Efficiency and performance

Wind Energy Fact Sheet 14

Many terms are used to describe the performance of wind turbines. This Fact Sheet explains the important ones.

Power and wind speed

The amount of power that a wind turbine generates depends on the wind speed at the time. The ***power curve*** describes the relationship between the wind speed and the power that the turbine generates.

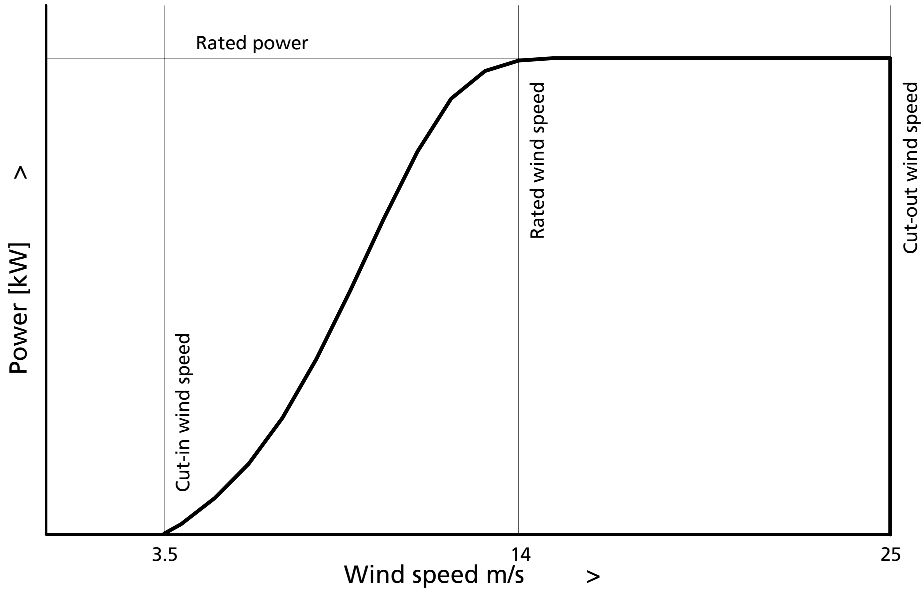

Figure 1 - Typical wind turbine power curve, showing how the power output varies with wind speed.

At very low wind speeds the turbine is unable to generate electricity. As the wind speed increases to the ***cut-in*** speed the turbine begins to operate. Between the cut-in and the ***rated*** wind speeds the turbine takes all the power it can from the wind. Above the rated wind speed and below ***cut-out*** the turbine maintains a constant power output, called the ***rated*** power which is lower than the actual available power in the wind but the maximum that the wind turbine is capable of producing. The rated power level is chosen to give a high electricity production for low wind turbine cost. This is achieved by limiting the electrical and physical loads. The rated power is the same as the installed capacity (see Fact Sheet 13).

When wind speeds are very high the turbine shuts down to protect itself from damage. This happens when the wind speed is higher than the turbine's ***cut-out*** wind speed.

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Capacity factor

The ***capacity factor***, sometimes referred to as the ***load factor***, is the energy generated during a given period divided by the energy that would have been generated had the wind farm been running continually at maximum output, ie:

$$\text{Capacity Factor} = \frac{\text{electricity production during the period [kWh]}}{\text{installed capacity [kW]} \times \text{number of hours in period [h]}}$$

Capacity factors are usually given as percentages. Figure 2 shows the average capacity factors for wind farms in the UK. Some wind farms in England and Wales were built under NFFO-1 and -2 contracts (see Fact Sheet 6 for more details on the NFFO). These contracts ended at the end of 1998 so, although most are still operating, information on their output is no longer available. The average capacity shown for these farms is for the last two full years of available data.

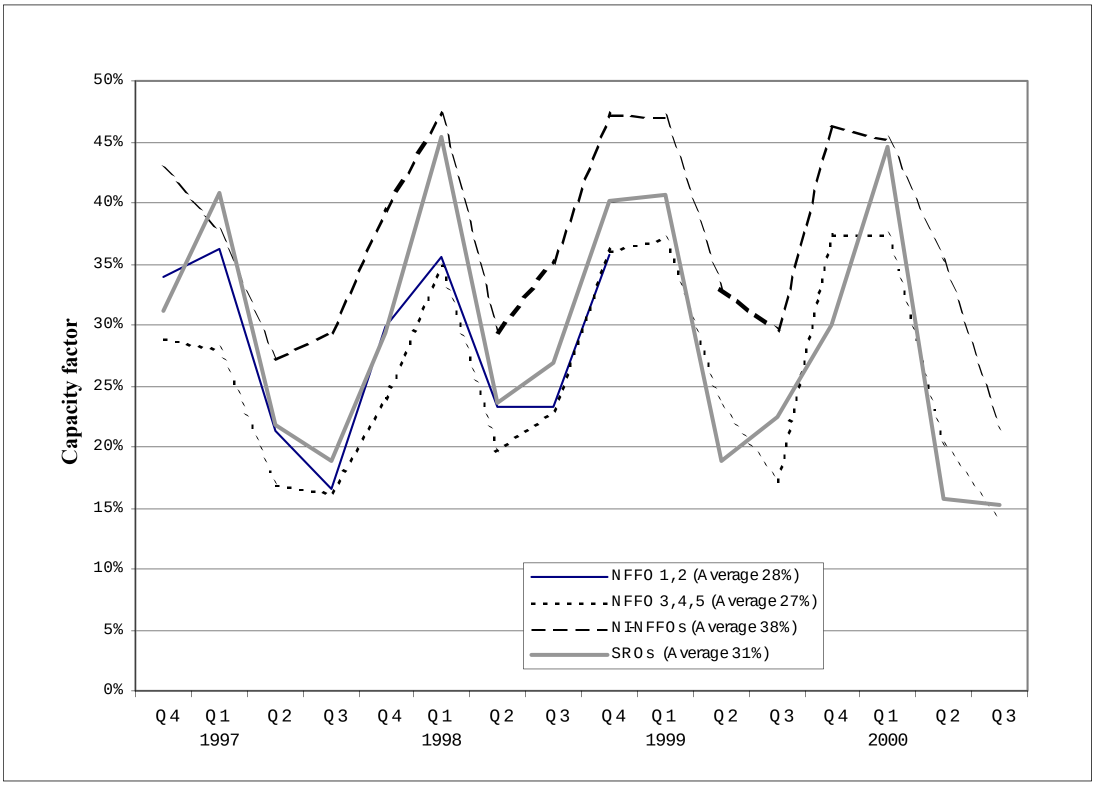

Figure 2 Average capacity factors in the UK

The amount of wind energy produced by the wind farms depends on the season. Quarter 1 (January-March) produces about twice as much energy as quarter 3 (July-September). This is because the winter months are windier than the summer months in the UK.

Scottish wind farms consistently generate more energy from their turbines than English and Welsh farms. Northern Irish farms generate even more. This reflects the wind speeds in the different countries: the wind speeds at wind farms in Northern Ireland are considerably higher than those in Scotland, which are generally higher than those in England and Wales.

In Europe capacity factors usually vary between 20% and 40%. Some of the highest capacity factors in Europe are found in Northern Ireland. This is not surprising since the UK has the best wind climate in Europe.

The variation in capacity factors is primarily due to differences in local wind speed, but the factors also depend on the design of the wind turbine, particularly the ratio of the rotor swept area to the capacity of the generator. A manufacturer will design wind turbines for particular wind conditions through careful selection of this ratio, so that the cost of energy is minimised. The resultant capacity factors of around 30% are a reflection of this optimisation of design and not a measure of the efficiency of the turbines. This can be illustrated by considering a wind turbine with an optimised rotor and generator size. The capacity factor could be increased by installing a smaller generator in the wind turbine, so that it ran at full output for a greater proportion of the time. Power generation would then be limited to this lower level at times when the turbine was in fact capable of generating more electricity. As a result the turbine would become less cost-effective.

Efficiency

Efficiency usually refers to the amount of energy that is extracted as a fraction of the total energy available. This is an important measure for technologies using fuels that have cost, are limited or present a disposal problem, such as coal, gas or radioactive materials.

Efficiency is a term that has little relevance to wind turbines, for which the fuel is cost-free and unlimited. Wind turbines are, consequently, not designed to maximise any measure of efficiency, but to achieve the best cost-effectiveness. Capacity factor should not be confused with efficiency.

The one technical context in which efficiency is applied to wind turbines is in the aerodynamic efficiency of the blades or rotor. This is a measure of the amount of energy extracted from the wind by the blades. It has a theoretical limit, called the ***Betz limit***, of 59.3%. The aerodynamic efficiency of the rotor varies with wind speed, but is around 80% of the maximum achievable (50% in absolute terms) for wind speeds below rated.

Availability

Availability is the proportion of the time that the turbine is available to produce power, including those periods when the turbine is on standby during calms and very high winds. For modern wind turbines, availability is typically 95-99%. Most new wind farms have availabilities of 97-99%.

Emissions savings

One of the main reasons for using renewable energy technologies is to reduce our emissions of greenhouse gases and other pollutants. Conventional power stations use fossil fuels, (eg coal- and gas-fired plant) which produce carbon dioxide (CO_2), sulphur dioxide (SO_2) and various nitrogen oxides (NO_x), as well as other pollutants.

Wind turbines obtain their energy from the wind. This does not involve burning fossil fuels so these emissions and pollutants are not produced. Generating electricity from turbines instead of from conventional power stations, therefore, helps to displace the emissions that they would have generated.

Wind farms do involve some emissions; these come from using conventional fuels during their construction and servicing. The ***life-cycle emissions*** take this into account. We can compare the life-cycle emissions of different technologies to calculate the emissions savings of a wind farm over its lifetime.

Emissions are measured in terms of the mass of gas emitted for each unit of energy produced. This is usually expressed as grams per kilowatt-hour (g/kWh). Table 1 shows how the different technologies compare over their whole life cycle.

Table 1 Life-cycle emissions from different electricity generating technologies [g/kWh].

	Onshore wind	Offshore wind	Coal (with fluid gas desulphurisation & low NO_x)	Gas (CCGT)	Average mix (1993)
CO_2	9	12	987	446	654
SO_2	0.06	0.09	1.49	0.00	7.82
NO_x	0.02	0.03	2.93	0.49	2.19

(Source: ETSU-R-122 New and Renewable Energy: Prospects for the 21st Century: Supporting Analyses).

Table 1 shows how the different technologies compare over their whole life cycle.

However, once all the different types of plant are built the emissions avoided when a wind farm operates depend on what type of power plant wind displaces and the **operating** emissions of that power plant. Reductions in emissions will be greatest if wind displaces coal, significantly less if it displaces gas or nuclear. The UK electricity market is extremely complex, particularly under the New Electricity Trading Arrangements (introduced March 2001), and it is not possible to make categorical statements on how wind changes the generation mix.

In 1998, the most recent figures available, emissions from operating all electricity generating plant in the UK were:150 million tonnes (in DUKES, see References) of CO_2, 1072 thousand tonnes of SO_2 and 364 thousand tonnes of NO_x, generating 342TWh of electricity in the UK (some electricity was also imported). In the same year wind energy in the UK generated 0.877TWh. If it is assumed that the wind generation operational emissions are effectively zero and wind output saves emissions pro rata (ie displaces the average plant mix) then in 1998 wind generation in the UK reduced emissions by approximately 390,000 tonnes of CO_2, 2,800 tonnes of SO_2 and 930 tonnes of NO_x. If, in fact, wind displaced largely coal generation then the emissions saved would have been substantially higher.

References

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