ENERGY FROM THE WIND

Introduction

Wind energy has been used for pumping water and milling grain for hundreds of years. More recently, wind energy has also been used for electricity generation. Wind turbines are now used for large-scale energy delivery, and can also be effective as small-scale remote applications.

Developing countries can take advantage of wind power on a small scale, both for irrigation (wind pumps) and for generation of electricity (wind generators). These options are described in the Technical Briefs *Wind Power for Electricity Generation* and *Windpumping*. This brief gives a general overview of the resource and how it can be exploited.

Energy in the wind

The power in the wind is proportional to the cube of wind velocity. If the wind speed doubles, therefore, the power in the wind will increase by a factor of eight.

The general formula for wind power is:

$$\text{Power} = \frac{\text{density of air} \times \text{swept area} \times \text{velocity cubed}}{2}$$

$$P = \tfrac{1}{2}.\rho.A.v^3$$

If the velocity (v) is in m/s, then at sea level (where the density of air is 1.2 kg/m^3), the power in the wind will be:

$$\text{Power} = 0.6 \times v^3 \text{ Watts per } m^2 \text{ of rotor swept area}$$

This means that the power in the wind will range from 10W/m^2 at 2.5m/s (a light breeze) to 41,000W/m^2 at 40m/s (a hurricane). Such variability of the wind affects nearly all aspects of wind energy system design, construction, siting, use and economy.

Wind

The speed of the wind is constantly changing. This is due to various factors such as land topography, the altitude, and nearby trees, all of which influence the turbulence of the wind and therefore its speed. An area with trees or buildings will produce more turbulence than a smooth surface such as a lake. Trees and buildings disturb the flow

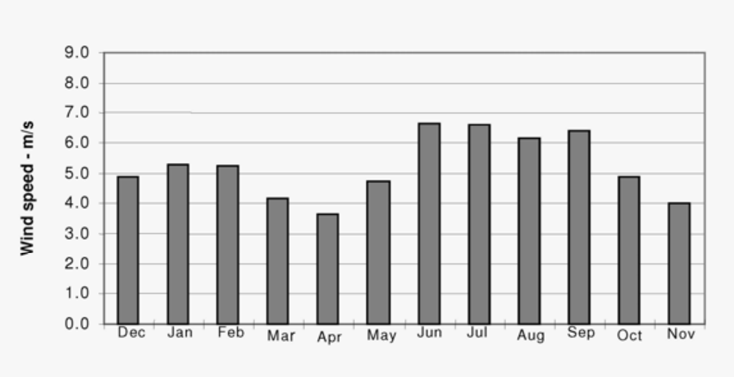

Figure 1: Monthly wind pattern in Hambantota, Sri Lanka, one of the locations in which Practical Action has implemented small-scale wind turbines for electricity generation.

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of the wind, reducing the energy that can be captured by a turbine. An increased level of turbulence causes wind speed to become more changeable from second to second. As well as wind speed changing constantly, wind patterns vary on daily and seasonal bases.

Choosing the site

A turbine should be located wherever the highest constant windspeed can be captured, and with as little turbulence as possible. An increase of 25% in average wind speed of a particular site can nearly double the power output of the turbine. There are considerable differences in component life for different locations. Gusts can put a large strain on blades.

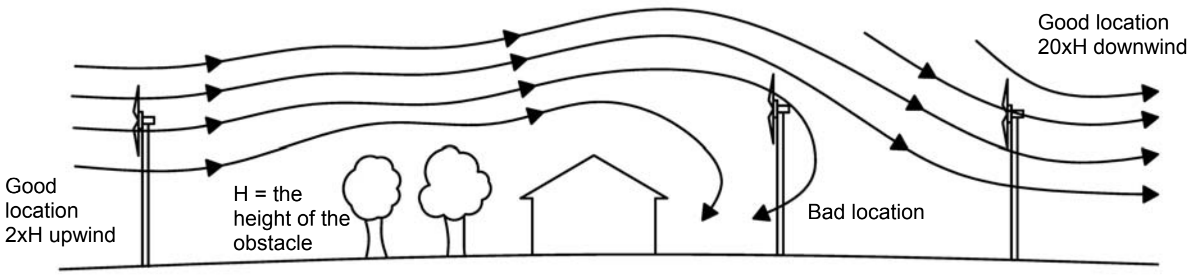

Figure 2: The wind turbine should be sited away from obstructions such as trees and buildings.
Illustration: Practical Action / Neil Noble.

Acceleration of wind over ridges can be exploited in order to generate more power from the turbine, although the shape of the ridge is, of course, important. A smooth ridge will not produce turbulence, whereas a sharp change in terrain, a bluff or a cliff will do.

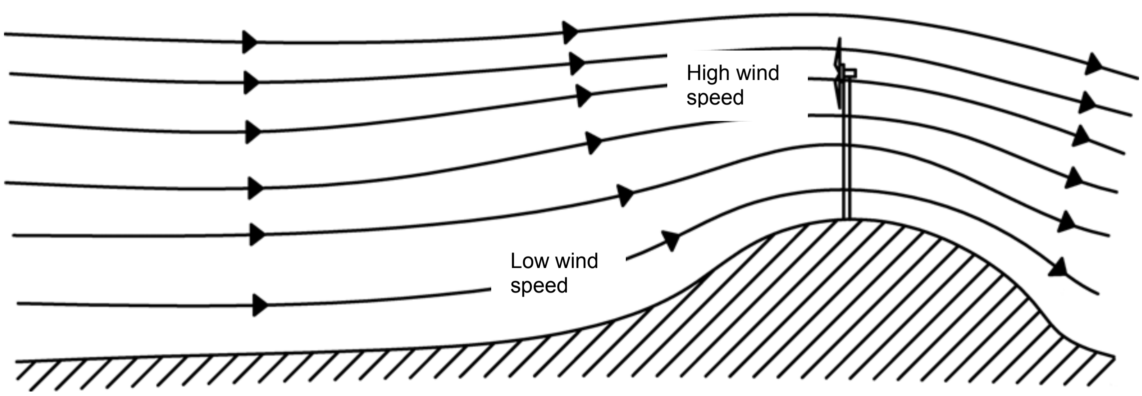

Figure 3: Wind speeds are strongest on the tops of ridges.
Illustration: Practical Action / Neil Noble.

It is preferable to locate the turbine at a point where the wind is perpendicular (ie. at right angles) to the side of the ridge (as in Figure 3). A turbine positioned on a ridge at which wind blows at a different angle – such as diagonally or long-ways - will be less effective.

Measuring the wind

When assessing the suitability of a site might be it is useful to have some record of wind speed in the area. Ideally for at least the last twelve months. There is a range of measurement equipment that can be used. Some instruments are used with data loggers that record wind speeds over long periods of time. The most commonly used measuring device is the cup anemometer, although other methods include:

- Propeller anemometers
- Drag devices - ERA gust anemometers
- Air pressure devices – pilot tubes
- Sonic devices – speed of sound in air
- Doppler devices – laser and sonar
- Calibrated kites
- Tatter flags

- Trees and other plants

It should be emphasised that, for large wind installations, it is very important to conduct detailed evaluation. For the small machines like those that Practical Action promotes, however, extensive evaluation is impractical and expensive. It is therefore necessary to collect other clues about wind speed by analysing available date (if it exists), by talking to local residents and asking about past experiences, and even by looking at the trees themselves to see by how much they lean:

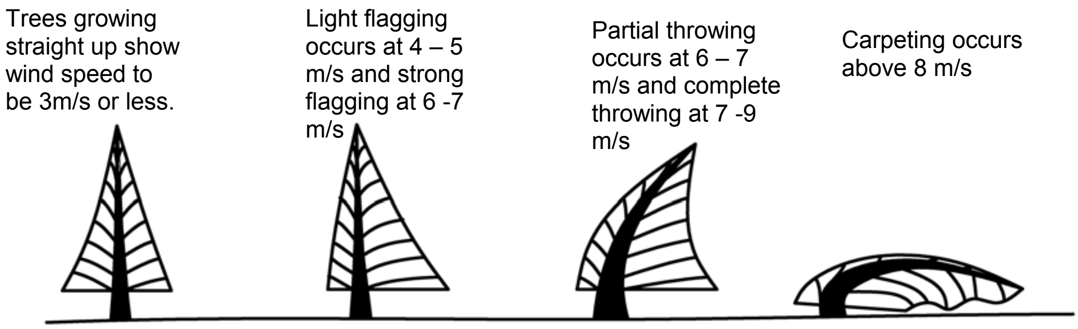

Figure 4: The strength of the wind can be estimated by the shape of the trees in the area.
Illustration: Practical Action / Neil Noble.

Average wind speed data is sometimes available from existing sources, such as wind maps or the meteorological office, although wind regimes are very localised, so data may be misleading. Anemometers are often set at a standard height of 10m: this height is too low for wind turbines. Furthermore, they are often positioned in places unsuitable for wind turbines - airport wind-speed monitoring -, providing poor information on wind speeds.

Records show that large areas of the world have mean annual wind speeds below 3m/s, and are therefore unsuitable for large wind power systems. Other areas have wind speeds in the intermediate range (3-4.5m/s), where wind power may or may not be an attractive option at a large scale. For very small wind machines like those promoted by Practical Action, it is found that mean wind speeds as low as 3m/s
can be suitable.

Principles of wind energy conversion

Energy can be extracted form the wind in two ways: via the forces of drag or by lift (or a combination of the two).

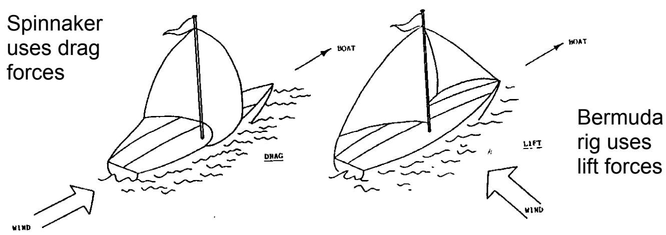

Figure 5: Drag and lift forces

The difference between drag and lift is illustrated by the difference between using a spinnaker sail, which fills like a parachute and pulls a sailing boat with the wind, and a Bermuda rig, the familiar triangular sail which deflects with wind and allows a sailing boat to travel across the wind or slightly into it (see Figure 5). Drag forces provide the most obvious means of propulsion, being the forces felt by a person (or object) exposed to the wind. Lift forces are the most efficient means of propulsion, but being more subtle than drag forces, are less well understood.

The basic features characterising lift and drag are that:

- drag is in the direction of airflow
- lift is perpendicular to the direction of airflow

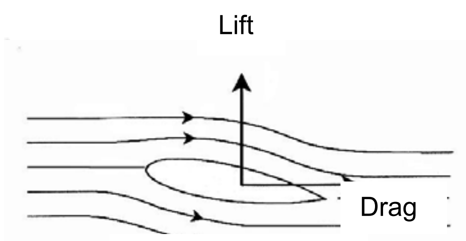

Figure 6: Aerofoil

- generation of lift always causes a certain amount of drag to develop
- with a good aerofoil, the lift produced can be more than thirty times greater than the drag
- lift devices are generally more efficient than drag devices

Types of rotors and their characteristics

Although various designs do exist, most wind turbines are horizontal axis machines. They use either lift or drag forces to harness the wind. Several technical parameters are used to characterise wind turbine rotors.

The **tip-speed ratio** is defined as the speed of the outer most point of the blade or turbine relative to the speed of the free wind. It is a measure of the 'gearing ratio' of the rotor. Drag devices always have tip-speed ratios less than one and hence turn slowly, whereas lift devices can have high tip-speed ratios and therefore turn more quickly relative to the wind.

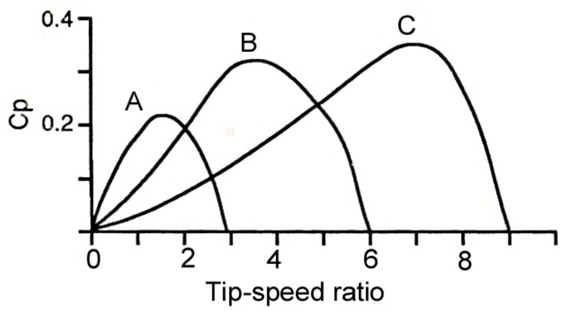

Figure 7: Tip-speed ratio against power coefficient
A = High solidity rotor
B = Intermediate solidity
C = Low solidity

$$\text{Tip-speed ratio} = \frac{\text{Blade tip speed}}{\text{Wind speed}}$$

The amount of power that the rotor can produce from the wind is termed the **coefficient of performance** (or power coefficient or efficiency; symbol C_p). Its variation as a function of tip-speed ratio is commonly used to characterise different types of rotor.

It is not possible to extract all the energy from the wind as this would bring the air behind the rotor to a standstill. Consequently there is a maximum value of C_p of 59.3% (known as the Betz limit), although in practice real wind rotors have maximum C_p values in the range of 25%-45%.

Solidity is the relation of the sum of the projected area of the blades to the area of the circumference of the rotor containing material rather than air. High-solidity machines carry a lot of material and have bigger angles of attack. They generate much higher starting torque than low-solidity machines but are considered by some to be less efficient than low-solidity machines Low-solidity machines use lift as their main method of extracting energy. They have low starting torque, and so the blades need to be carefully finished and balanced.

High-solidity machines are used for water pumping, as they have high torque at low speed. Low-solidity machines are used for electricity generation, where the higher rotational speed suits the generator.

Figure 8: High-solidity rotor
Photo: Practical Action

Figure 9: Low-solidity rotor
Photo: Practical Action

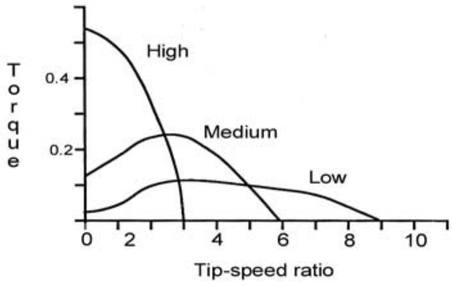

Figure 10: Solidity and torque graph

Some common rotor types and their characteristics are shown in Table 1 below:

Type	Speed	Torque	Manufacture	C_p	Solidity %
Horizontal Axis					
Cretan sail	Low	Medium	Simple	.05-.15	50
Cambered plate fan	Low	High	Moderate	.15-.30	50-80
Moderate speed aero-generator	Moderate	Low	Moderate	.20-.35	5-10
High speed aero-generator	High	Very low	Precise	.30-.45	< 5
Vertical Axis					
Panemone	Low	Medium	Crude	> .10	50
Savonius	Moderate	Medium	Moderate	.15	100
Darrieus	Moderate	Very low	Precise	> .25	10-20
Variable Geometry	Moderate	Very low	Precise	.20-.35	15-40

Table 1: Comparison of rotor types

Performance

Although the power available is proportional to the cube of wind speed, the power obtained from the turbine is lower. This is because the overall efficiency of the windmill - the product of rotor C_p,the transmission efficiency, and the pump or generator efficiency - changes with the varying wind speed. There are four important characteristic moments of wind speed:

- *cut-in windspeed:* when the machine begins to produce power
- *design windspeed:* when the windmill reaches its maximum efficiency
- *rated windspeed:* when the machine reaches its maximum output power
- *furling windspeed:* when the machine furls to prevent damage at high wind speeds.

Performance data can be misleading because they may refer to the peak efficiency (at design windspeed) or the peak power output (at the rated windspeed). The data could also refer to the average output over a time period (e.g. over a day or a month).

Because the power output varies with windspeed, the average output over a time period is dependent upon the local variation in windspeed from hour to hour. In order to predict the output for a given wind turbine, therefore, one needs to have output figures for the wind turbine and the windspeed distribution curve of the site – ie. the duration at various windspeeds. Multiplying the values of both graphs for each windspeed interval, then adding all the products, gives the total energy output of that particular wind turbine.

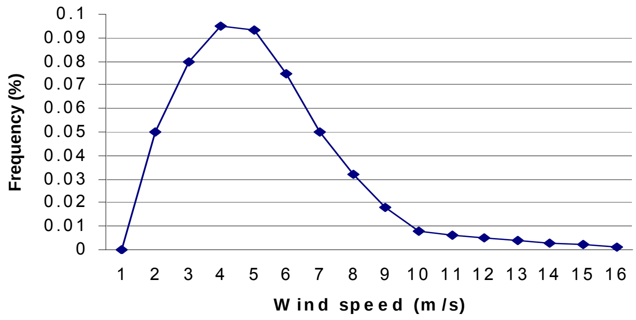

Figure 11: Wind speed distribution graph

References and further reading

- *Windpumping* Practical Action Technical Brief
- *Wind Power for Electricity Generation* Practical Action Technical Brief
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- *How to Build a Cretan Sail Windpump* Bob Mann, Practical Action Publishing http://developmentbookshop.com/product_info.php?products_id=143
- *Construction Manual For A Cretan Windmill* Niek van de Ven, WOT, 1977 http://www.wot.utwente.nl/knowledgecenter/publications/cretan.html

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