Renewable and Alternative Energies

Topic 1. Wind energy

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- **1.2.** Wind turbines: technical aspects.
- **1.3.** Wind farms.
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Topic 1. Wind energy

- **1.1. Wind as a power generator.**
- **1.2.** Wind turbines: technical aspects.
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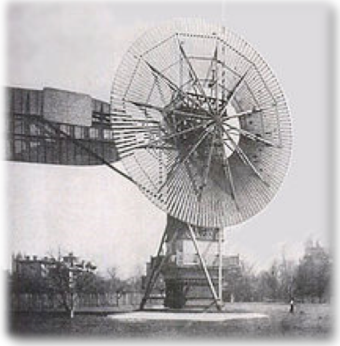
1.1. Wind as a power generator



Historical evolution:

- **5000 B.C.** Wind energy propelled boats sailing along the Nile River.
- **200 B.C.** The use of windmills in China for pumping water was documented.
- **Middle Age.** Primary applications for grain grinding and water pumping.
- **Between 1850 and 1970.** Over six million small windmills were installed in the U.S. alone for conversion of wind energy to mechanical energy.
- **1973.** The OPEC (Organization of Petroleum Exporting Countries) Oil Embargo. Wind energy got a big boost when several countries started investing in wind power related technologies.
- **Early 1980s.** A new market for wind energy generated electricity, the wind farms.

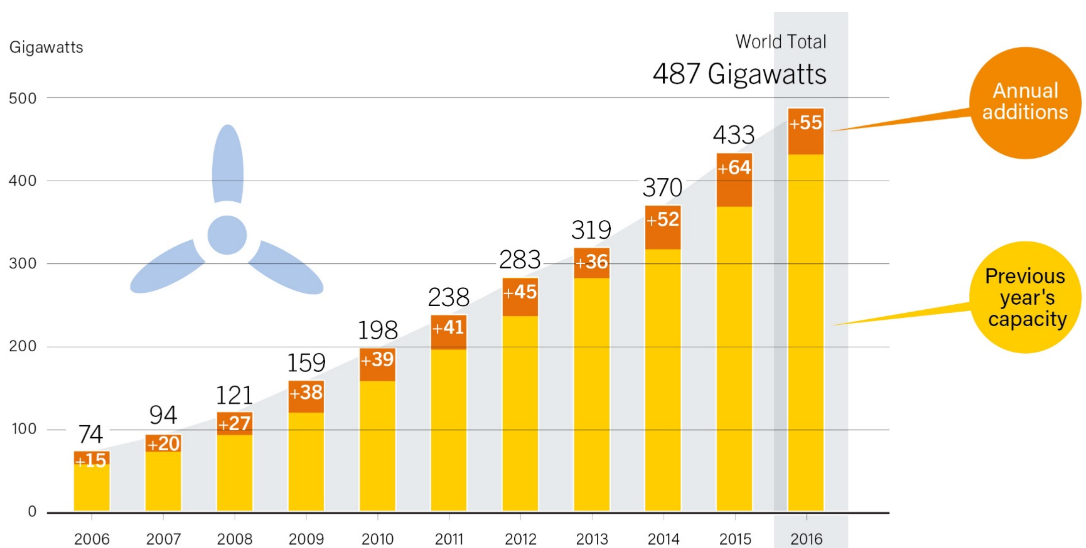
1.1. Wind as a power generator

Today (2016):*

* **Renewable Energy Policy Network For The 21st Century. Renewables 2017 Global Status Report.**

- The worldwide wind capacity reached 487 GW, out of which 55 GW were added in 2016.

Wind Power Global Capacity and Annual Additions, 2006-2016



1.1. Wind as a power generator

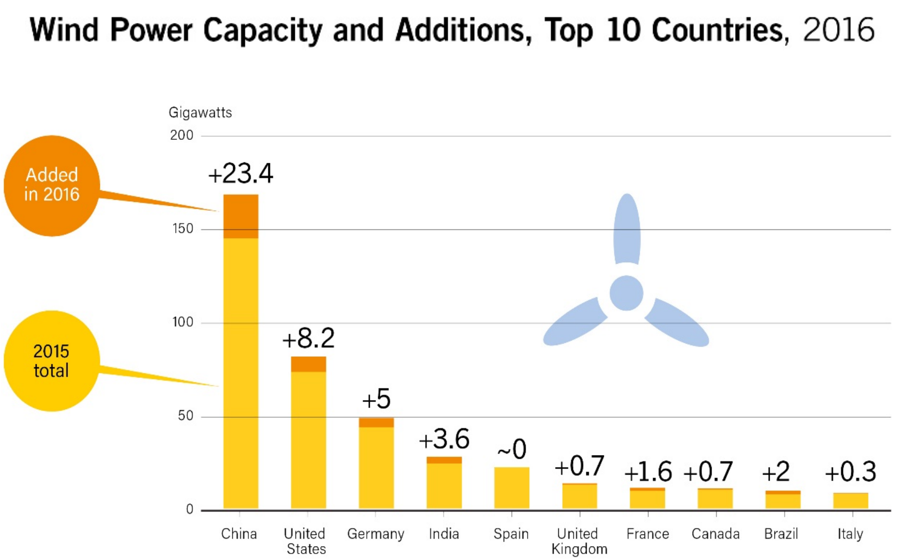
Today (2016):*

* **Renewable Energy Policy Network For The 21st Century. Renewables 2017 Global Status Report.**

- Asia was the largest regional market, representing about half of added capacity, with Europe and North America accounting for most of the rest.

- China added 23.4 GW of new capacity in 2016, maintaining its lead for new installations, followed distantly by the United States and Germany, with India taking Brazil's position in fourth place.

- By the end of 2016, over 90 countries had seen commercial wind activity, and 29 countries had more than 1 GW in operation.



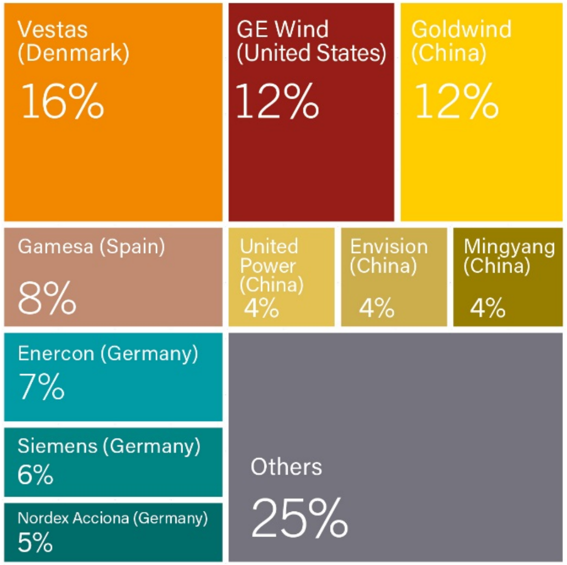
1.1. Wind as a power generator

Today (2016)*:

* **Renewable Energy Policy Network For The 21st Century. Renewables 2017 Global Status Report.**

- Wind has become the least expensive option for new power generating capacity in an increasing number of markets.
- Turbine Standardization: 3-blade Upwind, Horizontal-Axis, on a monopole tower. The world's top 10 turbine manufacturers captured nearly 75% of the 2016 market.
- 103 countries and regions used wind power for electricity generation.

Market Shares of Top 10 Wind Turbine Manufacturers, 2016



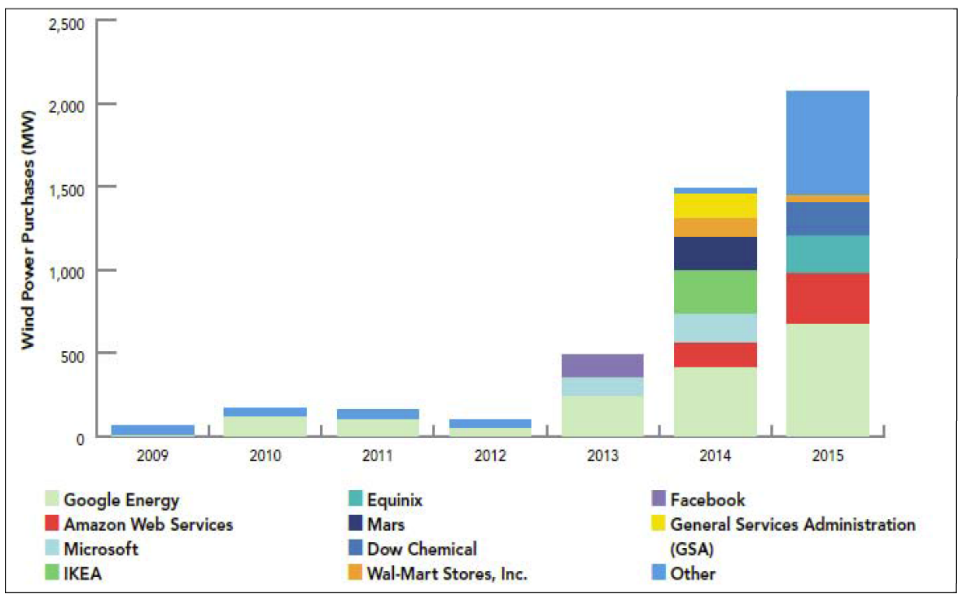
1.1. Wind as a power generator

Today (2015):*

* **U.S. Wind Industry 2015. Annual market update.**

- The number of private purchasers of wind-generated electricity and turbines rose during 2015, as did the scale of their purchases.

U.S. Non-Utility Wind Power Purchases by Year

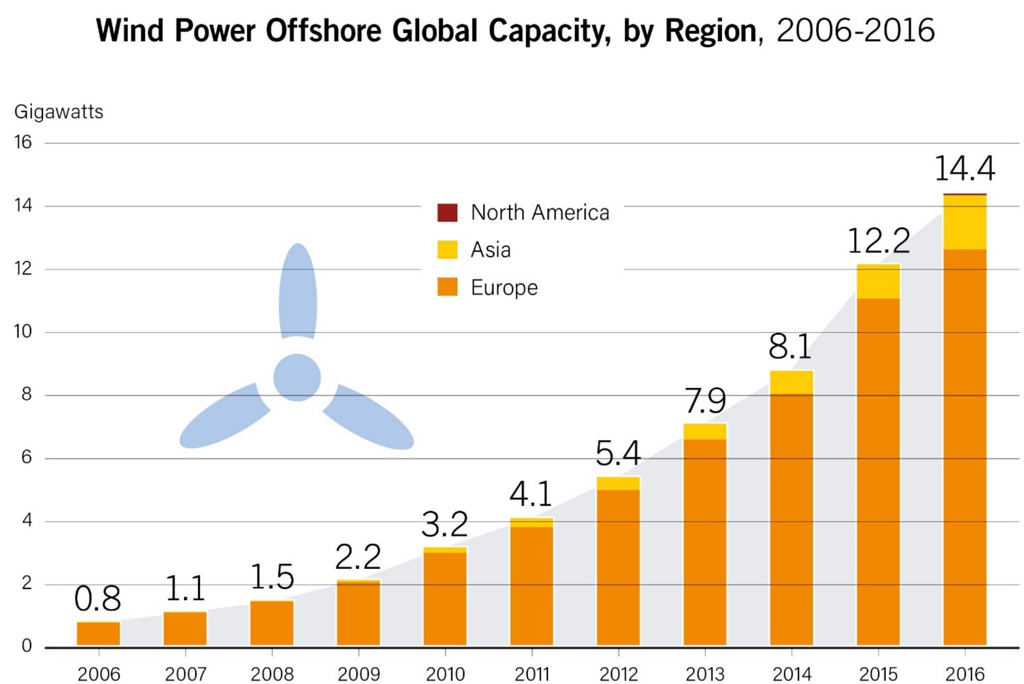


1.1. Wind as a power generator

Today offshore (2016):*

* **Renewable Energy Policy Network For The 21st Century. Renewables 2017 Global Status Report.**

- Global total: **14.4 GW**.
- **2.2 GW** of capacity connected to grid in 2016.
- Europe home of **70%** of global additions.



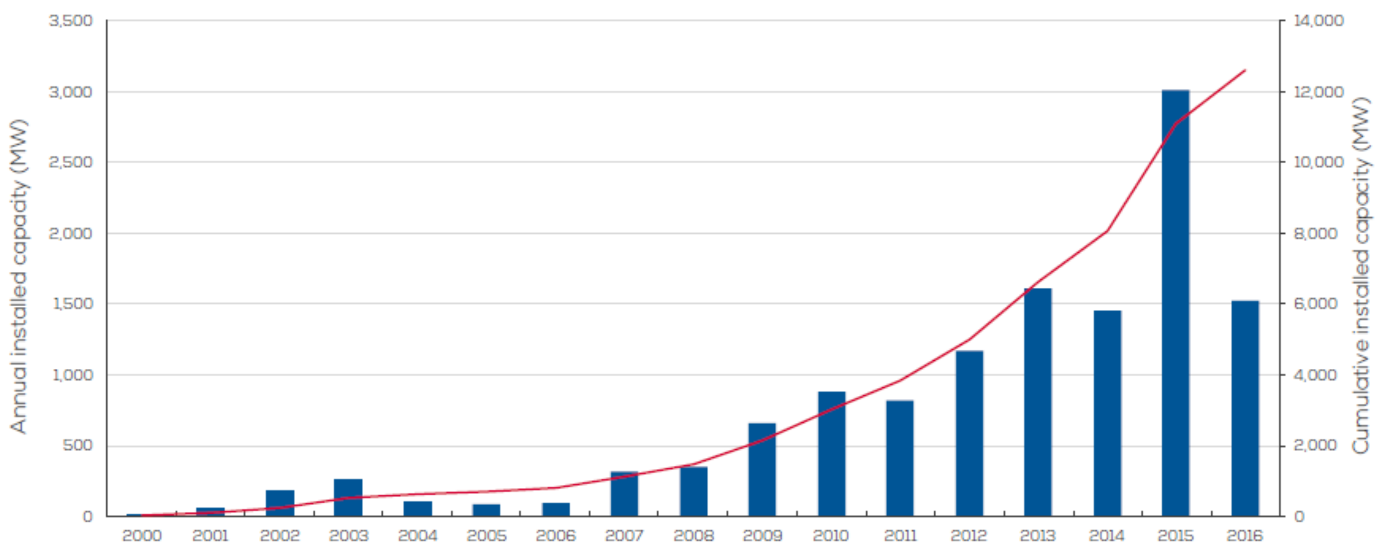
1.1. Wind as a power generator

Today offshore in Europe (2016):*

* **The European offshore wind industry.**
Key trends and statistics 2016.

- 1,558 MW added in 2016. 3589 turbines are now installed and grid-connected, making a cumulative total of 12631 MW.

12.6 of the 14.4 installed GW in the world are in Europe

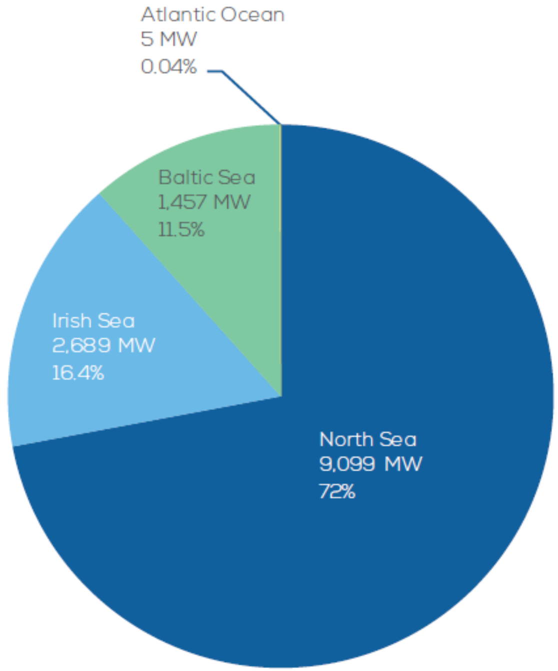


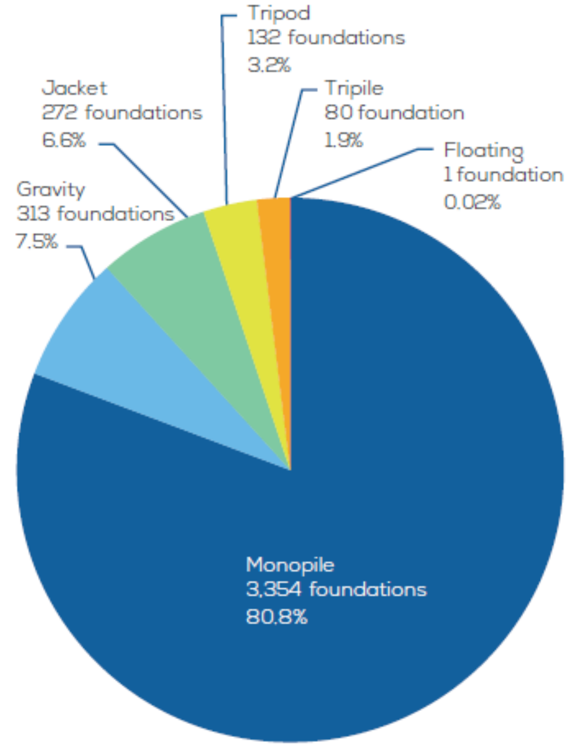
1.1. Wind as a power generator

Today offshore in Europe (2016):*

* **The European offshore wind industry. Key trends and statistics 2016.**

- 80.8% of substructures are monopoles and mainly installed in the North Sea, 72%.
- The average size was 4.8 MW, the average water depth 29.4 m and the average distance to shore 43.5 km.





1.1. Wind as a power generator

Today in Spain (2016):*

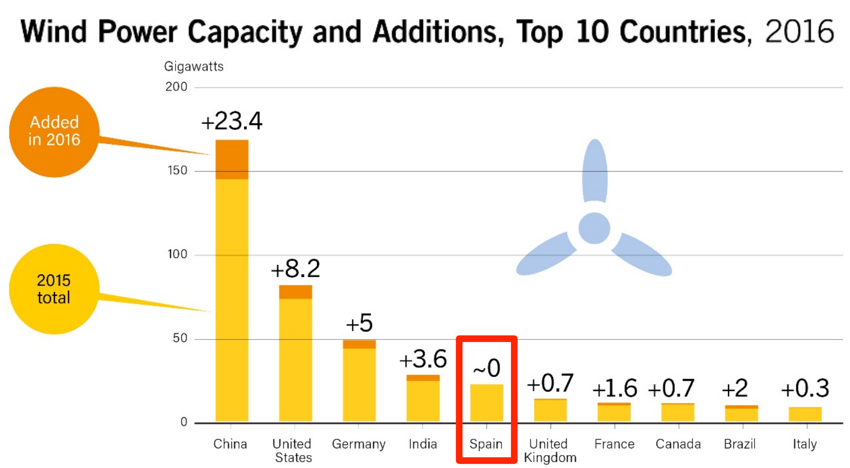
* **Renewable Energy Policy Network For The 21st Century. Renewables 2017 Global Status Report.**

- Installations concentrated in the top five markets in 2016 (Germany, France, the Netherlands, the United Kingdom and Poland) accounting for 75% of the region's newly added capacity.ternational position.

- India installed about 3.6 GW, taking Spain's position in fourth place globally for total wind power capacity.

- Spain is the fifth market in the world and second in Europe with 23 GW but it did not add any wind capacity in 2016.

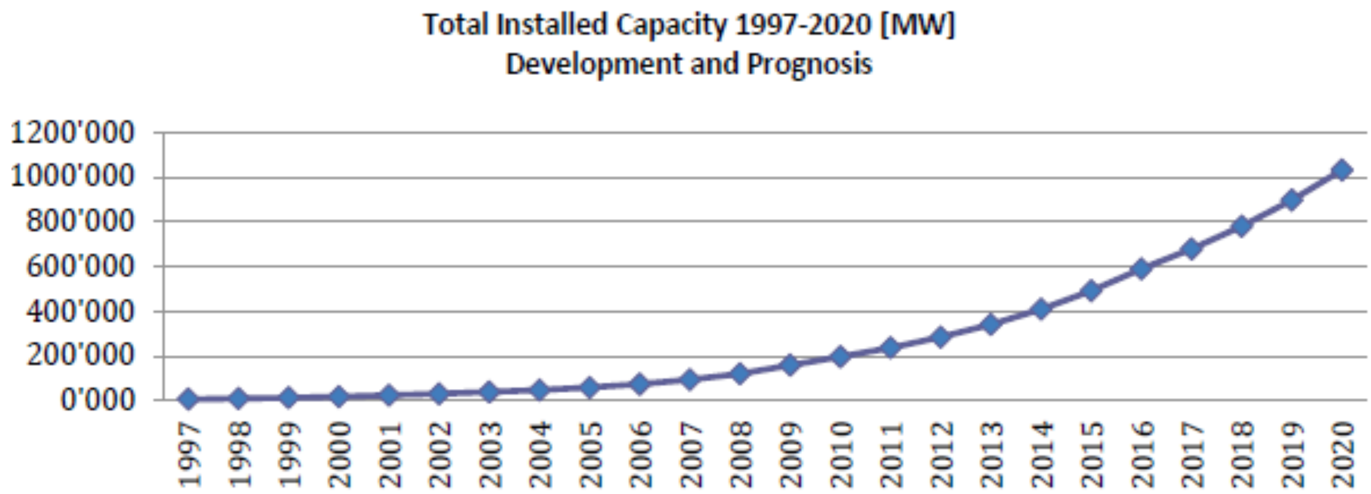
- The future support scheme for wind power is unclear, which is a big burden for the Spanish wind sector as it is at risk of losing its top international position.



1.1. Wind as a power generator

Forecast:

- World Wind Energy Association (WWEA) expects a global capacity of more than 500,000 MW by the end of 2016.
- Around 1,000,000 MW are possible by the year 2020.
- Policy uncertainties in major markets represent a major barrier for wind penetration.



1.1. Wind as a power generator

Harvesting Energy from Wind

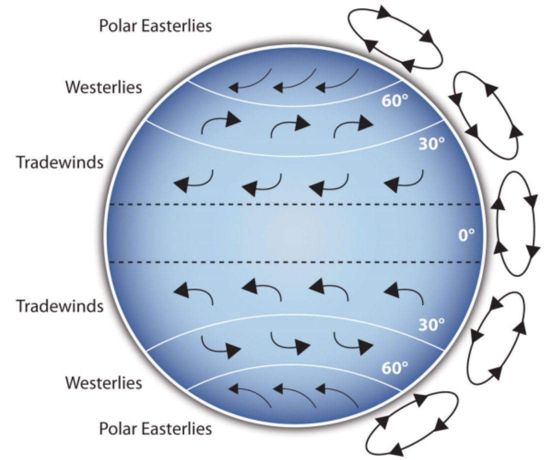
- Wind energy or wind power refers to the process by which **wind is captured to generate electricity**. About 1%-2% of the energy that the sun radiates to the earth per hour is converted into wind energy.

- Wind flow **patterns depend on the earth's terrain**, oceans, and vegetative coverage. Locally, buildings, plants and mountains control the wind pattern and also the speed.

- The kinetic energy in the **wind is harvested by wind turbines to generate** either **mechanical power or electricity**. Wind turbines first convert the kinetic energy in the wind into mechanical power, which then rotates a shaft to generate electricity.

1.1. Wind as a power generator

Harvesting Energy from Wind



- The wind rises from the equator and moves north and south to the higher layers of the atmosphere.
- At the equator, there will be a low pressure area close to ground level attracting winds from the north and south. At the poles, there will be high pressure due to the cooling of the air.
- Once air has been set in motion, it undergoes an apparent deflection called the Coriolis force.
- Due to the bending force of the Coriolis force, the following general direction for the prevailing wind results:

Latitude	90°-60°N	60°-30°N	30°-0°N	0°-30°S	30°-60°S	60°-90°S
Direction	NE	SW	NE	SE	NW	SE

Spain 40° N

1.1. Wind as a power generator

Wind Resource Map

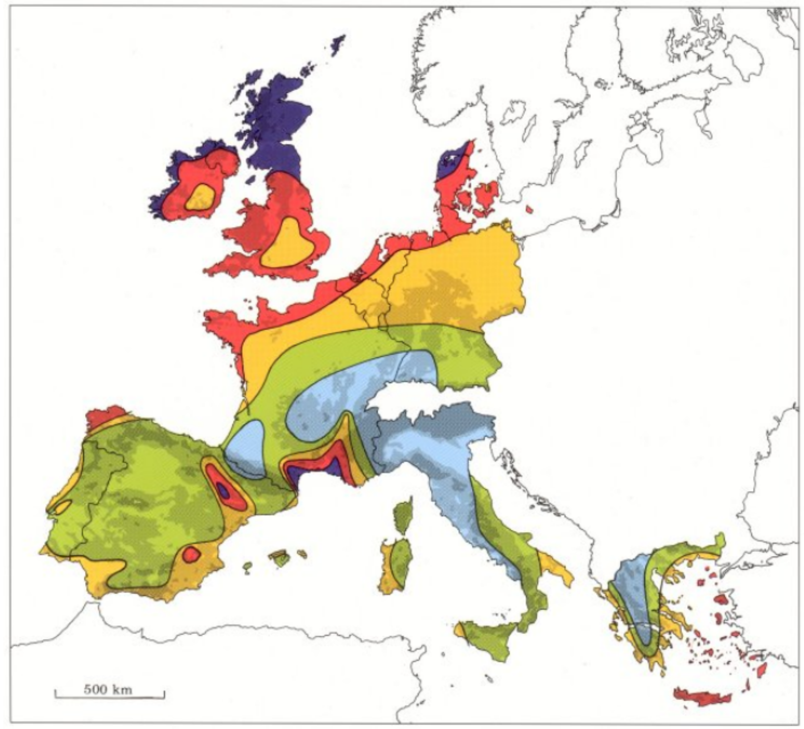
- Based on wind speed, wind resources are categorized into seven classes.
- A wind-class refers to a range of wind power density and speed that describes the energy contained in the wind.

Wind Power Class	10 m		50 m	
	Wind Power Density (W/m²)	Speed (m/s)	Wind Power Density (W/m²)	Speed (m/s)
1	0	0	0	0
2	100	4.4	200	5.6
3	150	5.1	300	6.4
4	200	5.6	400	7.0
5	250	6.0	500	7.5
6	300	6.4	600	8.0
7	400	7.0	800	8.8
	1000	9.4	2000	11.9

1.1. Wind as a power generator

Wind Resource Map

- Class 4 or greater are suitable for power generation using the wind turbines currently available.
- Class 3 may be suitable for future generation technology.
- Class 2 areas are marginal and Class 1 areas are unsuitable for wind energy development.
- The wind map is generally available from the local government or designated authority.

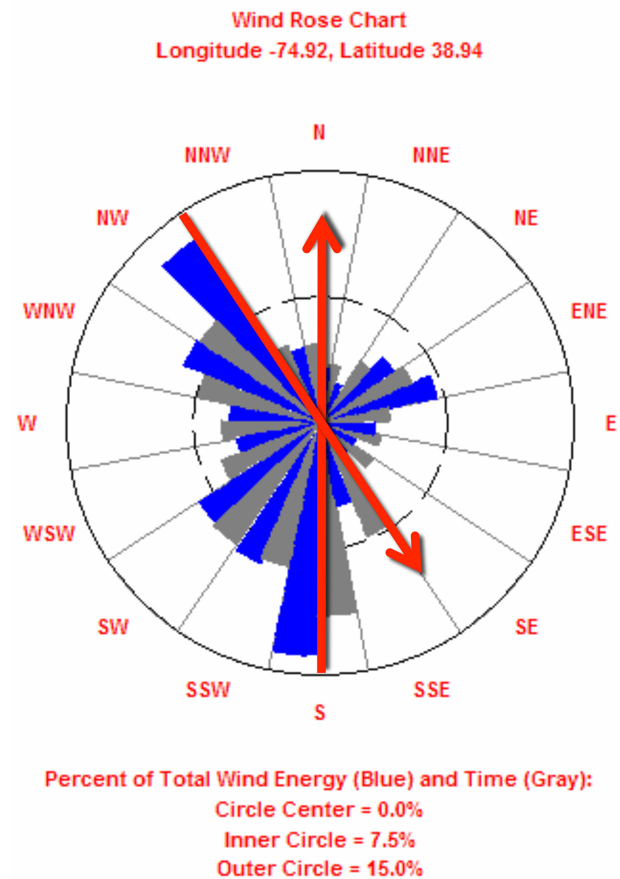


Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

1.1. Wind as a power generator

The Wind Rose

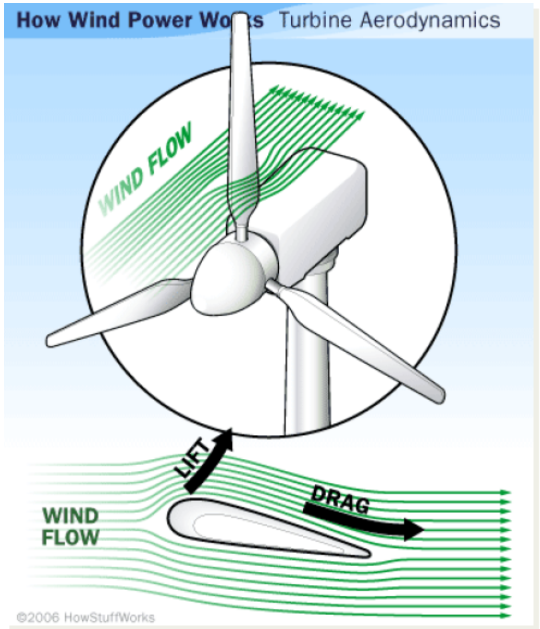
- Gives information about the wind speed and frequency of wind blowing from various directions.
- The length of each "spoke" around the circle is related to the frequency of time that the wind blows from a particular direction.
- Each concentric circle represents a different frequency from zero at the center to increasing frequencies at the outer circles.
- You can analyze a wind rose to determine the prevailing wind direction and frequency.
- In this example, prevailing winds come from the South Southwest and the Northwest with additional input from a variety of directions.



1.1. Wind as a power generator

Energy and power from wind: lift and drag forces

- Wind turbines operate by the action of the relative wind (the natural wind plus wind caused by rotor motion and rotor-induced flow), which creates aerodynamic forces on the rotating blades.
- Drag force defined by: $F_D = \frac{1}{2} * \rho * v^2 * C_D * A$
- Lift force defined by: $F_L = \frac{1}{2} * \rho * v^2 * C_L * A$



Where:
- **ρ:** density of the fluid.
- *v:* speed relative to the fluid.
- **A:** cross-sectional area.
- **C_D:** drag coefficient.
- **C_L:** lift coefficient.

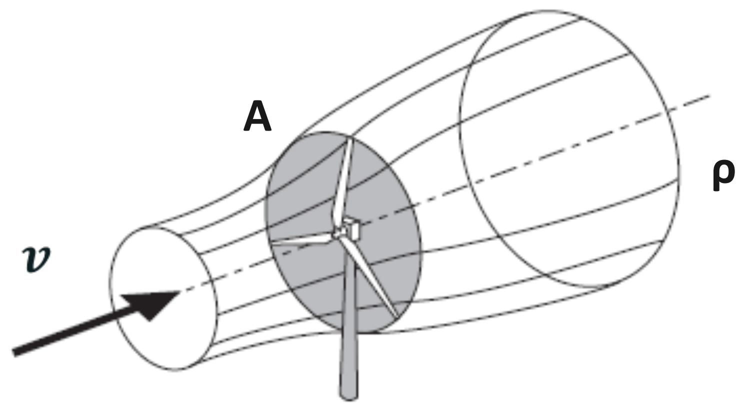
- It is normally assumed that the properties of airfoils that are desirable for wings will also be desirable for wind turbines. This assumption is only superficially valid.

1.1. Wind as a power generator

Energy and power from wind: kinetic energy and power

- The kinetic energy of wing is converted to mechanical or electrical energy using wind turbines. The amount of energy captured by the rotor depends on the density of the air, ρ, the rotor area, **A**, and the wind speed, v.

- Power that is obtained from wind flowing at a certain speed may be calculated by assuming that a parcel of air is moving towards a wind turbine at a velocity of v.



- Kinetic energy is: $KE = \frac{1}{2} * m * v^2$
- Power is *KE* per unit time: $P = \frac{1}{2} * \dot{m} * v^2$
- With: $\dot{m} = \rho * A * v$
- Thus: $\boxed{P = \frac{1}{2} * \rho * A * v^3}$

Power ~ cube of velocity.
Power ~ air density.
Power ~ rotor swept area.

Theoretical power in a free flowing stream of wind

1.1. Wind as a power generator

Energy and power from wind: Betz limit

- The **actual** power that is obtainable from a wind turbine is given by:

$$P = (C_p * \varepsilon_g * \varepsilon_b) * \frac{1}{2} * \rho * A * v^3$$

Where:

- C_p: coefficient of performance, also called power coefficient, the ratio of power extracted by the turbine to the total contained in the wind resource.
- ε_g: generator efficiency.
- ε_b: gearbox/bearings efficiency.

A value of greater than 0.80 is possible for ε_g.

The efficiency of gearbox and bearings can be greater than 95%.

The maximum theoretical value of C_p possible is 16/27 = **0.593** known as the **Betz limit**. The practical value of C_p is in the range of 0.35-0.40.

1.1. Wind as a power generator

Energy and power from wind: Betz limit

- Since the velocity at the rotor inlet (v_1) is different from that at the outlet (v_2), an average velocity is used to calculate the mass of the air streaming through the rotor per second as follows:

$$\dot{m} = \rho * A * \frac{v_1 + v_2}{2}$$

- The power extracted from the wind by the rotor using the average wind speed is given by:

$$P = \frac{1}{2} * \dot{m} * (v_1 - v_2)^2 = \frac{1}{4} * \rho * A * (v_1 - v_2)^2 * (v_1 + v_2)$$

- The total power in the wind P_0 streaming through exactly the same area, **A**, in the absence of the rotor can be written as:

$$P_0 = \frac{1}{2} * \rho * A * {v_1}^3$$

- The ratio of the two powers is given by: $C_p = \frac{P}{P_0} = \frac{1}{2} * \left[1 - \left(\frac{v_2}{v_1}\right)^2\right] * \left[1 + \left(\frac{v_2}{v_1}\right)\right]$

- This equation has the maximum at 0.593 when v_2/v_1 = 1/3 therefore the **maximum value for the power extracted** from the wind **is 0.593 or 16/27 of the total power in the wind**.

1.1. Wind as a power generator

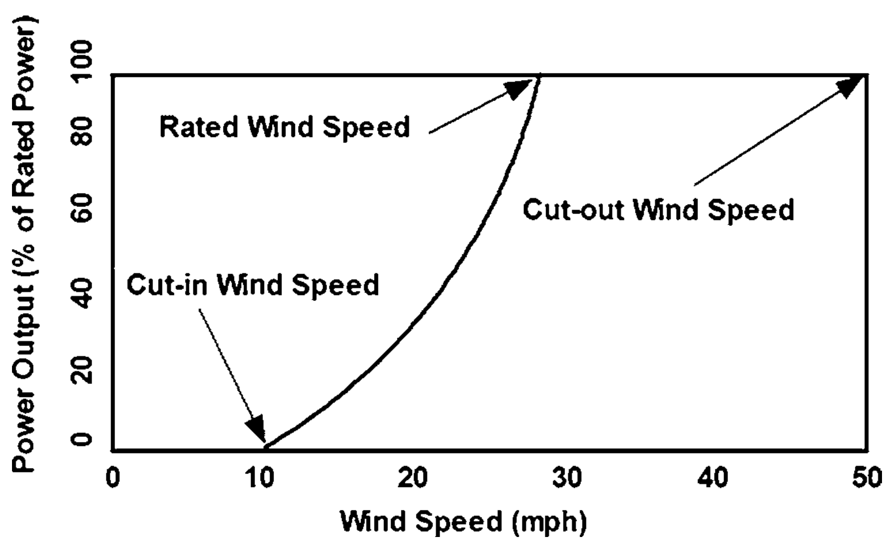
Energy and power from wind: capacity factor

- The **capacity factor (CF)** of a wind turbine is the actual energy output for the year divided by the energy output if the turbine operated at its rated power output for the entire year.

Capacity Factor = Average Output / Peak Output ≈ 30%

- The relationship between wind speed and rated power is called a power curve.

- The turbine starts to produce power only when a certain wind speed is reached (called cut-in wind speed). As the wind speed increases, the power output increases sharply.



1.1. Wind as a power generator

Energy and power from wind: capacity factor

- If the wind speed is above a certain value, known as cut-out wind speed, the wind turbine is forced to remain idle. The “rated wind speed” is the wind speed at which the **“rated power (RF)”** is achieved.

- If the wind speed is above the rated wind speed, the power output is mechanically or electrically maintained at a constant level using an advanced control system or the wind turbine is cut off from power production.

- Using the power curve, it is possible to determine roughly how much power will be produced at the average or mean wind speed prevalent at a site.

- CF is based on both the characteristics of the turbine and the site characteristics –it is very sensitive to the average wind speed–.

- A reasonable capacity factor would be between 0.25 and 0.30. A very good capacity factor would be 0.40.

1.1. Wind as a power generator

Energy and power from wind: capacity factor

- For accurate estimate of CF and energy production, the wind distribution of the site should be known. If it is not available, there are two common wind distribution functions that are used:
- The Weibull distribution: $f(U) = k * \frac{U^{k-1}}{c^k} * exp\left[-\left(\frac{U}{c}\right)^k\right]$

  Where:

  - $f(U)$: probability density function.
  - U: mean wind speed.
  - k : shape parameter which describes the variability about the mean.
  - c : scale parameter.
- The Rayleigh distribution: a special case of the Weibull with k = 2, which is actually a fairly typical value for many locations.
- An estimate of annual energy production can be obtained by multiplying the rated power output (RP) by the capacity factor (CF) and the number of hours of the turbine use in a year (h).

Annual Energy Production = RP ·CF · h

Topic 1. Wind energy

- **1.1.** Wind as a power generator.
- **1.2. Wind turbines: technical aspects**.
- **1.3.** Wind farms.
- **1.4.** Legal aspects of wind energy.

1.2. Wind turbines: technical aspects

Turbine types

- Wind turbines can be divided into two categories based on the axis about which the turbine rotates:

Vertical Axis Wind Turbines (VAWTs)

Horizontal Axis Wind Turbines (HAWTs)

1.2. Wind turbines: technical aspects

Turbine types: Vertical Axis Wind Turbines (VAWTs)

- The blades of vertical-axis wind turbines spin in a horizontal plane. VAWTs have the main rotor shaft running vertically.

- **Advantages:**
  - The generator and/or gearbox can be placed at the bottom, near the ground; therefore, a tower is not needed to support the turbine.
  - The turbine does not need to be pointed into the wind.

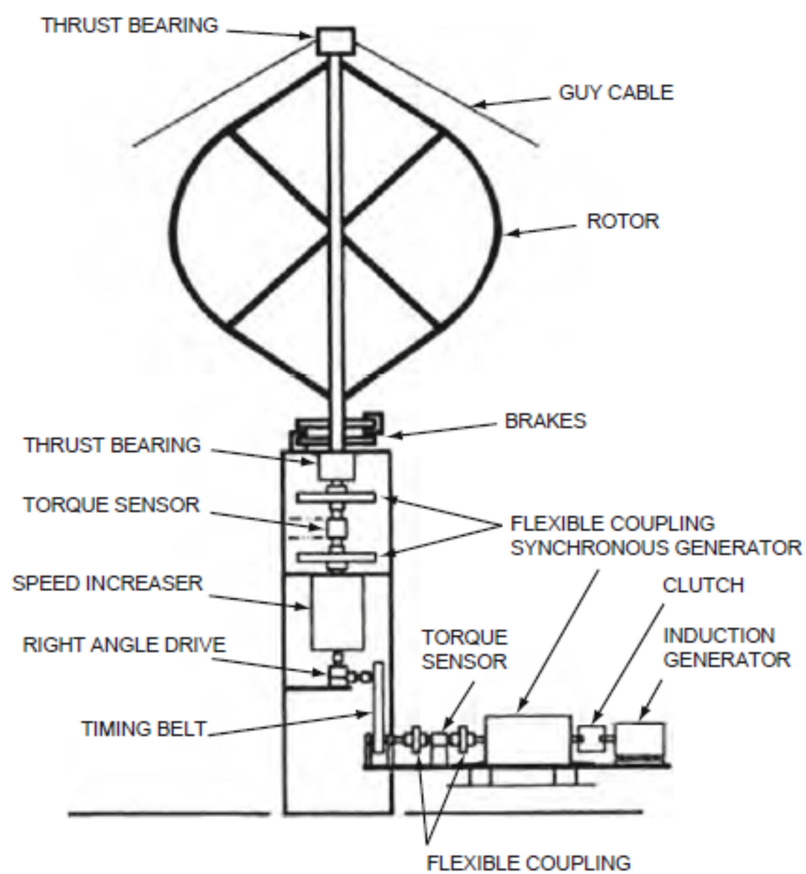
- **Disadvantages:**
  - The pulsating torque that is produced during each revolution and the drag created when the blade rotates into the wind.
  - They need higher and more turbulent air flow near the ground.
  - Lower energy extraction efficiency.

1.2. Wind turbines: technical aspects

Turbine types: Vertical Axis Wind Turbines (VAWTs)

A variety of designs for VAWTs have been proposed:

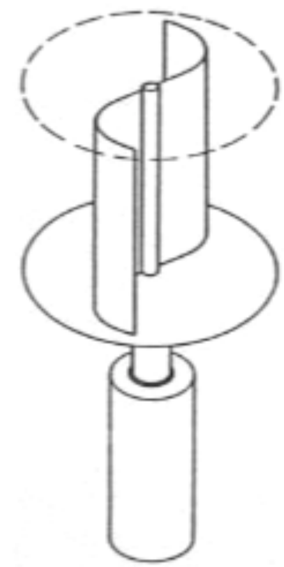
- **Darrieus Wind Turbine:**
  - It is the most common type of VAWT.
  - Generally, an external power source is required to start the rotation.
  - The starting torque is very low.
  - In the newer design, three or more blades are used which results in a higher solidity for the rotor.



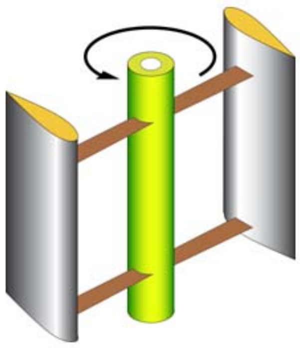
1.2. Wind turbines: technical aspects

Turbine types: Vertical Axis Wind Turbines (VAWTs)

- **Savonius Wind Turbine:**
  - It consists of two half-cylinders mounted on a vertical shaft that has an S-shape appearance when viewed from the top.
  - This drag-type VAWT turns relatively slowly, but yields a high torque.
  - Most of the swept area of a Savonius turbine is near the ground.
  - They are cheap and reliable.



- **Giromill Wind Turbine:**
  - H-bar design, in which the "egg beater" blades of the Darrieus design are replaced with straight vertical blade sections attached to the central tower with horizontal supports.



1.2. Wind turbines: technical aspects

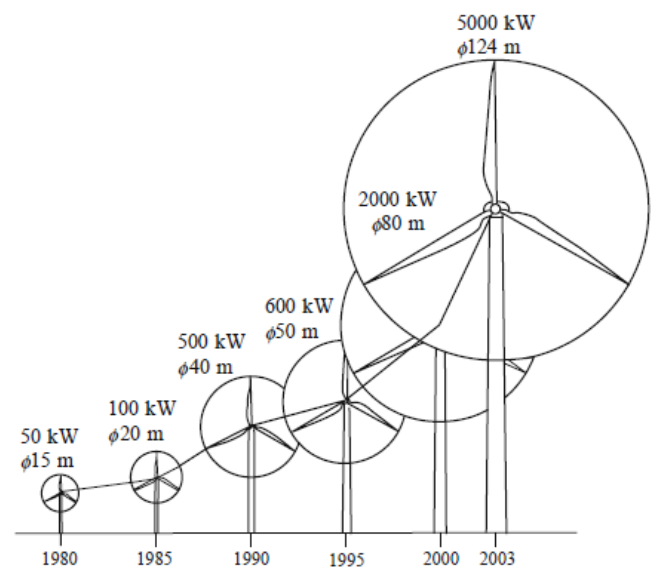
Turbine types: Vertical Axis Wind Turbines (VAWTs)

- The blades of horizontal-axis wind turbines spin in a vertical plane.
- During rotation, blades move more rapidly over one side, creating a low pressure area behind the blades and a high pressure area in front of it. The difference between these two pressures creates a force which causes blades to spin.
- The HAWTs have the main rotor shaft and electrical generator at the top of a tower, and are pointed into the wind.
- Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor.
- Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable for generating electricity.

1.2. Wind turbines: technical aspects

Turbine types: Vertical Axis Wind Turbines (VAWTs)

- HAWTs are most widely used for commercial power generation and can be designed for higher power. This is possible due to higher rotor diameters that can be used when designing HAWTs.
- The turbine capacity depends on the rotor diameter and the rated power output from a single wind turbine has increased steadily due to development of wind turbines with a large rotor diameter.
- Currently three blade rotor systems are preferred; however, one blade and two blade wind turbines have been designed and tested generating 15% and 5% less power than three blade wind turbines, respectively.
- Wind turbines with more than three blades (multi-blade) have also been explored, but no significant gain in costs or stability of multi-blade systems over three-blade turbines was achieved.



1.2. Wind turbines: technical aspects

Turbine types: Vertical Axis Wind Turbines (VAWTs)

- **Advantages:**
  - The design and location of blades provide a better stability of the structure.
  - The ability to pitch the rotor blades in a storm minimizes the damage.
  - The use of a tall tower allows access to stronger wind in sites with wind sheer and placement on uneven land.
  - The manufacturing cost can be less because of higher production volume, larger sizes and, in general, higher capacity factors and efficiencies.

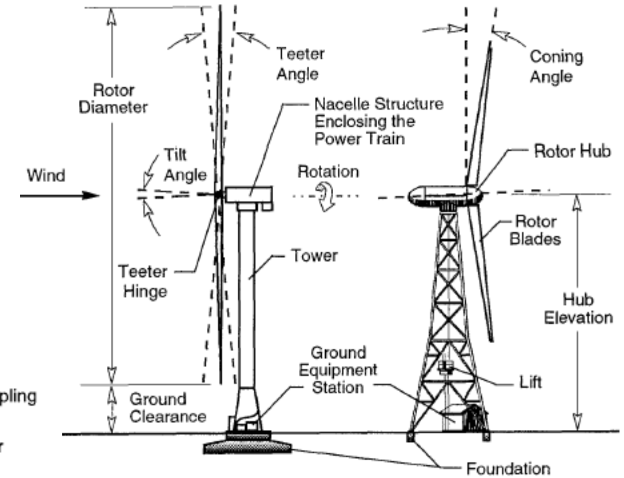
- **Disadvantages:**
  - Tall towers and long blades are difficult to transport.
  - Higher install and maintenance costs..

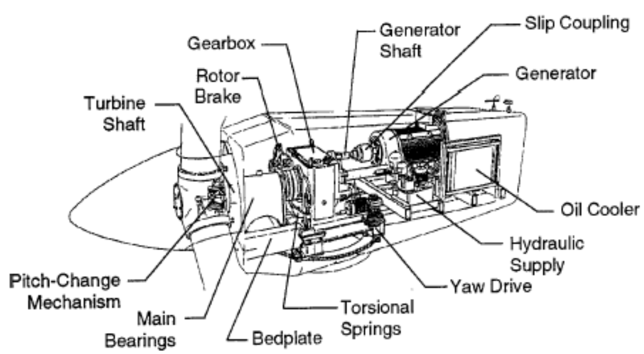
1.2. Wind turbines: technical aspects

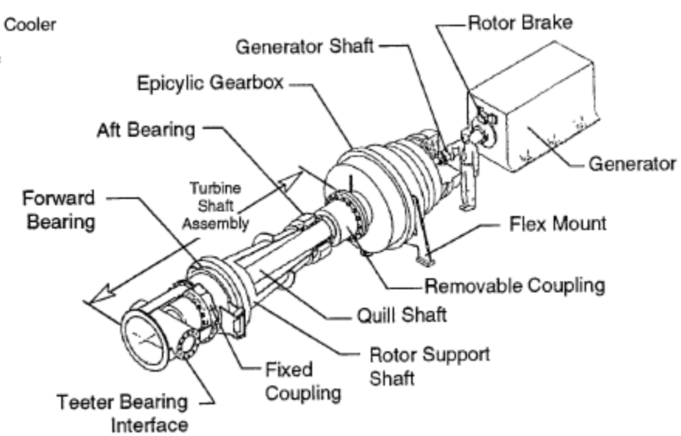
Turbine types: Horizontal Axis Wind Turbine Components (HAWTs)

The basic components of a wind turbine are as follows:

- Nacelle.
- Rotor blades.
- Hub.
- Low speed shaft.
- Gearbox.
- High speed shaft with its mechanical brake.
- Electrical generator.
- Yaw mechanism.
- Electronic controller.
- Tower.
- Anemometer.
- Wind vane.







1.2. Wind turbines: technical aspects

Turbine types: Horizontal Axis Wind Turbine Components (HAWTs)

- **Nacelle:**
  - The nacelle contains the key components of a wind turbine, including the gearbox, and the electrical generator.
- **Rotor blades:**
  - The rotor blades capture the wind and transfer its power to the rotor hub. The generator then turns this movement into electricity.
- **Hub:**
  - The hub of the rotor is attached to the low speed shaft of a wind turbine.
- **Low speed shaft:**
  - The low speed shaft of a wind turbine connects the rotor hub to the gearbox. The rotor rotates at about 19-30 rotations per minute (rpm) in a 1,000 kWe wind turbine. The shaft contains pipes for the hydraulics system to enable the aerodynamic brakes to operate.

1.2. Wind turbines: technical aspects

Turbine types: Horizontal Axis Wind Turbine Components (HAWTs)

- **Gearbox:**
  - Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 19 to 30 rpm to about 1,000-1,800 rpm, which is required by most generators to produce electricity. The recent design uses “direct-drive” generators that operate at lower rotational speeds and do not need gear boxes.

- **High speed shaft with Its mechanical brake:**
  - This drives the generator and employs a disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

- **Electrical generator:**
  - The generator converts the mechanical energy of the rotating shaft into electrical energy.

1.2. Wind turbines: technical aspects

Turbine types: Horizontal Axis Wind Turbine Components (HAWTs)

- **Yaw mechanism:**
  - The yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, since the wind blows the rotor downwind.
- **Electronic controller:**
  - The controller starts the machine at the specified wind speed which is generally between 4 and 7 m/s and shuts off the machine at about 25 m/s.
- **Tower:**
  - The tower is a high stationary support structure for the wind turbine, so that consistent wind speed can be sustained for the operation of the turbine.

1.2. Wind turbines: technical aspects

Turbine types: Horizontal Axis Wind Turbine Components (HAWTs)

- **Anemometer:**
  - It measures the wind speed and transmits wind speed data to the controller.

- **Wind vane:**
  - It measures wind direction and directs the yaw drive to an appropriate orientation so that the turbine is properly aligned with respect to the wind direction.

- **Video:**
  - What's inside a wind turbine.

1.2. Wind turbines: technical aspects

Turbine types: comparison between turbines

- Wind turbines may be compared with each other by comparing their coefficient of performance (CP) against tip speed ratio (λ) which is defined by:

$$\lambda = \frac{speed\ of\ rotor\ tip}{Wind\ speed} = \frac{\omega * r}{v}$$

- The tip speed ratio is an important factor in designing the wind turbine. The rotor must rotate at an optimum speed to maximize its efficiency.

- A high tip speed ratio is desirable, but there are a number of disadvantages for operating a turbine at high λ:

  1) A high rotating speed can cause erosion of the blades from impact with dust or sand particles in the air.

  2) The level of noise increases, both in the audible and non-audible ranges.

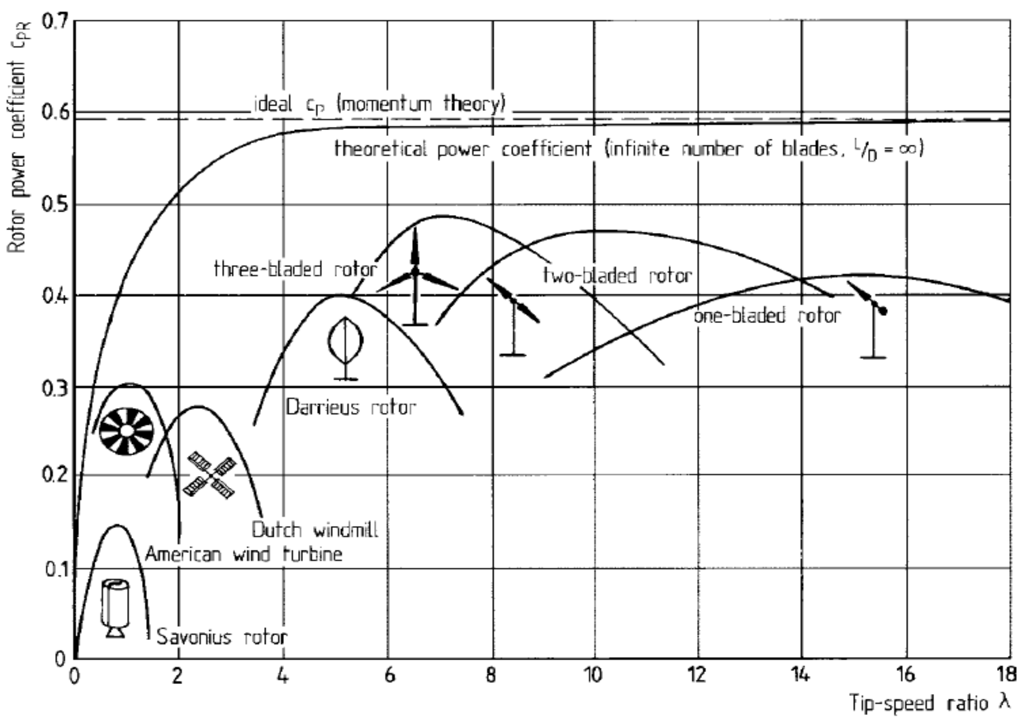
  3) The vibration also increases, and there is a change of catastrophic failure.

1.2. Wind turbines: technical aspects

Turbine types: comparison between turbines

The power coefficients CP for various turbines plotted against tip speed ratio λ:

- HAWTs with three blades have the best power coefficient.
- Out of VAWTs, the Darrieus turbine has the highest power coefficient, and the Savonius rotor has the lowest value.
- For most commercial applications, three-blade HAWTs are preferred.



Topic 1. Wind energy

- **1.1.** Wind as a power generator.
- **1.2.** Wind turbines: technical aspects.
- **1.3. Wind farms**.
- **1.4.** Legal aspects of wind energy.

1.3. Wind farms

- A wind farm is a **collection of wind turbines** in the same location and is used for the generation of a large amount of electricity.
- Even if all the individual wind turbines are rated the same, **the power production generally varies** from one turbine to another.
- Due to the variability in power production and the quality of the power, **integration** of the wind farm into the power grid is **complicated**.
- Wind farms are **not suitable for base-load electricity** supply. This is because wind power output is variable and difficult to predict as it depends on wind resources, which cannot be controlled.
- In order to assure continuous power supply, **a separate power generation facility** is required that can be put on-line and ramped up in approximately the same time that wind power diminishes.

1.3. Wind farms

Steps involved in building a wind farm

1. **Understand your wind resource:** a site must have a minimum annual average wind speed in the neighborhood of 5-6 m/s to even be considered. Local weather data and wind maps for the area should be studied.

2. **Determine proximity to existing transmission lines:** existing transmission lines and their availability should be determined and considered in selecting a site.

3. **Secure access to land:** the area should be accessible via roads.

4. **Establish access to capital:** the developer must secure sufficient cash flow for both installation and operation until the generation of revenue.

5. **Identify reliable power purchaser or market:** local power purchasers and distributors should be contacted and also a survey of the local market for power should be conducted.

1.3. Wind farms

Steps involved in building a wind farm

6. **Address siting and pt feasibility considerations:** these include impact on endangered or protected species, site's geological suitability, effect of noise and aesthetic issues on the local community, local air traffic, and other issues related to site development, such as roads.

7. **Understand wind energy's economics:** the economic feasibility and payback time should be determined.

8. **Obtain zoning and permitting expertise:** the county, city, and the state should be consulted for permitting purposes and any concern should be addressed before starting construction.

9. **Selection of turbine:** the selection of turbines should take into account the required generation capacity, site specific design criteria, and costs.

10. **Secure agreement to meet operating and maintenance needs:** an agreement should be in place for regular maintenance of the wind turbines and also for emergency response.

1.3. Wind farms

Land area requirement

- The primary objective of a wind project design is to locate the wind turbines in the **best wind sites** to maximize energy production.
- Wind turbines are **arranged in single or multiple rows**. A single row on ridgelines and hilltops and multiple rows on broader and flatter lands. In both cases, rows are laid out to be as perpendicular as possible to the prevailing wind direction(s).
- The main consideration in placing the wind turbines is the interference of one wind turbine from another turbine, called the **"wake effect"** or "array effect".
- The **distance between turbine** rows and between turbines within a row is described **in terms of rotor diameters** and varies depending on the type and the location of the land.
- Due to the **low energy density** of the wind energy, **large land areas** are required compared to conventional sources. i.e. a 20-turbine wind farm requires an area of about 1 km^2, but only 1% of the land area would be used to house the turbines, electrical infrastructure and access roads.

1.3. Wind farms

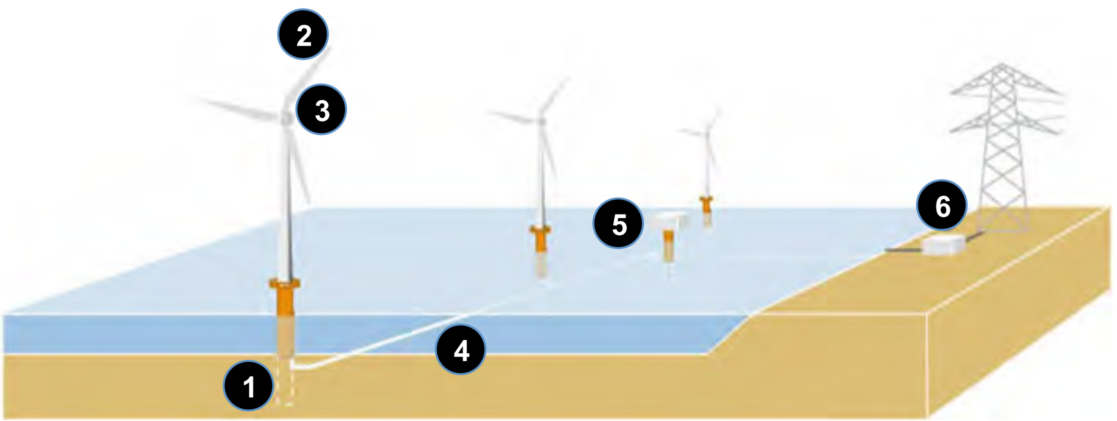
Offshore wind farms

- Offshore wind farms are generally located about 10 km or more from the land.
- Offshore wind turbines are less obtrusive than turbines on land. The wind resources in the water are much more consistent compared to land.
- The average wind speed is usually considerably higher over open water and capacity factors are considerably higher than for onshore locations.
- From among various countries, Denmark and England are making significant efforts to develop offshore wind energy systems.
- Only HAWTs are used in offshore farms since they are easy to install and also they provide the highest capacity.
- One of the main concerns of offshore wind turbines is the extreme weather conditions to which they will be exposed.

1.3. Wind farms

Offshore wind farms: anchoring methods

- The current practice is to drive piles **(1)** into the seabed. The turbine blades **(2)** rotate around a horizontal hub, which is connected to a shaft inside the nacelle **(3)**.
- The power generated by the turbines is transmitted by subsea cables **(4)** to an offshore transformer **(5)** which converts the electricity to high voltage before connecting to the grid at a substation on land **(6)**.
- For anchoring in the seabed, a monopole is most widely used. A tripod fixed bottom or a floating structure has been proposed for installations at greater depths.



Source: British Wind Energy Association.

1.3. Wind farms

Electricity generation: distinctive features

The distinctive features of wind/electricity generating systems are:

- Wind turbine efficiency is greater if rotational frequency varies to **maintain constant tip-speed ratio**, however electricity generation is most efficient at constant or nearly constant frequency.
- Mechanical control of a turbine by blade pitch or other mechanical **control at powers less than rated, increases complexity** and expense.
- The **optimum rotational frequency** of a turbine **decreases with increase in radius** to maintain constant tip-speed ratio. Only small turbines can be coupled directly to conventional generators. Larger machines need a gearbox which is relatively expensive and heavy, requires maintenance and can be noisy.
- The **rotor can be decoupled from the load**, with the advantage of allowing the rotor to be optimized to the wind.
- There are always periods without **wind so wind turbines must be linked** to energy storage or parallel generating systems.

1.3. Wind farms

Electricity generation: main control objectives

Some of the main control objectives to take into account in the design of a wind turbine controller should include:

- **Reliability and availability:** the design of advanced control techniques has to improve the reliability, long-term operation and high availability of the machines.

- **Energy capture maximization:** the first requirement for a turbine's control algorithms is to maximize the energy capture over the low-medium operating wind spectrum.

- **Mechanical load and fatigue attenuation:** one of the main purposes of the control system is to keep both the maximum mechanical loads on the turbine structure and the mechanical fatigue within the design limits.

1.3. Wind farms

Electricity generation: main control objectives

- **Provide damping:** the control system must ensure that the dynamics of the turbine are sufficiently damped to avoid resonant modes in the closed-loop system that may be excited by external disturbances.

- **Energy quality and grid stability:** the controller must assure the quality of the power supplied, including the ability to:
  - React to sudden voltage dips.
  - Avoid power flickers.
  - Correct the power factor.
  - Contribute to control the grid frequency.
  - Regulate the voltage.
  - Provide low harmonics content.

1.3. Wind farms

Electricity generation: types of wind turbine speed regulation

There are essentially **two types of wind turbine speed regulation:**

Constant Speed Wind Turbines:

- Based on a gearbox and an asynchronous generator.
- The gearbox speeds up the rotational shaft speed from the rotor to a fixed generator speed.
- The generator produces electricity through a direct grid connection with a set of capacitors to compensate reactive power. Due to the lack of a frequency converter, the generator speed is dictated by the grid frequency.
- Disadvantages:
  - Poor aerodynamic efficiency.
  - Gives only a limited power quality because asynchronous generators demand reactive energy from the grid.

1.3. Wind farms

Electricity generation: types of wind turbine speed regulation

Variable Speed Wind Turbines:

- Many different options to achieve speed variation:
  - Dual speed generators with pole switching: the rotor spins at two different speeds, a lower speed at low winds, which improves performance and reduces noise emission; and a faster speed (lower number of poles) at high winds.
  - High slip asynchronous generators for a low range of variable speed.
  - Doubly fed induction generators for a moderate range of variable speed.
  - Direct drive systems for a wide range of variable speed.
- The power electronics used are more expensive.
- They are able to reduce mechanical loading and drive train fatigue and to capture more energy over a wider range of wind speeds.
- Ability to control independently their active and reactive power and thus to assist the power system.

1.3. Wind farms

Electricity generation: control strategies

There are **three main strategies** for regulating the amount of power captured by the rotor:

1) Passive stall control or fixed pitch:

- The generator reaction torque regulates rotor speed below rated operation to maximize energy capture.
- The power delivered by the rotor is limited at high winds, thanks to a particular design of the blades that provokes a loss of efficiency.
- The pitch angle is fixed and tip brakes are the only part of the blade which can rotate to spill off the spare energy and shut down the wind turbine.

1.3. Wind farms

Electricity generation: control strategies

2) Variable pitch control:

- The blades regulate the power delivered by the rotor either by pitching the blades towards the wind to maximize energy capture or by pitching to feather to discard the excess of power and to ensure that mechanical limitations are not exceeded.

- To maintain power and rotor speed at their rated value, the torque is held constant and the pitch is continually changed following the demands of a closed-loop rotor speed controller that optimizes energy capture and follows wind speed variations.

- The machine is turned off by simply turning the blade to feather position, i.e. perpendicular to the wind.

1.3. Wind farms

Electricity generation: control strategies

3) Active stall control:

- This technique is a combination of stall and pitch control.
- The blades are designed in a similar way to stall control blades but the entire blade can be turned ninety degrees to adjust its pitch.
- The blades are rotated only by small amounts and less frequently than in pitch control to optimize the performance of the blades over the range of wind speeds, especially with low wind speeds.

Stall controlled wind turbines are still attractive because they are simple to construct and much cheaper.

However, as machines get larger and the loads greater there is a trend toward pitch control and active stall control because they improve the power quality and produce more energy than stall machines.

1.3. Wind farms

Electricity generation: control strategies

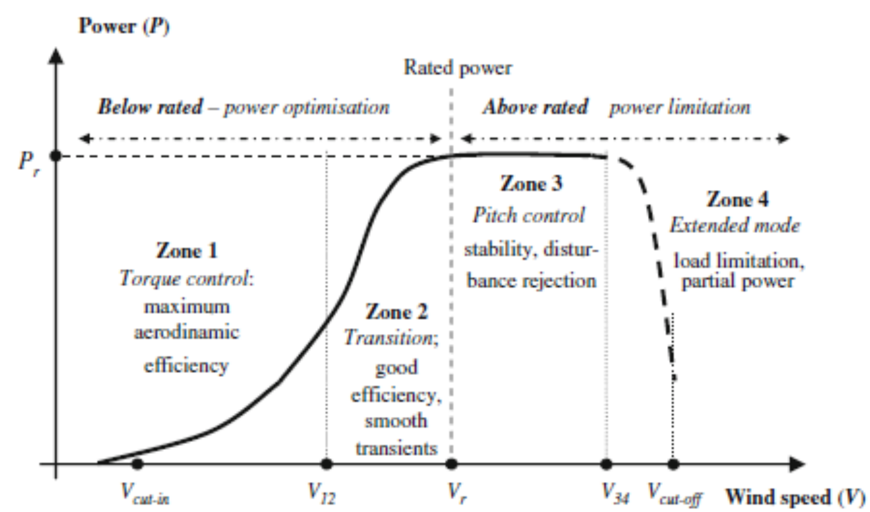
The control system of a wind turbine consists of a hardware/software configuration. It handles all the necessary variables and parameters to govern the wind turbine, aiming at two overall objectives: reliability and performance.

Zona 1. Torque control: lowest wind, between 3-4 and 7-8 m/s. The objective is to obtain the maximum aerodynamic power coefficient C_p.

Zona 2. Transition: medium wind, between 7-8 and 11-13 m/s. It is not possible to get the desired tip speed ratio, rotor speed is near to maximum.

Zona 3. Pitch control: high wind, between 11-13 and 20-25 m/s. The blades have to move the pitch angle to limit the power, control the rotor speed and minimize the mechanical loads.

Zona 4. Extended mode: very high wind, between 20-25 and 25-30 m/s. It can be done by means of varying the pitch closed-loop performance.



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1.4. Legal aspects of wind energy

Environmental aspects and impacts

The potential negative impacts of wind energy can be divided into the following categories:

- **Avian interaction with wind turbines:** many bird species are very habitat-specific and often particularly sensitive to habitat changes.
- **Visual impact of wind turbines:** one of wind power's perceived adverse environmental impact factors and a major concern of the public, but it is the least quantifiable.
- **Wind turbine noise:** the problems associated with wind turbine noise have been one of the most studied environmental impact areas.
- **Electromagnetic interference effects of wind turbines:** wind turbines can present an obstacle for incident electromagnetic waves, which may be reflected, scattered, or diffracted by the wind turbine.
- **Land-use impact of wind power systems:** the development of a wind farm may affect other uses on or adjacent to a site.

1.4. Legal aspects of wind energy

Spanish policy

Multiple administrative jurisdiction:

- Industrial level:
  - National government establishes basic regulations concerning energy.
  - Regional governments regulate energy production, distribution and transport.
- Urbanistic level:
  - Completely regulated by regional governments.
- Environmental level:
  - National government establishes basic regulations concerning environmental protection.

Strong investment from the main wind energy companies.

Unclear future as regards public funding for renewable energies.
26 December 2013: New electricity law (Ley 24/2013).

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