wind will go through the space between them. But if they spin too fast, the blades look like a solid wall to the wind. So turbines are made to have the best tip speed ratio to get as much power as possible from the wind. The tip speed ratio is found by dividing the speed of the blade tips by the speed of the wind. For instance, if the wind is blowing at 20 mph and the blade tips are moving at 80 mph, the tip speed ratio is 80 divided by 20, which is 4.

3.6 Force on a wind turbine. Air moving over any surface makes two kinds of forces: drag, which goes in the same direction as the wind, and lift, which is at a right angle to the wind. Either one or both of these forces can be used to make the blades of a wind turbine turn [4,9]

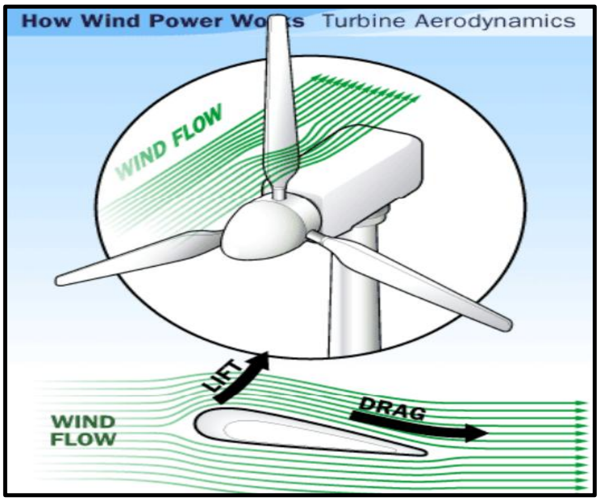


Figure 4. Force on a wind turbine [9].

4. Types of Wind Power Plants (WPPs)

A wind power plant is simply a collection of wind turbines in one area. There are several different types of wind power plants. The following classification is based on their construction, size, and usage [4].

4.1 Remote Wind Power Plants. Areas that are far away but have good wind speeds and often strong winds need wind turbines that don't need much maintenance. Imagine a service technician walking through mountains or riding a bullock cart to fix a turbine again and again. These turbines should be able to work well in tough weather conditions, even if they are smaller than regular turbines. These types of turbines are called remote wind power turbines and are made with these goals in mind [4].

4.2 Hybrid Wind Power Plants.
Wind power isn't always dependable, so we can't rely on it by itself to generate electricity. The best way is to combine a wind power plant with another clean energy source, like solar energy. When there is a lot of sunshine, the solar panels can work, and when it is cloudy and the wind is blowing, the wind plant can take over. This setup is called a hybrid system and is useful in areas with both high temperatures and wind [4].

4.3 Grid-Connected Wind Power Plants.
This idea is similar to a hybrid system. The wind power plant works together with the main electricity grid, which provides most of the power. The main job of the wind turbines is to add more electricity to the grid, while in a hybrid system, the main goal is to support the power supply, which is why the setups are a bit different [4].

4.4 Wind Farms.

A wind farm is a group of wind turbines that work together to supply electricity to a certain area or utility. By working together, they can generate more power than a single turbine. These setups are used in different places depending on the local conditions and the availability of other electricity sources [4, 5]. The biggest wind farm in the world is the Gansu Wind Farm in China. Even though it is not fully completed, by the end of 2014, it had 10.73 gigawatts of installed power [5].

4.5 Parts of Wind Power Plants.

There are three main groups of parts: mechanical, electrical, and control. Here is a brief explanation of the main parts as shown in Figure 5 [4.8]

- **The tower** is the main structure that holds the wind turbine. It supports the rotor, nacelle, blades, and other wind turbine. Most commercial towers are usually 50–120 meter tall, and they are made from concrete or reinforced steel.
- **Blades** are parts structures that are designed to capture as much wind energy as possible.
    - They work best when is between wind speed in the range of about 3–15 meter per second. Each blade is usually 20 meters or longer, depending on the size of the turbine.
- **The nacelle** is the box that holds of the generator, gearbox, and other important parts inside the turbine. It protects these parts from the weather.
- **The rotor** is the part that spins when the wind blows. It transfers the energy from the wind to the shaft. The rotor hub holds the blades and is connected to the gearbox through the low-speed shaft.
- **Pitch** is the system that changes the angle of the blades, This helps the blades adjust to changes in wind direction and speed.
- **There are two types of shafts**: low-speed and high-speed, The low-speed shaft sends mechanical energy from the rotor to the gearbox. The high-speed shaft sends energy from the gearbox to the generator.
- **Yaw** is the part that turns the turbine so it faces the wind. It can turn clockwise or counterclockwise. The yaw system includes a yaw motor and a yaw drive. The yaw drive helps the turbine face the wind when it changes direction, and the yaw motor moves the yaw system.
- **The brake** is a mechanical part that connects to the high-speed shaft. It helps slow down or stop the turbine if it's spinning too fast or in an emergency.
- **A gearbox** is a mechanical part that changes the speed of rotation. In wind turbines, it's used to control the speed of the generator.
- **The generator** is the part that turns mechanical energy into electrical energy. The most common types of generators used in wind turbines are induction generators (IGs), doubly fed induction generators (DFIGs), and permanent magnet synchronous generators (PMSGs).
- **The controller** is like the brain of the turbine. It keeps track of the turbine's condition and manages the pitch and yaw systems to get the most power from the wind.
- **An anemometer** is a sensor that measures wind speed. This information is important for getting the most power and for safety in emergencies.
- **The wind vane** is a sensor that measures wind direction. This information is needed for the yaw control system to work properly [4,8]

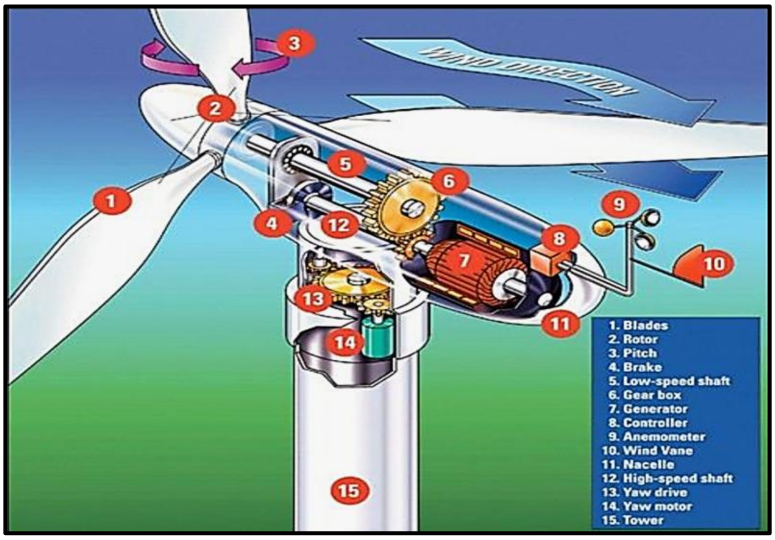


Figure 5. Components of a wind turbine [8].

5. Types of wind turbines

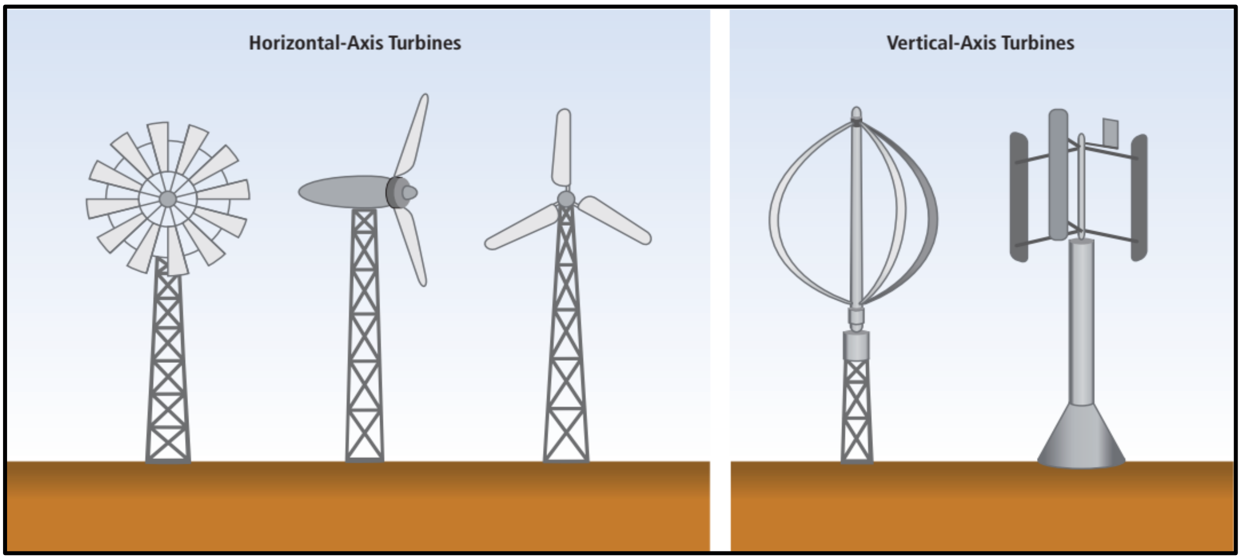
There are two main types of wind turbine designs:

5.1 Horizontal-axis turbines.

These turbines look similar to an airplane's propeller. They are the most common type used in large wind farms because they can generate more electricity from the same amount of wind [6, 7]. This type of turbine has a few blades that are shaped to move efficiently through the air. To control how much power it produces, the blades can be tilted (Pitch-regulation). Another, less expensive way to control the turbine is to shape the blades so that the air flowing over them starts to get messy at a certain speed (Stall-Regulation). These turbines can produce power from 10 kilowatts up to several megawatts. Most large wind turbines are upwind horizontal-axis turbines with three blades. Most small wind turbines are also horizontal-axis, as shown in Figure 6a [6].

5.2 Vertical-axis turbines.

These turbines have blades that are attached to the top and bottom of a vertical rotor. They look like an egg beater or a whisk. These types of turbines are often used in homes or smaller wind farms because they work well in areas with unpredictable wind and are good for places where it's hard to put turbines high enough to catch steady winds, as shown in Figure 6b [7]. New designs for vertical-axis turbines are being used in cities, especially in China. These turbines lose a lot of energy due to the shape of the blades and rotor (50-60%), some mechanical loss at the gear (4%), and more loss at the generator (6%). Overall, the efficiency of electricity generation is usually between 30% and 40% at wind farms [13].



(a) (b)

Figure 6. Early horizontal and vertical axis wind turbines (South et al., 1983) [3]

5.3 Technical design of wind turbines with gearbox.

The main feature of the traditional design is the split-shaft system, where the main shaft turns slowly as the rotor blades spin, and the torque is sent through a gearbox to a high-speed secondary shaft that powers a generator with few poles. The transfer of torque to the generator stops when a large disk brake on the main shaft is activated. A mechanical system controls the angle of the blades, known as pitch control. This system can also stop the turbine, for example, during storms. The pitch mechanism is powered by a hydraulic system that uses oil as the main fluid. This system requires maintenance almost every year and constant pressure checks, along with regular oiling of the gearbox. Because of the mechanical losses in the gearbox, the oil must be treated and cooled. In designs that don't have a main brake, each blade's pitch angle is controlled by a small electric motor. This is the usual setup for most wind converters, as shown in Figure 7 [3.6, 11].

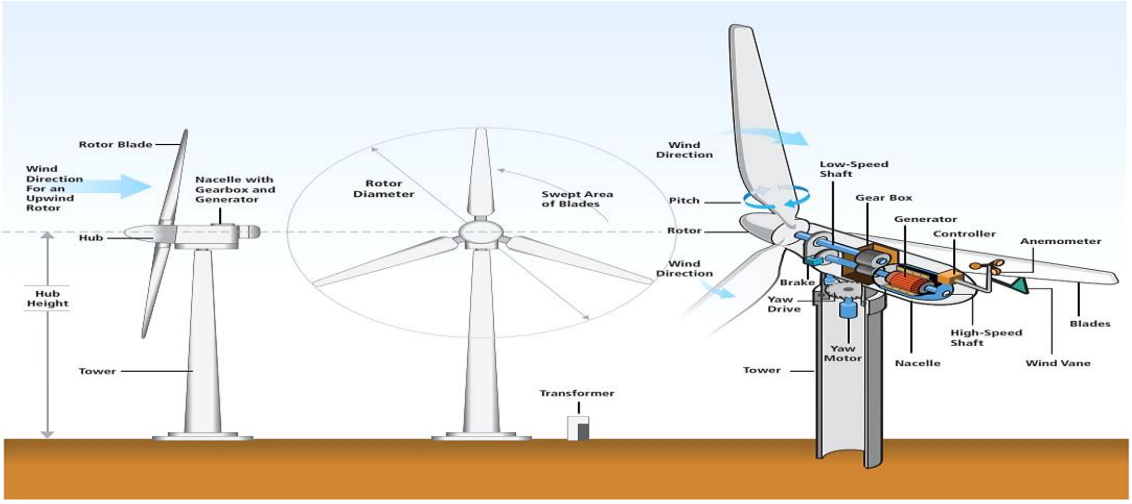


Figure 7. Basic components of a modern, horizontal-axis wind turbine with a gearbox (Design by the National Renewable Energy Laboratory (NREL) [3]

5.4 Technical design of wind turbines without a gearbox.

This setup uses a single fixed shaft. Both the rotor blades and the generator are attached to this shaft. The generator looks like a big wheel with, for example, forty-two pairs of poles around its outer edge. Stators are mounted on a fixed frame around the wheel. The wheel is connected to the blade structure, so it turns slowly along with the blades. Because of this, there's no need for a gearbox, rotating shafts, or a disk brake. Having fewer mechanical parts makes the turbine easier to maintain and produce. The entire system is controlled automatically. A central computer manages pitch control and the direction of the hub by operating small directional motors, as shown in Figure 8 [6]

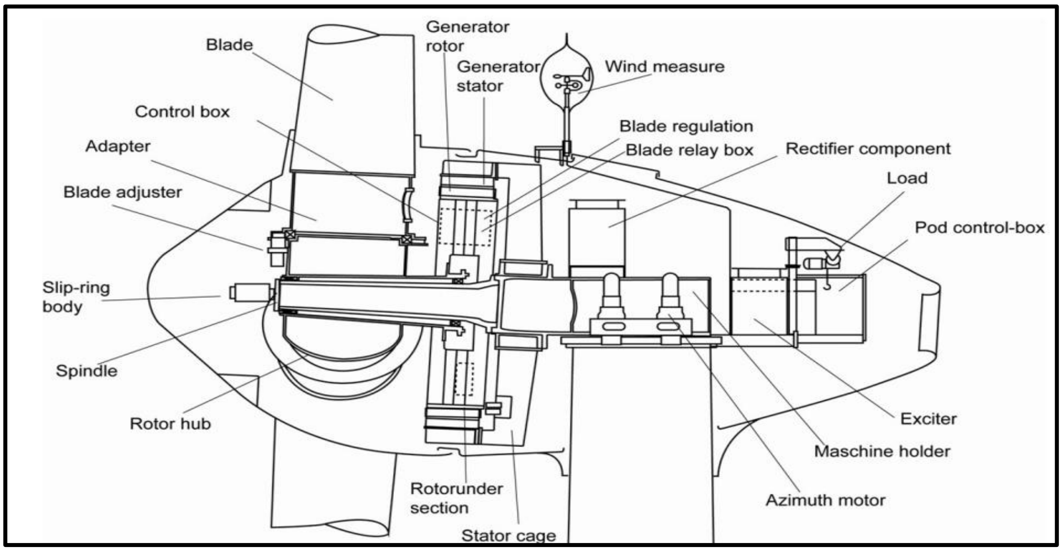


Figure 8. The design without a gearbox [6].

6 Environmental Impacts

Wind energy is seen as good for the economy because it doesn't require mining, drilling, transporting fuel, or using a lot of water. It also doesn't create harmful or dangerous waste like radioactive materials [1]. But wind energy can be tricky because the wind doesn't always blow consistently in most places. So, the electricity made by home wind turbines has to be stored in batteries or there needs to be a backup generator, which makes the overall cost of wind energy systems higher. On the other hand, wind farms are usually connected to the power grid, so other power plants can step in when the wind isn't blowing. Some people worry about wind farms because they might look bad, make noise with their blades, or affect birds that migrate. However, things like cell towers, power lines, and even domestic cats are also big threats to birds. It's also important to look at the waste and pollution created during the making, shipping, and setting up of wind energy systems. If we can understand these effects and reduce the environmental damage during production, wind energy will become more attractive [3, 5, and 14].

7 Current status and prospects

Wind is the fastest-growing energy source in the world today. The world's wind power capacity is growing by at least 40% each year. For example, the European Union aims to get 25% of its energy from renewable sources by 2012. In 2010, Spain was proud when wind energy made up 53% of its total electricity generation. More than 80% of all wind installations are in Europe. It's expected that installed wind capacity will reach 1.2 million MW by 2020 [8]. In 2014, wind power made up more than 3% of the world's electricity supply. In 2015, China was the leader in adding new wind power capacity with 32.9 gigawatts, followed by the United States (8.6 GW) and Germany (4.9 GW). By the end of 2015, more than 434 GW of wind power capacity had been installed worldwide [13]. Figure 9 shows the total onshore and offshore wind installations around the world [2]

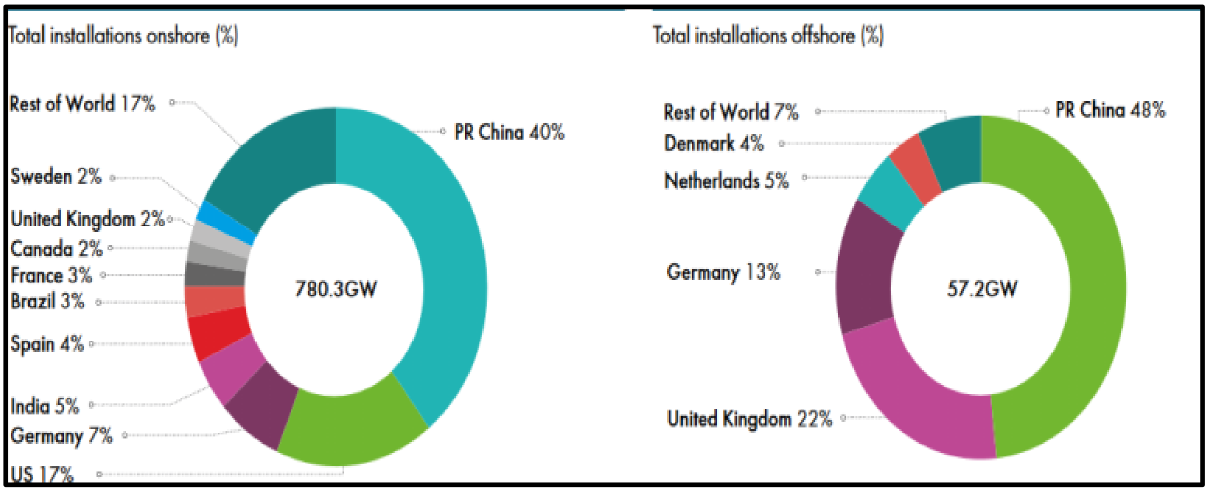


Figure 9. Percentage of new and total onshore and offshore wind installations by country (2021). Source: Global Wind Energy Council (2022) [2].

8 Conclusions

In this article, the basic ideas about wind energy were explained. For example, it talked about how winds form on Earth's surface, how different land areas affect wind patterns, and how energy can be taken from these winds. The article also explained what wind power plants are, their parts, and how they work. It also discussed the environmental effects of using wind energy and its possible future as a key renewable energy source around the world. Even though wind energy is well developed in many countries, like China, the United States, European Union nations, and some countries in Asia and North Africa, it still faces challenges such as lowering costs and improving wind turbine designs. These challenges are what push countries around the world to create plans and strategies to overcome them.

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