See Also:

[Aerodynamics]
[Wind Turbine configurations]
[Noise (Low Frequency)]
[Wind Turbine Power Production]
[Vertical Axis Wind Turbines]
[Power in the Wind]
[Wind Energy Resource Evaluation]

Terms:
Capacity Factor
Wind Distribution
Cut-In Speed
Cut-Out Speed

How Does A Wind Turbine's Energy Production Differ from Its Power Production?

While wind turbines are most commonly classified by their rated power at a certain rated wind speed, annual energy output is actually a more important measure for evaluating a wind turbine's value at a given site.

We know that . . .

Energy = Power x Time

This means that the amount of time a wind turbine produces a given power output is just as important as the level of power output itself. And wind turbine operators don't get paid for producing a large amount of power for a few minutes (except in rare circumstances.) They get paid by the number of kilowatt-hours (kWh) their turbines produce in a given time period.

The best crude indication of a wind turbine's energy production capabilities is its rotor diameter--which determines its swept area, also called the capture area. A wind turbine may have an impressive "rated power" of 100 kW, but if its rotor diameter is so small that it can't capture that power until the wind speed reaches 40 mph (18 m/s), the wind turbine won't rack up enough time at high power output to produce a reasonable annual energy output.

Expected energy output per year can be reliably calculated when the wind turbine's ***capacity factor*** at a given average annual wind speed is known. The capacity factor is simply the wind turbine's actual energy output for the year divided by the energy output if the machine operated at its rated power output for the entire year. A reasonable capacity factor would be 0.25 to 0.30. A very good capacity factor would be 0.40.

NOTE: Capacity factor is very sensitive to the average wind speed. When using the capacity factor to calculate estimated annual energy output, it is extremely important to know the capacity factor at the average wind speed of the intended site.

Lacking a calculated capacity factor, the machine's power curve can actually provide a crude indication of the annual energy output of any wind turbine. Using the power curve, one can find the predicted power output at the average wind speed at the wind turbine site. By calculating the percentage of the rated power (RP) produced at the average wind speed, one can arrive at a ***rough capacity factor*** (RCF) for the wind turbine at that site. And by multiplying the rated power output by the rough capacity factor by the number of hours in a year, (8,760), a very crude annual energy production can be estimated. For example, for a 100 kW turbine producing 20 kW at an average wind speed of 15 mph, the calculation would be:

100 kW (RP) x .20 (RCF) = 20 kW x 8760 hours = 175,200 kWh

Actually, because of the effect of the cubic power law, the annual energy output will probably be somewhat higher than this figure at most windy sites. This is determined by the ***wind power distribution,*** which shows the percentage of time the wind blows at various wind speeds over the course of an average year. Lacking precise data on a given site, there are two common wind distributions used to make energy calculations for wind turbines: the ***Weibull distribution*** and a variant of the Weibull called the ***Rayleigh distribution*** that is thought to be more accurate at sites with high average wind speeds.

Energy output is also greatly influenced by more subtle features of a wind turbine's design, including

- ***cut-in speed***, or the wind speed at which it begins to produce power (if the turbine's cut-in speed is significantly below a site's average wind speed, problems are inevitable)
- the power it produces at moderate wind speeds, determined largely by ***blade airfoil shape and geometry***
- the ***cut-out speed*** (the wind speed at which the turbine may be shut down to protect the rotor and drive train machinery from damage) or high wind ***stalling characteristics***.
- ***operating characteristics*** such as low speed on-off cycling, shut-down behavior, and overall reliability, which together determine the turbine's availability to produce power when the wind speeds are in its operating range
- the ***efficiency*** of drive train components, such as the generator and gear box.

These more subtle features should not be underestimated when looking for ways to improve energy output. In recent years, the U.S. wind industry has begun using seemingly insignificant refinements in blade airfoil shapes to increase annual energy output from 10 to well over 25 percent. These increases have helped to dramatically lower the cost of wind-generated energy and increase the number of areas in the U.S. at which wind plants are feasible.

Wind FAQ | AWEA Home Page