WindTurbine

A research presented to Engineering Syndicate \ Sulaimaniyah branch

Prepared by:

Eng. Ali Hammadi Chitheer

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١.٠ Introduction

Wind turbines harness the power of the wind and use it to generate electricity. About ٤٠ per cent of all wind energy in Europe blows over the UK, making it an ideal country for domestic turbines (known as micro-wind or small-wind turbines). A typical system in an exposed site can easily generate more power than your lights and electrical appliances use.

A **wind turbine** is a device that converts the wind's kinetic energy into electrical power.

Wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

٢.٠ How do wind turbines work?

Wind turbines use large blades to catch the wind. When the wind blows, the blades are forced round, driving a turbine which generates electricity. The stronger the wind, the more electricity produced.There are two types of domestic-sized wind turbine:

- Pole mounted: these are free standing and are erected in a suitably exposed position, often about ٥kW to ٦kW.
- Building mounted: these are smaller than mast mounted systems and can be installed on the roof of a home where there is a suitable wind resource. Often these are around ١kW to ٢kW in size.

٣.٠ The advantages of wind turbines at home

Reduce electricity bills: Wind is free, so once you've paid for the initial installation your electricity costs will be reduced.

Reduce carbon footprint: Wind electricity is green, renewable energy and doesn't release any harmful carbon dioxide or other pollutants.

Store electricity for a calm day: If your home isn't connected to the national grid you can store excess electricity in batteries and use it when there is no wind.

٣.١ Resources

A quantitative measure of wind energy available at any location is called the Wind Power Density (WPD). It is a calculation of the mean annual power available per square meter of swept area of a turbine, and is tabulated for different heights above ground. Calculation of wind power density includes the effect of wind velocity and air density. Color-coded maps are prepared for a particular area described, for example, as "Mean Annual Power Density at ٥٠ Metres". In the United States, the results of the above calculation are included in an index developed by the National Renewable Energy Laboratory and referred to as "NREL CLASS". The larger the WPD, the higher it is rated by class. Classes range from Class ١ (٢٠٠ watts per square meter or less at ٥٠ m altitude) to Class ٧ (٨٠٠ to ٢٠٠٠ watts per square m). Commercial wind farms generally are sited in Class ٣ or higher areas, although isolated points in an otherwise Class ١ area may be practical to exploit.

Figure ١: Wind turbine in Germany

Wind turbines are classified by the wind speed they are designed for, from class I to class IV, with A or B referring to the turbulence

Class	**Avg Wind Speed (m/s)**	**Turbulence**

IA	١٠	١٨٪
IB	١٠	١٦٪
IIA	٨.٥	١٨٪
IIB	٨.٥	١٦٪
IIIA	٧.٥	١٨٪
IIIB	٧.٥	١٦٪
IVA	٦	١٨٪
IVB	٦	١٦٪

٣.٢ Efficiency

Not all the energy of blowing wind can be used, but some small wind turbines are designed to work at low wind speeds.

Conservation of mass requires that the amount of air entering and exiting a turbine must be equal. Accordingly, Betz's law gives the maximal achievable extraction of wind power by a wind turbine as ١٦/٢٧ (٥٩.٣٪) of the total kinetic energy of the air flowing through the turbine.

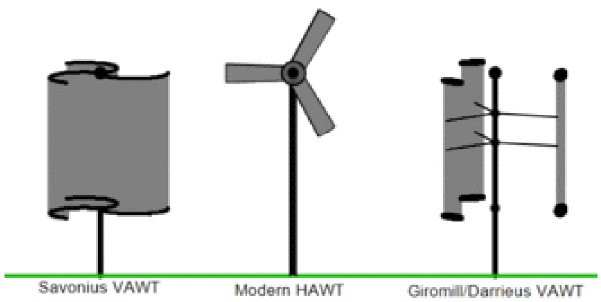
The maximum theoretical power output of a wind machine is thus ١٦/٢٧ times the kinetic energy of the air passing through the effective disk area of the machine. If the effective area of the disk is A, and the wind velocity v, the maximum theoretical power output P.

As wind is free (no fuel cost), wind-to-rotor efficiency (including rotor blade friction and drag) is one of many aspects impacting the final price of wind power.[١٦] Further inefficiencies, such as gearbox losses, generator and converter losses, reduce the power delivered by a wind turbine. To protect components from undue wear, extracted power is held constant above the rated operating speed as theoretical power increases at the cube of wind speed, further reducing theoretical efficiency. In ٢٠٠١, commercial utility-connected turbines deliver ٧٥٪ to ٨٠٪ of the Betz limit of power extractable from the wind, at rated operating speed.

Efficiency can decrease slightly over time due to wear. Analysis of ٣١٢٨ wind turbines older than ١٠ years in Denmark showed that half of the turbines had no decrease, while the other half saw a production decrease of ١.٢٪ per year. Vertical turbine designs have much lower efficiency than standard horizontal designs.

٣.٣ Types

The three primary types: VAWT Savonius, HAWT towered; VAWT Darrieus as they appear in operation



Wind turbines can rotate about either a horizontal or a vertical axis, the former being both older and more common. They can also include blades (transparent or not)or be bladeless.Vertical designs produce less power and are less common.

٣.٤ Horizontal axis

Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position

Figure ٣: A turbine blade convoy passing through Edenfield, UK

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be 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 to drive an electrical generator.

Any solid object produces a wake behind it, leading to fatigue failures, so the turbine is usually positioned upwind of its supporting tower. Downwind machines have been built, because they don't need an additional mechanism for keeping them in line with the wind. In high winds, the blades can also be allowed to bend which reduces their swept area and thus their wind resistance. In upwind designs, turbine blades must be made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount.

Turbines used in wind farms for commercial production of electric power are usually three-bladed. These have low torque ripple, which contributes to good reliability. The blades are usually colored white for daytime visibility by aircraft and range in length from ٢٠ to ٨٠ meters (٦٦ to ٢٦٢ ft). The size and height of turbines increase year by year. Offshore wind turbines are built up to ٨MW today and have a blade length up to ٨٠m. Usual tubular steel towers of multi megawatt turbines have a height of ٧٠ m to ١٢٠ m and in extremes up to ١٦٠ m.

The blades rotate at ١٠ to ٢٢ revolutions per minute. At ٢٢ rotations per minute the tip speed exceeds ٩٠ meters per second (٣٠٠ ft/s).Higher tip speeds means more noise and blade erosion. A gear box is commonly used for stepping up the speed of the generator, although designs may also use direct drive of an annular generator.

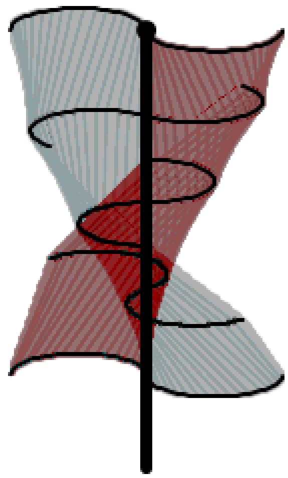


Figure ٤: A vertical axis Twisted Savonius type turbine.

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance. However, these designs produce much less energy averaged over time, which is a major drawback.

The key disadvantages include the relatively low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the ٣٦٠-degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modelling the wind flow accurately and hence the challenges of analysing and designing the rotor prior to fabricating a prototype.

When a turbine is mounted on a rooftop the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of a rooftop mounted turbine tower is approximately ٥٠٪ of the building height it is near the optimum for maximum wind energy and minimum wind turbulence. Wind speeds within the built environment are generally much lower than at exposed rural sites, noise may be a concern and an existing structure may not adequately resist the additional stress.

Subtypes of the vertical axis design include:

Figure ٥: Offshore Horizontal Axis Wind Turbines (HAWTs) at Scroby Sands Wind Farm, UK

Figure ٦: Onshore Horizontal Axis Wind Turbines in Zhangjiakou, China

Darrieus wind turbine

٤.٠ Design and construction

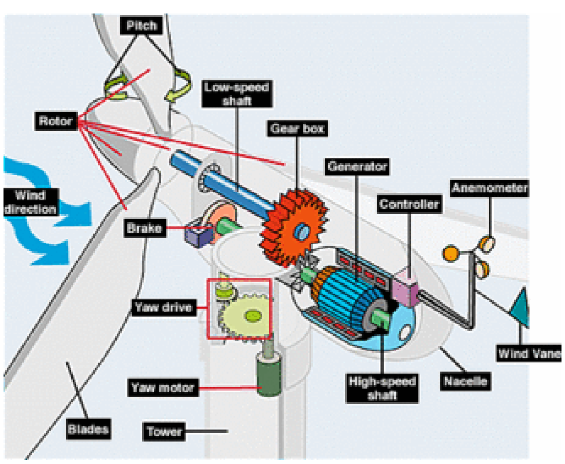


Figure ٧: Components of a horizontal-axis wind turbine

Figure ٨: Inside view of a wind turbine tower, showing the tendon cables.

Wind turbines are designed, using a range of computer modelling techniques,[٣٩] to exploit the wind energy that exists at a location. For example, Aerodynamic modeling is used to determine the optimum tower height, control systems, number of blades and blade shape.

Wind turbines convert wind energy to electricity for distribution. Conventional horizontal axis turbines can be divided into three components:

- The rotor component, which is approximately ٢٠٪ of the wind turbine cost, includes the blades for converting wind energy to low speed rotational energy.
- The generator component, which is approximately ٣٤٪ of the wind turbine cost, includes the electrical generator,[٤٠][٤١] the control electronics, and most likely a gearbox (e.g. planetary gearbox),[٤٢]adjustable-speed drive or continuously variable transmission[٤٣] component for converting the low speed incoming rotation to high speed rotation suitable for generating electricity.
- The structural support component, which is approximately ١٥٪ of the wind turbine cost, includes the tower and rotor yaw mechanism.[٤٤]

A ١.٥ MW wind turbine of a type frequently seen in the United States has a tower ٨٠ meters (٢٦٠ ft) high. The rotor assembly (blades and hub) weighs ٢٢,٠٠٠ kilograms (٤٨,٠٠٠ lb). The nacelle, which contains the generator component, weighs ٥٢,٠٠٠ kilograms (١١٥,٠٠٠ lb). The concrete base for the tower is constructed using ٢٦,٠٠٠ kilograms (٥٨,٠٠٠ lb) of reinforcing steel and contains ١٩٠ cubic meters (٢٥٠ cu yd) of concrete. The base is ١٥ meters (٥٠ ft) in diameter and ٢.٤ meters (٨ ft) thick near the center.

Among all renewable energy systems wind turbines have the highest effective intensity of power-harvesting surfacebecause turbine blades not only harvest wind power, but also concentrate it.

٤.١ Unconventional designs

Figure ٩: Counter rotating wind turbine (dual rotor)

Figure ١٠: The corkscrew shaped wind turbine at Progressive Field in Cleveland, Ohio

An E-٦٦ wind turbine in the Windpark Holtriem, Germany, has an observation deck for visitors. Another turbine of the same type with an observation deck is located in Swaffham, England. Airborne wind turbine designs have been proposed and developed for many years but have yet to produce significant amounts of energy. In principle, wind turbines may also be used in conjunction with a large vertical solar updraft tower to extract the energy due to air heated by the sun.

Wind turbines which utilise the Magnus effect have been developed.[٤٨]

A ram air turbine (RAT) is a special kind of small turbine that is fitted to some aircraft. When deployed, the RAT is spun by the airstream going past the aircraft and can provide power for the most essential systems if there is a loss of all on-board electrical power,[٤٩] as in the case of the "Gimli Glider".

The two-bladed SCD ٦MW offshore turbine designed by aerodyn Energiesysteme and built by MingYang Wind Power has a helideck for helicopters on top of its nacelle. The prototype was erected in ٢٠١٤ in Rudong, China.

٥.٠ Small wind turbines

A small Quietrevolution QR٥Gorlov type vertical axis wind turbine in Bristol, England. Measuring ٣ m in diameter and ٥ m high, it has a nameplate rating of ٦.٥ kW to the grid.

Small wind turbines may be used for a variety of applications including on- or off-grid residences, telecom towers, offshore platforms, rural schools and clinics, remote monitoring and other purposes that require energy where there is no electric grid, or where the grid is unstable. Small wind turbines may be as small as a fifty-watt generator for boat or caravan use. Hybrid solar and wind powered units are increasingly being used for traffic signage, particularly in rural locations, as they avoid the need to lay long cables from the nearest mains connection point. The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) defines small wind turbines as those smaller than or equal to ١٠٠ kilowatts. Small units often have direct drive generators, direct current output, aeroelastic blades, lifetime bearings and use a vane to point into the wind.

Larger, more costly turbines generally have geared power trains, alternating current output, flaps and are actively pointed into the wind. Direct drive generators and aeroelastic blades for large wind turbines are being researched.

٥.١ Wind turbine spacing

On most horizontal windturbine farms, a spacing of about ٦–١٠ times the rotor diameter is often upheld. However, for large wind farms distances of about ١٥ rotor diameters should be more economically optimal, taking into account typical wind turbine and land costs. This conclusion has been reached by research[٦٣] conducted by Charles Meneveau of the Johns Hopkins University,[٦٤] and Johan Meyers of Leuven University in Belgium, based on computer simulations[٦٥] that take into account the detailed interactions among wind turbines (wakes) as well as with the entire turbulent atmospheric boundary layer. Moreover, recent research by John Dabiri of Caltech suggests that vertical wind turbines may be placed much more closely together so long as an alternating pattern of rotation is created allowing blades of neighbouring turbines to move in the same direction as they approach one another

٦.٠ Operability

٦.١ Maintenance

Wind turbines need regular maintenance to stay reliable and available, reaching ٩٨٪.Modern turbines usually have a small onboard crane for hoisting maintenance tools and minor components. However, large heavy components like generator, gearbox, blades and so on are rarely replaced and a heavy lift external crane is needed in those cases. If the turbine has a difficult access road, a containerized crane can be lifted up by the internal crane to provide heavier lifting.

٦.٢ Repowering

Installation of new wind turbines can be controversial. An alternative is repowering, where existing wind turbines are replaced with bigger, more powerful ones, sometimes in smaller numbers while keeping or increasing capacity.

٦.٣ Demolition

Older turbines were in some early cases not required to be removed when reaching the end of their life. Some still stand, waiting to be recycled or repowered.A demolition industry develops to recycle offshore turbines at a cost of DKK ٢–٤ million per MW, to be guaranteed by the owner.

٧.٠ Advantages and Disadvantages

٧.١ Advantages

Wind turbines are generally inexpensive. They will cost between two and six cents per kilowatt hour, which is one of the lowest-priced renewable energy sources in today's world.And as technology needed for wind turbines continues to improve, the prices will decrease as well. In addition, there is no competitive market for wind energy, as it does not cost money to get ahold of wind.The main cost of wind turbines are the installation process. The average cost is between $٤٨,٠٠٠ and $٦٥,٠٠٠ to install. However, the energy harvested from the turbine will offset the installation cost, as well as provide virtually free energy for years after.

Wind turbines provide a clean energy source, emitting no greenhouse gases and no waste product. Over ١,٥٠٠ tons of carbon dioxide per year can be eliminated by using a one megawatt turbine instead of one megawatt of energy from a fossil fuel. Being environmentally friendly and green is a large advantage of wind turbines.

Wind turbines are also quite efficient. Wind farms can generate between ١٧ and ٣٩ times as much power as they consume, and in the United States alone, wind turbines have produced about ١٦ billion kilowatt-hours of energy per year.

٧.٢ Disadvantages

Wind turbines can be very large, reaching over ٤٠٠ feet tall and with blades ٥٠ yards long, and people have often complained about their visual impact.Environmental impact of wind power includes effect on wildlife. Thousands of birds, including rare species, have been killed by the blades of wind turbines, though wind turbines contribute a relatively insignificantly to anthropogenic avian mortality. For every bird killed by a wind turbine in the US, nearly ٥٠٠,٠٠٠ are killed by each of feral cats and buildings.

Energy harnessed by wind turbines is intermittent, and is not a "dispatchable" source of power; it's availability is based on whether the wind is blowing, not whether electricity is needed. Turbines can be placed on ridges or bluffs to maximize the access of wind they have, but this also limits the locations where they can be placed. In this way, wind energy is not a particularly reliable source of energy.

٨.٠ Records

Fuhrländer Wind Turbine Laasow, in Brandenburg, Germany, among the world's tallest wind turbines

Éole, the largest vertical axis wind turbine, in Cap-Chat, Quebec, Canada

Largest capacity conventional drive

The Vestas V١٦٤ has a rated capacity of ٨ MW,later upgraded to ٩ MW. The windmill has an overall height of ٢٢٠ m (٧٢٢ ft), a diameter of ١٦٤ m (٥٣٨ ft), is for offshore use, and is the world's largest-capacity wind turbine since its introduction in ٢٠١٤. The conventional drive train consist of a main gearbox and a medium speed PM generator. Prototype installed in ٢٠١٤ at the National Test Center Denmark nearby Østerild. Series production began end of ٢٠١٥.

Largest capacity direct drive

The Enercon E-١٢٦ with ٧.٥٨ MW and ١٢٧ m rotor diameter is the largest direct drive turbine. It's only for onshore use. The turbine has parted rotor blades with ٢ sections for transport. In July ٢٠١٦, Siemens upgraded its ٧ to ٨ MW.

Largest vertical-axis

Le Nordais wind farm in Cap-Chat, Quebec has a vertical axis wind turbine (VAWT) named Éole, which is the world's largest at ١١٠ m. It has a nameplate capacity of ٣.٨ MW.

Largest ١-bladed turbine

Riva Calzoni M٣٣ was a single-bladed wind turbine with ٣٥٠ kW, designed and built In Bologna in ١٩٩٣

Largest ٢-bladed turbine

The biggest ٢-bladed turbine is built by Mingyang Wind Power in ٢٠١٣. It is a SCD٦.٥MW offshore downwind turbine, designed by aerodyn Energiesysteme.

Largest swept area

The turbine with the largest swept area is the Samsung S٧.٠–١٧١, with a diameter of ١٧١ m, giving a total sweep of ٢٢٩٦٦ m٢.

Tallest

A Nordex ٣.٣ MW was installed in July ٢٠١٦. It has a total height of ٢٣٠m, and a hub height of ١٦٤m on ١٠٠m concrete tower bottom with steel tubes on top (hybrid tower).

Vestas V١٦٤ was the tallest wind turbine, standing in Østerild, Denmark, ٢٢٠ meters tall, constructed in ٢٠١٤. It has a steel tube tower.

Highest tower

Fuhrländer installed a ٢.٥MW turbine on a ١٦٠m lattice tower in ٢٠٠٣ (see Fuhrländer Wind Turbine Laasow and Nowy Tomyśl Wind Turbines).

Most rotors

Lagerwey has build Four-in-One, a multi rotor wind turbine with one tower and four rotors near Maasvlakte.In April ٢٠١٦, Vestas installed a ٩٠٠ kW quadrotor test wind turbine at Risø, made from ٤ recycled ٢٢٥ kW V٢٩ turbines.

Most productive

Four turbines at Rønland Offshore Wind Farm in Denmark share the record for the most productive wind turbines, with each having generated ٦٣.٢ GWh by June ٢٠١٠.

Highest-situated

Since ٢٠١٣ the world's highest-situated wind turbine was made and installed by WindAid and is located at the base of the Pastoruri Glacier in Peru at ٤,٨٧٧ meters (١٦,٠٠١ ft) above sea level.The site uses the WindAid ٢.٥ kW wind generator to supply power to a small rural community of micro entrepreneurs who cater to the tourists who come to the Pastoruri glacier.

Largest floating wind turbine

The world's largest—and also the first operational deep-water *large-capacity*—floating wind turbine is the ٢.٣ MW Hywind currently operating ١٠ kilometers (٦.٢ mi) offshore in ٢٢٠-meter-deep water, southwest of Karmøy, Norway. The turbine began operating in September ٢٠٠٩ and utilizes a Siemens ٢.٣ MW turbine

٩.٠ Result: Cost, Saving and Financial Support

The cost of a system will depend on the size and the mounting method. Building-mounted turbines cost less to install than pole-mounted ones, but they tend to be less efficient.

For equipment and installation, with VAT at ٥ per cent:

- a roof-mounted ١kW micro wind system costs up to £٣,٠٠٠
- a ٢.٥kW pole-mounted system costs between £٩,٩٠٠ and £١٩,٠٠٠
- a ٦kW pole-mounted system costs between £٢١,٠٠٠ and £٣٠,٠٠٠.

Building-mounted turbines tend to produce less electricity per kW than pole-mounted ones. A well-sited ٦kW turbine can generate around ١٠,٠٠٠kWh and the equivalent of around ٤.٥ tonnes of carbon dioxide a year.

Wind turbines are eligible for Feed-in Tariffs and you will be paid for the electricity generated by your system. You will also receive another payment for the electricity you export.

Wind turbine maintenance

Maintenance checks are necessary every few years, and will generally cost around £١٠٠ to £٢٠٠ per year depending on turbine size. A well-maintained turbine should last more than ٢٠ years, but you may need to replace the inverter at some stage during this time, at a cost of £١,٠٠٠ to £٢,٠٠٠ for a large system.

For off-grid systems, batteries will also need replacing, typically every ٦ to ١٠ years. The cost of replacing batteries varies depending on the design and scale of the system. Any back-up generator will also have its own fuel and maintenance costs.

Wind speed The amount of electricity a wind turbine can generate depends on the wind speed on your site. For a wind turbine to be economically valuable, you need an average wind speed of at least five meters per second (٥m/s) in an area free from turbulence caused by surrounding obstacles such as trees or buildings. There are a range of tools that let you find out whether you have an adequate wind speed in your area for a wind turbine. Assessing wind speed is crucial to the economic viability wind turbines; it is therefore very important to measure wind speed before taking any decision to proceed. Not enough wind speed? Explore other renewable and low-carbon technologies to suit your home with our Renewables Selector. Obstacles Wind turbines work best in exposed locations, without turbulence caused by obstacles such as trees or buildings. Go to the RenewableUK website for information on siting a small wind turbine. RenewableUK is the trade and professional body for the UK wind and marine renewables industries. Off grid Is your home located away from the local grid? Small domestic wind systems are particularly suitable for use in remote locations where mains electricity is unavailable. Unless the gird is very close by, the cost of getting a mains connection can easily be more than the cost of installing an independent wind power system. Find out more about off-grid possibilities.

Why is measuring wind speed so important? The amount of electricity a wind turbine can generate depends on the local wind speed. The wind speed itself depends on a number of factors such as:

- where you are in the UK
- whether there are any obstructions such as trees and buildings nearby (which slow the wind down and cause turbulence)
- the height above ground level: wind speeds increase with height so that the higher a turbine is the more electricity it is likely to produce. The location of a wind turbine is therefore crucial for maximising its overall performance. Although the power carried by the wind is proportional to the cube of the wind speed, the actual power output delivered by a wind turbine is more complex. Power output is zero up to the 'cut in' wind speed - the speed at which power is generated - and flat above the 'rated' wind speed. However, between the 'cut in' and 'rated' wind speeds, the power output is roughly proportional to the cube of the wind speed. The diagram below illustrates this (wind speeds vary for each turbine). Therefore it is crucial to measure the wind speed before installing a turbine to make sure it will be financially worthwhile.

How can I measure the wind speed? As a first step we recommend that you use our Wind Speed Prediction Tool. This tool (which is very easy to use) provides an estimated wind speed when you put in your postcode and the type of area you live in. The tool enables you to find out quickly whether the wind at the site you are interested in is strong enough to warrant further investigation. We do not recommend installing a domestic small scale wind turbine in areas with wind speeds of less than ٥ metres per second (٥m/s) as speeds less than this are unlikely to provide a cost-effective way of producing electricity with current technologies. If the Wind Speed Prediction Tool predicts that the wind speed at the location selected is ٥m/s or above, and if the project still looks viable the next step is to check the wind speed predictions using an anemometer or wind gauge. You should do this for at least three months and ideally for twelve months or more. If you measure wind speeds for less than six months, you will need to apply a seasonal adjustment factor as wind speed varies by season.

What is an anemometer? Anemometers can also make use of ultrasound sonic waves rather than cups. Handheld anemometers that have a built-in impeller to measure wind speed can also be purchased. However, these are not designed for assessing whether a site has sufficient wind for a turbine as they can provide only intermittent data. The purpose of the anemometer is to measure average, minimum and maximum wind speed as well as how much turbulence there is at the site. If two anemometers are put at different heights on the same mast this provides useful additional information about the wind shear - the difference in wind speed at different heights. They can also provide useful information about the intensity of any wind turbulence at the site. You will also need to measure wind direction. You can do this by using a separate weathervane (also called a wind vane or direction indicator) although some anemometers include a direction indicator, such as the Power Predictor and Pro Anemometer referred to below. Ultrasonic devices can also have built-in wind direction monitors, although these are more expensive. The pole, anemometer and wind vane equipment are often referred to as a meteorological mast or met mast for short. Information on wind speed and direction is collected by a data logger and can be analysed using computer software. The wind data collected also needs to be cross-checked for accuracy against data from a nearby Met Office weather station. More professional data loggers not only measure wind speeds but also do real-time calculations with that data over regular intervals, usually set at ١٠ minutes. These calculations include the average and maximum wind speeds over the interval selected. The ideal scenario is to have anemometer sited at the same site and height as the hub of the proposed wind turbine, so you can leave it in situ while the wind speed is being monitored.

How do I measure wind speed with an anemometer? If you want to measure the wind speed you can:

- buy an anemometer and a data logger and interpret the data yourself, or

- instruct a consultant or installer to do this for you - the bigger the potential investment the more likely it is to be worth your while employing an experienced third party to do this work for you. If you are already in contact with an MCS-certified installer this is something that you could discuss with them. MCScertified installers are required by the Microgeneration Installation Standard (find out about MIS ٣٠٠٣ at the MCS website) on small wind turbine systems to undertake a three-step calculation to assess the likely performance of a wind turbine. The installation of an anemometer is not a requirement of MCS although it does state that 'accurate measurement over a period of one year is the preferred method for determining the actual wind speed in a given location and should always be considered.' Where can I buy an anemometer? If you want to measure the wind speed yourself, there are a number of companies that manufacture and sell anemometers – from those which can be handheld to those with an international calibration certificate. Here are some samples:

Wind turbine measuring wind speed

Choosing a wind turbine

To be eligible for payments through the Feed in Tariff, your wind turbine must be certified under the Microgeneration Certification Scheme (MCS) and the turbine must be installed by an MCS-certified installer.

MCS-certified wind turbines below ١٥kW This information has been extracted from the manufacturers' websites and technical data sheets during April ٢٠١٢. Please note that we are not responsible for the accuracy of the data presented. For the latest list of certified turbines, and turbines ١٥kW and over (to ٥٠kW) if you have a suitable site for a larger turbine, check the MCS wind turbine product database. Click on the name of any of the turbines to find out more at the manufacturer's website.

Turbine Rated power Wind speed at rated power

BWEA reference annual energy at ٥m/s

Diameter of blades Tower height

Skystream ٣.٧ ٢.٤kW ١٣m/s ٣,٤١٦kWh ٣.٧٢m ١٠.٢, ١٣.٧ or ١٨.٣m

Evance R٩٠٠ ٥kW ١٢m/s ٨,٧٨٠kWh ٥.٥m ١٠, ١٢, ١٥, or ١٨m

Kingspan KW٦ ٥.٢kW ١١m/s ٨,٩٤٩kWh ٥.٥m ٩, ١١.٦ or ١٥m Eoltec Scirocco ٦kW ١٢m/s ٩,٨٨١kWh ٥.٦m ١٢ or ١٥m Qr٥ ٧.٢kW ١٣.٥m/s ٤.١٩٧kWh ٣.١m;٥.٥m tall ٦m roof mounted, ١٨m ground mounted Evoco ١٠ ٩.٥٥kW ١١m/s ٢١.٧٠٦kWh ٧.٢m ١٢ or ١٥m Aircon١٠S ١٠kW ١١m/s not given ٧.٥m ١٨, ٢٤ or ٣٠m Bergey Excel ١٠ ١٠kW ١٢.٥m/s ١٣,٨٠٠kWh ٧m ١٨ to ٤٩m Xzeres ٤٤٢SR ١٠kW ١١m/s ١٥,٣٢٩kWh ٩.٧m not given

Gala-Wind ١٣٣ ١١kW not given ٢٧.٥٠٢kWh ١٣m

١٥ or ١٨m (lattice) or ١٨ and ٢٧m (monopole) C&F Green Energy ١١kW ٩m/s ٢٤,٠٠٠ ٩m ١٥ or ١m C&F Green Energy ١٥kW ٨m/s ٤٣,٤٠٠kWh ١٣.١ ٢٠m

Power ratings You will notice that the rated power (in kW) of different wind turbines is given at different windspeeds measured in meters per second (m/s). This makes it difficult to make a side by side comparison of the likely output of one wind turbine compared with another even if both state that their rated power is, for example, ٥kW. To overcome this problem RenewableUK introduced the Small Wind Turbine Performance and Safety Standard. As part of the MCS approval process the approved wind turbine has to be measured against this standard. This will result in additional information being available in the form of a summary report which will help you assess the likely performance of one turbine against another. In general terms the information includes:

- the BWEA Reference Power, which is the rated power of the wind at ١١m/s

- the BWEA Reference Annual Energy, which is the amount of energy in kWh that the turbine will produce in a year at a constant windspeed of ٥m/s at a stipulated hub height

- the BWEA Reference Sound Levels at ٢٥ and ٦٠m rounded up to the nearest decibel (dB) from the turbine. A turbine which meets the requirements of the BWEA small wind turbine standard will have a label (which should be used on all product literature and advertising). The label will say 'Certified by BRE'. Evidence of compliance with the Standard is required before small wind turbines (up to ٥٠kW) can be certified through MCS, as set out in MCS٠٠٦.

Connection to your home Part P Building Regulation approval is required for electrical installation and connection of the system to your home. Building regulation approval can be obtained by making an application to the local authority for consent or by using a member of a competent person scheme (CPS). All MCS installers are required to be members of a Competent Persons scheme for Part P electrical work. Obtaining Building Regulation approval is therefore a job for your installer.

Connection to the grid ,the installer should liaise with your District Network Operator (DNO) to connect your wind turbine to the local grid. Smaller systems If the wind turbine is up to ١٦A per phase (equivalent to ٣.٦٨kW) it falls under G٨٣/٢, and your installer can simply inform the DNO within ٢٨ days of commissioning that a connection has been made. Download a guide to connecting generation that falls under G٨٣/٢ from Energy Networks Association.

Larger systems If your wind turbine system is too large to fall under G٨٣/٢, your installer will need to get permission from your DNO before any connection to the grid is made. The DNO will carry out a network study (which it may charge you for) to ensure that the local grid network can take the extra power that your wind turbine system will generate. If the local grid network needs extra work before it can accept your connection, this will have to be done at your own cost. The DNO has ٤٥ days to provide you with a quotation for this work; it must be able to justify the costs it wants to charge, and this is regulated by Ofgem. Find key documents on grid connection at the Energy Network Association website.

Distribution Network Operators (DNOs)

Registering for Feed-in Tariff (FIT) payments It is a job for your installer to register your wind turbine installation with the Microgeneration Certification Scheme within ١٠ days of the commissioning date. Once this has been done you will get a certificate which you can then use to claim the FIT. You may want to provide advance notice to your FIT supplier to ensure you can receive payments from the commissioning date. Find out more about registering for FITs.

Measuring the electricity export

Householders who do not have an export meter fitted (which is normal for anyone with a less than ٣٠kWp solar PV or wind system) are deemed to be exporting ٥٠ per cent of the electricity generated back to the grid. Their FIT payment will be based on this amount no matter what their actual export is. For a wind system, in general only ٣٠ per cent of domestic supply coincides with the wind generation profile. This means that in practice up to ٧٠ per cent of wind power is exported to the grid. Therefore, you may gain more by receiving payment for the exact amount of energy supplied to the grid with the export meter installed. Bear in mind that it is you who will be liable for the cost of the export meter and installation, so it is worth checking that you are exporting more than ٥٠ per cent of your generation and that the extra money paid for export over ٥٠ per cent is enough to pay back the cost of the meter. Calculating what you export If you want to do a rough calculation of how much electricity you export over a year you can carry out a very rough estimate by:

• calculating the amount of electricity you used in the year before your wind or PV system was installed in kWh (import year ٠), from previous electricity bills

• calculating the electricity you've imported in the year since your wind or PV system was installed (import year ١), again using electricity bills

• making a note from your generation meter of the amount of electricity your wind or PV system generated in year ١ (total generation), over exactly the same period.

For example, if you imported ٤,٠٠٠kWh in year ٠, imported ٣,٤٠٠kWh in year ١ and your total generation in year ١ was ١٨٠٠kWh then you will be exporting ٦٧ per cent rounded to the nearest decimal point. This has been calculated using the formula: Total% exported = (١ – change in import over two periods (kWh)/total generation (kWh)) x ١٠٠ ٦٧٪ = (١ – (٤,٠٠٠ – ٣,٤٠٠)kWh/١,٨٠٠kWh) x ١٠٠) In this example, the fact that you're exporting ٦٧ per cent of the electricity generated also implies that ٣٣ per cent is used on site which is the saving you make from import. This is only a rough estimate, as it assumes your consumption over the two years is identical – it is much less accurate than an export meter.

If you have had your wind or PV system installed for less than a year, you can compare figures over a shorter period. This will be less accurate but not very far out - electricity usage does not fluctuate much over the year unless you use electricity to heat your home. If you want to know whether you are likely to be exporting electricity at any given moment of time you can look at the graphic display on your inverter. This will show the current amount of electricity being generated by your wind turbine or PV panels which you can then compare to the total consumption of all the appliances in your home that are on.

We can make a rough calculation of this by adding together the rated power of each appliance. Or you can buy a monitor for £١٢٥-١٥٠ (based on the Geo Solo PV Energy Monitor and the Sunny Boy Beam). This is particularly useful if your inverter is in an out-of-the-way location such as an attic or garage. Using Bluetooth technology you can also monitor the output of your wind or PV system remotely - although the cost of this might be more than the value of the electricity you save. This process can also be managed automatically by installing a home energy management system that compares your electricity production and consumption in real time. If there is surplus electricity the management system decides whether the surplus should be stored (as heat or hot water) or exported to the grid. An example of this is the Energy and Micro-generator Manager or EMMA for short.

Getting an export meter fitted If you are still exporting more than ٥٠ per cent of the electricity you generate, you will be getting paid for less than that. If you wanted to have an export meter fitted the way to do this is to contact your energy supplier and request one. Having an export meter only makes sense financially if you have a relatively large system and you can either get an export meter fitted for free or at low cost. However, many electricity suppliers now have a policy of not installing export meters for installations under ٣٠kW as below this limit it is not compulsory to have one. To receive payment under the Feed-in Tariff, the installation and maintenance of the export meter must be done by your energy supplier rather than your wind or PV system installer. As the work done by an export meter will be superseded by smart meters which are due to be installed in every household (at your energy supplier's cost) between ٢٠١٤ and ٢٠١٩ you might prefer to wait rather than paying now. Smart meters with export meter functionality may be rolled out by some energy suppliers as early as ٢٠١٣. In summary:

- The advantage of an export meter is that you get paid for every kWh of electricity you generate even if that is over ٥٠ per cent

- The disadvantage is that you get paid less for export than you pay for electricity you import and you are likely to have to pay for the export meter to be fitted. This web content was developed by the Energy Saving Trust in partnership with the OCTES project, with funding from the Northern Periphery Programme (NPP) and the Scottish Government. Go to the OCTES website.

Global wind farms

List of onshore wind farms

Wind farm	Current capacity (MW)	Country
Gansu Wind Farm	٦,٠٠٠	China
Muppandal wind farm	١,٥٠٠	India
Alta (Oak Creek-Mojave)	١,٣٢٠	United States
Jaisalmer Wind Park	١,٠٦٤	India
Shepherds Flat Wind Farm	٨٤٥	United States
Roscoe Wind Farm	٧٨٢	United States
Horse Hollow Wind Energy Center	٧٣٦	United States
Capricorn Ridge Wind Farm	٦٦٢	United States
Fântânele-Cogealac Wind Farm	٦٠٠	Romania

Wind farm	Current capacity (MW)	Country
Fowler Ridge Wind Farm	٦٠٠	United States
Whitelee Wind Farm	٥٣٩	United Kingdom

A wind farm is a group of wind turbines in the same location used for production of electric power. A large wind farm may consist of several hundred individual wind turbines distributed over an extended area, but the land between the turbines may be used for agricultural or other purposes. For example, Gansu Wind Farm, the largest wind farm in the world, has several thousand turbines. A wind farm may also be located offshore.

Almost all large wind turbines have the same design — a horizontal axis wind turbine having an upwind rotor with three blades, attached to a nacelle on top of a tall tubular tower.

In a wind farm, individual turbines are interconnected with a medium voltage (often ٣٤.٥ kV), power collection system and communications network. In general, a distance of ٧D (٧ × Rotor Diameter of the Wind Turbine) is set between each turbine in a fully developed wind farm. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system

Generator characteristics and stability

Induction generators, which were often used for wind power projects in the ١٩٨٠s and ١٩٩٠s, require reactive power for excitation so substations used in wind-power collection systems include substantial capacitor banks for power factor correction. Different types of wind turbine generators behave differently during transmission grid disturbances, so extensive modelling of the dynamic electromechanical characteristics of a new wind farm is required by transmission system operators to ensure predictable stable behaviour during system faults. In particular, induction generators cannot support the system voltage during faults, unlike steam or hydro turbine-driven synchronous generators.

Today these generators aren't used any more in modern turbines. Instead today most turbines use variable speed generators combined with partial- or full-scale power converter between the turbine generator and the collector system, which generally have more desirable properties for grid interconnection and have Low voltage ride through-capabilities.Modern concepts use either doubly fed machines with partial-scale converters or squirrel-cage induction generators or synchronous generators (both permanently and electrically excited) with full scale converters.

Transmission systems operators will supply a wind farm developer with a grid code to specify the requirements for interconnection to the transmission grid. This will include power factor, constancy of frequency and dynamic behaviour of the wind farm turbines during a system fault.

Offshore wind power

The world's second full-scale floating wind turbine (and first to be installed without the use of heavy-lift vessels), WindFloat, operating at rated capacity (٢ MW) approximately ٥ km offshore of Póvoa de Varzim, Portugal

Offshore wind power refers to the construction of wind farms in large bodies of water to generate electric power. These installations can utilize the more frequent and powerful winds that are available in these locations and have less aesthetic impact on the landscape than land based projects. However, the construction and the maintenance costs are considerably higher.

Siemens and Vestas are the leading turbine suppliers for offshore wind power. DONG Energy, Vattenfall and E.ON are the leading offshore operators.[٤٣] As of October ٢٠١٠, ٣.١٦ GW of offshore wind power capacity was operational, mainly in Northern Europe. According to BTM Consult, more than ١٦ GW of additional capacity will be installed before the end of ٢٠١٤ and the UK and Germany will become the two leading markets. Offshore wind power capacity is expected to reach a total of ٧٥ GW worldwide by ٢٠٢٠, with significant contributions from China and the US.

In ٢٠١٢, ١,٦٦٢ turbines at ٥٥ offshore wind farms in ١٠ European countries produced ١٨ TWh, enough to power almost five million households. As of August ٢٠١٣ the London Array in the United Kingdom is the largest offshore wind farm in the world at ٦٣٠ MW. This is followed by Gwynt y Môr (٥٧٦ MW), also in the UK.

Wind farm	**Capacity (MW)**	**Country**	**Turbines and model**	**Commissioned**
London Array	٦٣٠	United Kingdom	١٧٥ × Siemens SWT-٣.٦	٢٠١٢

Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned
Gwynt y Môr	٥٧٦	United Kingdom	١٦٠ × Siemens SWT-٣.٦ ١٠٧	٢٠١٥
Greater Gabbard	٥٠٤	United Kingdom	١٤٠ × Siemens SWT-٣.٦	٢٠١٢
Anholt	٤٠٠	Denmark	١١١ × Siemens SWT-٣.٦–١٢٠	٢٠١٣
BARD Offshore ١	٤٠٠	Germany	٨٠ BARD ٥.٠ turbines	٢٠١٣

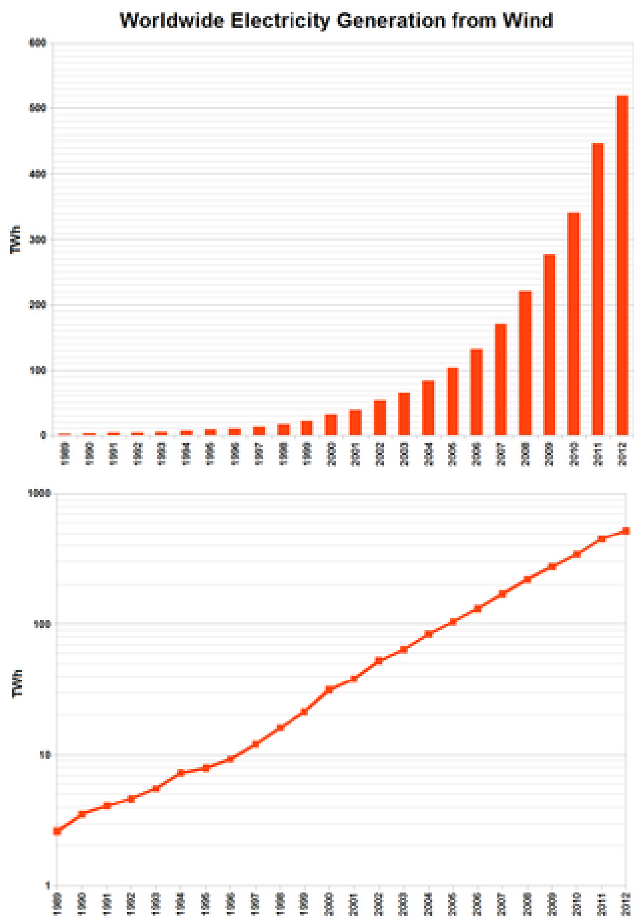
Collection and transmission network

In a wind farm, individual turbines are interconnected with a medium voltage (usually ٣٤.٥ kV) power collection system and communications network. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

A transmission line is required to bring the generated power to (often remote) markets. For an off-shore station this may require a submarine cable. Construction of a new high-voltage line may be too costly for the wind resource alone, but wind sites may take advantage of lines installed for conventionally fueled generation.

One of the biggest current challenges to wind power grid integration in the United States is the necessity of developing new transmission lines to carry power from wind farms, usually in remote lowly populated states in the middle of the country due to availability of wind, to high load locations, usually on the coasts where population density is higher. The current transmission lines in remote locations were not designed for the transport of large amounts of energy.As transmission lines become longer the losses associated with power transmission increase, as modes of losses at lower lengths are exacerbated and new modes of losses are no longer negligible as the length is increased, making it harder to transport large loads over large distances. However, resistance from state and local governments makes it difficult to construct new transmission lines. Multi state power transmission projects are discouraged by states with cheap electric power rates for fear that exporting their cheap power will lead to increased rates. A ٢٠٠٥ energy law gave the Energy Department authority to approve transmission projects states refused to act on, but after an attempt to use this authority, the Senate declared the department was being overly aggressive in doing so.Another problem is that wind companies find out after the fact that the transmission capacity of a new farm is below the generation capacity, largely because federal utility rules to encourage renewable energy installation allow feeder lines to meet only minimum standards. These are important issues that need to be solved, as when the transmission capacity does not meet the generation capacity, wind farms are forced to produce below their full potential or stop running all together, in a process known as curtailment. While this leads to potential renewable generation left untapped, it prevents possible grid overload or risk to reliable service.

Wind power capacity and production



Worldwide there are now over two hundred thousand wind turbines operating, with a total nameplate capacity of ٤٣٢ GW as of end ٢٠١٥.The European Union alone passed some ١٠٠ GW nameplate capacity in September ٢٠١٢, while the United States surpassed ٧٥ GW in ٢٠١٥ and China's grid connected capacity passed ١٤٥ GW in ٢٠١٥.

World wind generation capacity more than quadrupled between ٢٠٠٠ and ٢٠٠٦, doubling about every three years. The United States pioneered wind farms and led the world in installed capacity in the ١٩٨٠s and into the ١٩٩٠s. In ١٩٩٧ installed capacity in Germany surpassed the U.S. and led until once again overtaken by the U.S. in ٢٠٠٨. China has been rapidly expanding its wind installations in the late ٢٠٠٠s and passed the U.S. in

٢٠١٠ to become the world leader. As of ٢٠١١, ٨٣ countries around the world were using wind power on a commercial basis.

Wind power capacity has expanded rapidly to ٣٣٦ GW in June ٢٠١٤, and wind energy production was around ٤٪ of total worldwide electric power usage, and growing rapidly. The actual amount of electric power that wind is able to generate is calculated by multiplying the nameplate capacity by the capacity factor, which varies according to equipment and location. Estimates of the capacity factors for wind installations are in the range of ٣٥٪ to ٤٤٪.By doubling installed capacity an average ٤٠٪ increase in electricity production would be expected.

Europe accounted for ٤٨٪ of the world total wind power generation capacity in ٢٠٠٩. In ٢٠١٠, Spain became Europe's leading producer of wind energy, achieving ٤٢,٩٧٦ GWh. Germany held the top spot in Europe in terms of installed capacity, with a total of ٢٧,٢١٥ MW as of ٣١ December ٢٠١٠. In ٢٠١٥ wind power constituted ١٥.٦٪ of all installed power generation capacity in the EU and it generates around ١١.٤٪ of its power.

Top wind-power electric power producing countries in ٢٠١٢

Country	**Wind-power Production (TWh)**	**% of World Total**
United States	١٤٠.٩	٢٦.٤٪
China	١١٨.١	٢٢.١٪
Spain	٤٩.١	٩.٢٪
Germany	٤٦.٠	٨.٦٪
India	٣٠.٠	٥.٦٪
United Kingdom	١٩.٦	٣.٧٪
France	١٤.٩	٢.٨٪
Italy	١٣.٤	٢.٥٪
Canada	١١.٨	٢.٢٪
Denmark	١٠.٣	١.٩٪
(rest of world)	٨٠.٢	١٥.٠٪

Top wind-power electric power producing countries in ٢٠١٢		
Country	**Wind-power Production (TWh)**	**% of World Total**
World Total	٥٣٤.٣	١٠٠.٠٪

Growth trends

The wind power industry set new records in ٢٠١٤ – more than ٥٠ GW of new capacity was installed. Another record breaking year occurred in ٢٠١٥, with ٢٢٪ annual market growth resulting in the ٦٠ GW mark being passed. In ٢٠١٥, close to half of all new wind power was added outside of the traditional markets in Europe and North America. This was largely from new construction in China and India.

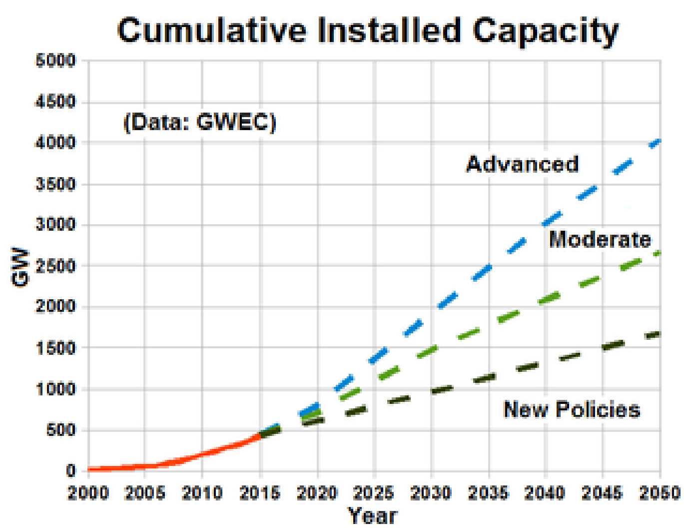


Figure ١١: Worldwide installed wind power capacity forecast