WIND ENERGY AS A POWER GENERATION OPTION CHAPTER 3

Wind energy is firmly established as a mature technology for electricity generation, with a reported 65 000 MW installed base worldwide. It is one of the fastest growing electricity generating technologies with installed capacity increasing by ~10 000 MW annually, and features in energy plans worldwide. Use of wind for electricity generation is essentially a non-consumptive use of a natural resource, and produces an insignificant quantity of greenhouse gases in its life cycle. A wind energy facility also qualifies as a Clean Development Mechanism (CDM) project (i.e. a financial mechanism developed to encourage the development of renewable technologies) as it meets all international requirements in this regard.

Environmental pollution and the emission of CO_2 from the combustion of fossil fuels constitute a threat to the environment. The use of fossil fuels is reportedly responsible for ~70% of greenhouse gas emissions worldwide. The climate change challenge needs to include a shift in the way that energy is generated and consumed. Worldwide, many solutions and approaches are being developed to reduce emissions. However, it is important to acknowledge that the more cost effective solution in the short-term is not necessarily the least expensive long-term solution. This holds true not only for direct project cost, but also indirect project cost such as impacts on the environment. Renewable energy is considered one of the ‘clean sources of energy’ with the potential to contribute greatly to a more ecologically, socially and economically sustainable future. The challenge now is ensuring wind energy projects are able to meet all economic, social and environmental sustainability criteria.

3.1. Investigations into Wind Energy for South Africa

Eskom commissioned the Klipheuwel Wind Energy Demonstration Facility (north of Durbanville in the Western Cape) in February 2003. Research at this facility has focused on how the technology interacts with the South African environment and has highlighted unique factors that can impact performance. The research information collected ranges from production statistics, daily operational requirements, detailed condition monitoring and national resource understanding and analysis. This 3.2 MW installation generates about 4 GWh annually with an availability of 90% and an energy utilisation factor of 16%.

The demonstration facility has been a major success and results of the research has provided Eskom with valuable technical and strategic information pertaining to utilising wind as a source of energy, and has provided guidance with regards to the establishment of a large scale commercial facility.

Figure 3.1: Photograph of the existing three turbines at the Klipheuwel Demonstration Facility, Durbanville

As a part of Eskom’s wind research programme a national wind atlas for South Africa was compiled (in conjunction with the DME and the CSIR for the South African Renewable Resource Database). Areas of high potential for future commercial wind farm development were identified, and high-accuracy meteorological measurement stations erected at these sites for on-going monitoring.

Based on the lessons learnt from the Klipheuwel pilot demonstration facility as well as the analyses on Eskom’s measured wind data, Eskom have determined that a full-scale commercial wind energy facility can successfully be established in South Africa, with the West Coast north of the Olifants River been identified to experience some of the best wind resources for the development of a Wind Energy Facility (i.e. the incidence of wind within the required velocity range) in the country. The construction of such a commercial facility is now being proposed on the West Coast on a site to the north of the Olifants River (refer to Chapter 4 for more details).

3.2. The Importance of the Wind Resource for Energy Generation

Wind energy has the attractive attribute that the fuel is free. The economics of a wind energy project crucially depend on the wind resource at the site. Detailed and reliable information about the speed, strength, direction, and frequency of the wind resource is vital when considering the installation of a wind energy facility, as the wind resource is a critical factor to the success of the installation.

Wind speed is the rate at which air flows past a point above the earth's surface. Average annual wind speed is a critical siting criterion, since this determines the cost of generating electricity. With a doubling of average wind speed, the power in the wind increases by a factor of 8, so even small changes in wind speed can produce large changes in the economic performance of a wind farm (for example, an increase of average wind speed from 22 km/hr to 36 km/hr (6 m/s to 10 m/s) increases the amount of energy produced by over 130%). Wind turbines can start generating at wind speeds of between 10 km/hr to 15 km/hr (~3 m/s to 4 m/s), with nominal wind speeds required for full power operation varying between ~45 km/hr and 60 km/hr (~12.5 m/s to 17 m/s). Wind speed can be highly variable and is also affected by a number of factors, including surface roughness of the terrain.

Wind power is a measure of the energy available in the wind.

Wind direction at a site is important to understand, but it is not critical in site selection as wind turbine blades automatically turn to face into the predominant wind direction at any point in time.

South Africa can be considered as having a moderate wind resource as compared to Northern Europe (Scandinavia), Great Britain and Ireland, New Zealand and Tasmania. Typical annual wind speeds range from 15 km/hr to 25 km/hr (4 m/s to 7 m/s) around South Africa’s southern, eastern and western coastlines (with more wind typically along the coastline). This relates to an expected annual energy utilisation factor of between 15% and 30%, the value depending on the specific site selected. It is commonly accepted that wind speeds of 25 km/hr to 30 km/hr (7 m/s to 8 m/s) or greater are required for a wind energy facility to be economically viable in Europe.

When considering recorded annual energy utilisation factors for wind energy facilities internationally, it is evident that the performance of a South African facility would be in line with international trends (refer Table 3.1 below).

Table 3.1: Record of Annual Energy Utilisation Factors

Location	Average Capacity Factor
UK	29%
Rural Germany	16%
Denmark	24%
Klipheuwel Demonstration facility – South Africa	16%*

*Actual Performance over a period of 3 years

In comparison, actual wind measurements (over a period of 3 years) at the proposed site applied to typical wind turbine performance has indicated that a wind energy facility on the West Coast would perform as well as international facilities, with an energy utilisation factor of 26%. Climatic variation may impact this production figure by as much as 30% on a year-on-year basis (both negative and positive).

Figure 3.2 provides a wind rose of actual measured data from the Eskom meteorological station at De Punt. “Wind rose” is the term given to the diagrammatic representation of joint wind speed and direction distribution at a particular location. The length of time that the wind comes from a particular sector is shown by the length of the spoke, and the speed is shown by the thickness of the spoke. The wind direction is conventionally indicated from the periphery towards the centre of the graph, and not from the centre outwards.

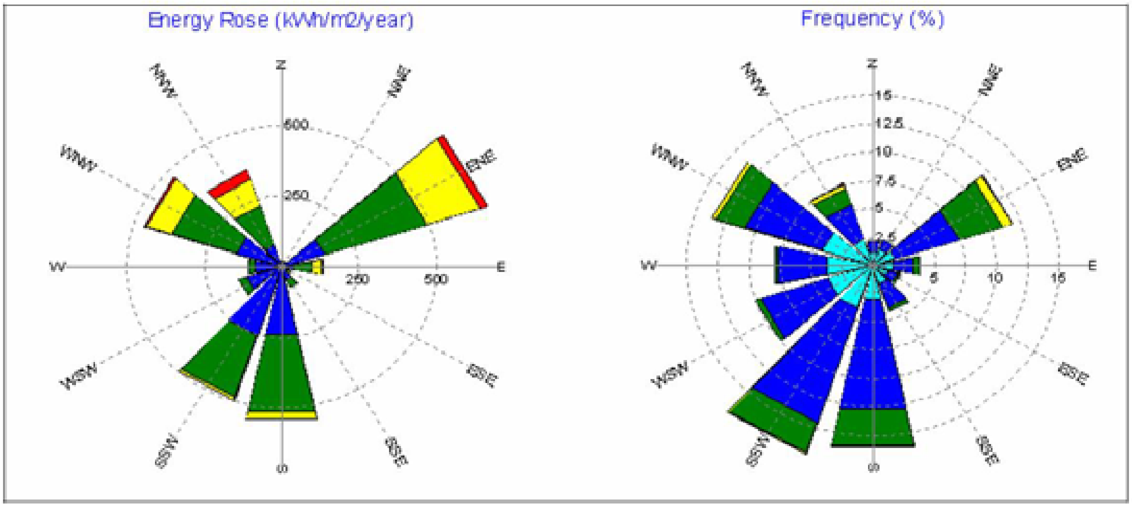


Figure 3.2: Wind Rose from measured data at the Eskom meteorological station at De Punt, indicating both wind energy as well as frequency of wind direction (% of time in a direction)

Figure 3.2 illustrates that the predominant wind direction experienced on the West Coast is from the SSW (i.e. percent of time in a direction). This is, however, not the strongest wind (or wind with most energy) experienced in this area, but the SSW wind is experienced most frequently. The design (and micro-siting) of a wind farm is sensitive to the shape of the wind rose for the site. Although modern wind turbines are able to yaw to the direction of the wind, the micro-siting must consider the wind direction and strength of the wind in the optimal positioning of the turbines.

The wind speed measured at a meteorological station is also affected by the local topography (extending to a few tens of kilometres from the station) or surface roughness. The effect of height variation/relief in the terrain is seen as a speeding-up/slowing-down of the wind due to the topography. Elevation in the topography exerts a profound influence on the flow of air, and results in turbulence within the air stream, and this also has to be taken into account in the placement of turbines.

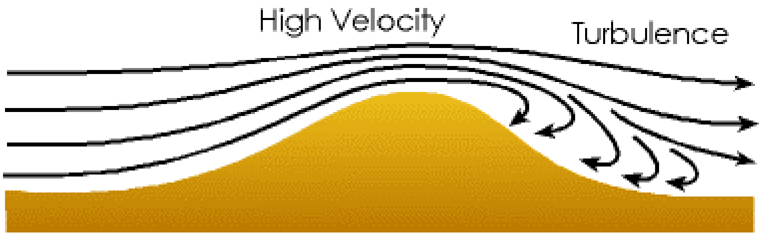


Figure 3.3: Illustration of the effect of relief on air flow

A wind resource measurement and analysis programme must be conducted for the site proposed for development, as only measured data will provide a robust prediction of the facility's expected energy production over its lifetime.

The placement of a wind energy facility, and in fact the actual individual turbines must, therefore, consider the following technical factors:

» Predominant wind direction and frequency
» Distance from coast, where wind moving over the land mass results in a loss of wind energy (and ultimately a loss in production)
» Topographical features or relief affecting the flow of the wind (e.g. causing shading effects and turbulence of air flow)
» Effect of adjacent turbines on wind flow and speed – specific spacing is required between turbines in order to reduce the effects of wake turbulence.

Wind turbines typically need to be spaced approximately 2 to 3xD apart, and 5 to 7xD where a turbine is behind another (D = the diameter of the rotor blades). This is required to minimise the induced wake effect the turbines might have on each other. Considering a typical 2 MW capacity turbine whose rotors are approximately 90 m in diameter, each turbine would be separated by approximately 180 m to 300 m. The erection of turbines in parallel rows one behind another would require a distance between rows of 500 m to 700 m. Once a viable footprint for the establishment of the wind energy facility has been determined (through the consideration of both technical and environmental criteria), the micro-siting of the turbines on the site will be determined using industry standard software systems, which will automatically consider the spacing requirements.

3.3. What is a Wind Turbine and How Does It Work

The kinetic energy of wind is used to turn a wind turbine to generate electricity. A wind turbine consists of **three rotor blades** and a **nacelle** mounted at the tip of a tapered **steel tower**. The mechanical power generated by the rotation of the blades is transmitted to the generator within the nacelle via a gearbox and drive train.

Turbines are able to operate at varying speeds. The amount of energy a turbine can harness depends on both the wind velocity and the length of the rotor blades. It is anticipated that the turbines utilised for the proposed wind energy facility on the West Coast will have a hub height of ~80 m, and a rotor diameter of ~90 m (i.e. each blade ~40 m – 45 m in length). These turbines would be capable of generating in the order of 2 MW each (in optimal wind conditions). Wind turbines can start generating at wind speeds of between 10 km/hr to 15 km/hr (~3 m/s to 4 m/s), with nominal wind speeds required for full power operation varying between ~45 km/hr and 60 km/hr (12.5 m/s and 17 m/s).

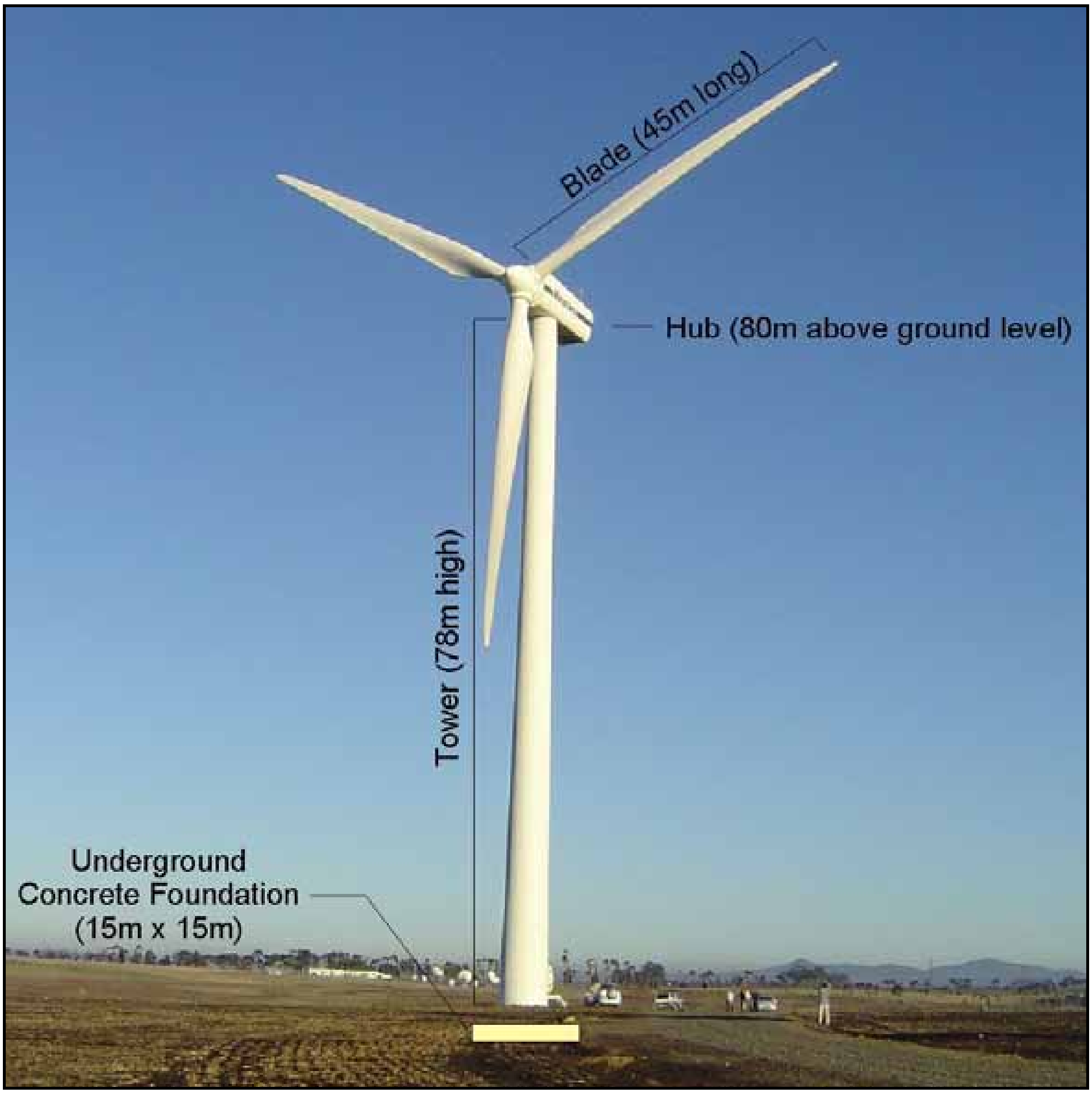
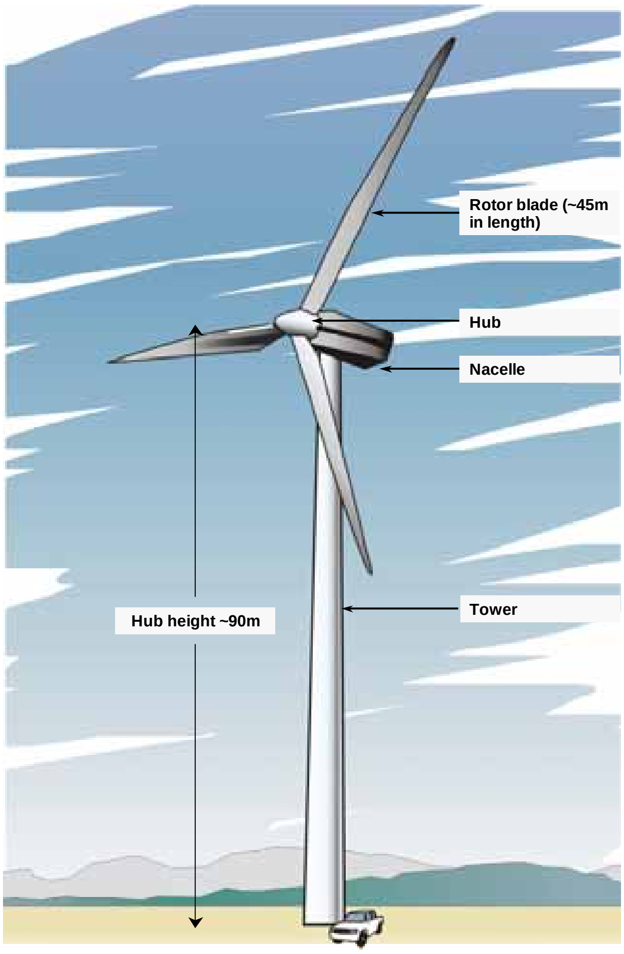


Figure 3.4: Illustration of the main components of a wind turbine (photograph of a turbine at Eskom's Klipheuwel wind demonstration facility)

3.3.1. Main Components of a Wind Turbine



The turbine consists of the following major components:

- The tower
- The rotor
- The nacelle

The tower

The tower, which supports the rotor, is constructed from tubular steel. It is approximately 80 m tall. The nacelle and the rotor are attached to the top of the tower.

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Larger wind turbines are usually mounted on towers ranging from 40 to 80 m tall. The tower must be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the wind turbine.

The Rotor

The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor converts the energy in the wind into rotational energy to turn the generator. The rotor has three blades that rotate at a constant speed of about 15 to 28 revolutions per minute (rpm). The speed of rotation of the blades is controlled by the nacelle, which can turn the blades to face into the wind ('yaw control'), and change the angle of the blades ('pitch control') to make the most use of the available wind.

The rotor blades function in a similar way to the wing of an aircraft, utilising the principles of **lift** (Bernoulli). When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines are well suited for electricity generation.

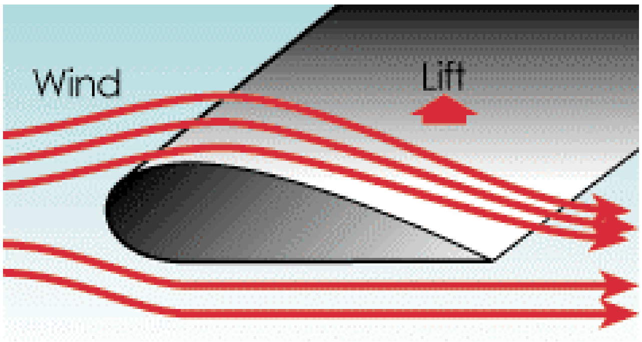


Figure 3.5: Illustration of the principle of lift

The rotation of the rotor blades produces a characteristic ‘swishing’ sound as the blades pass in front of the tower roughly once a second. The other moving parts, the gearbox and generator, cannot be heard unless the observer is physically inside the turbine tower.

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have optimum tip-speed ratios of around 4 to 5.

The nacelle

The nacelle contains the generator, control equipment, gearbox and anemometer for monitoring the wind speed and direction (as shown in Figure 3.6).

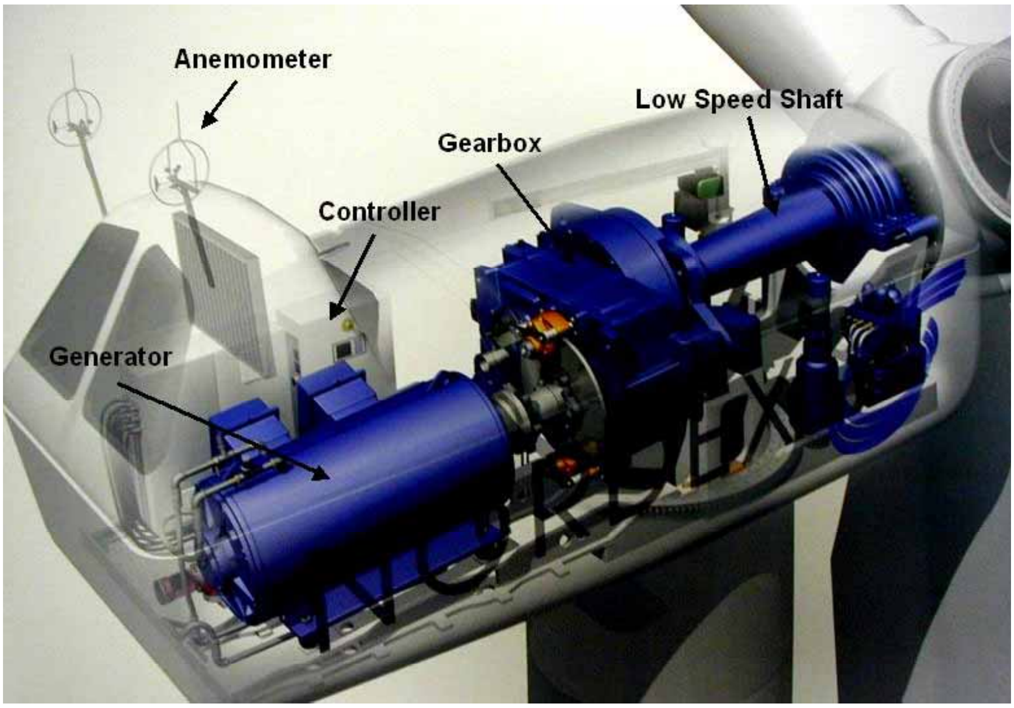


Figure 3.6: Detailed structure of a nacelle of a horizontal axis turbine

The **generator** is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.

3.3.2. Operating Characteristics of a Wind Turbine

A turbine is designed to operate continuously, unattended and with low maintenance for more than 20 years or >120 000 hours of operation. Once operating, a wind farm can be monitored and controlled remotely, with a mobile team for maintenance, when required.

The **cut-in speed** is the minimum wind speed at which the wind turbine will generate usable power. This wind speed is typically between 10 and 15 km/hr (~3 m/s and 4 m/s).

At very high wind speeds, typically over 90 km/hr (25 m/s), the wind turbine will cease power generation and shut down. The wind speed at which shut down occurs is called the **cut-out speed**. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

3.3.3. Understanding the Betz Limit

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately 59%. This value is known as the Betz Limit. If the blades were 100% efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop. In practice, the collection efficiency of a rotor is not as high as 59%. A more typical efficiency is 35% to 45%. A wind energy system (including rotor, generator etc) does not exhibit perfect efficiencies, and will therefore deliver between 10% and 30% of the original energy available in the wind (between 20% to 25% being typical for modern systems).

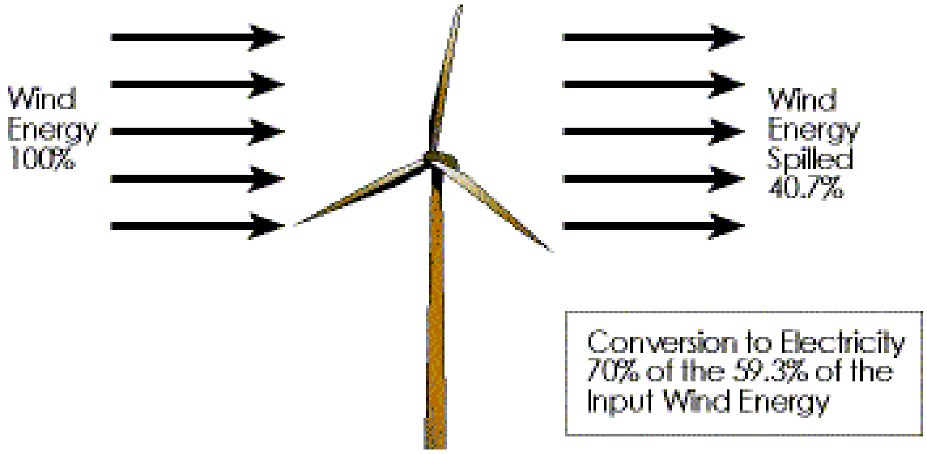
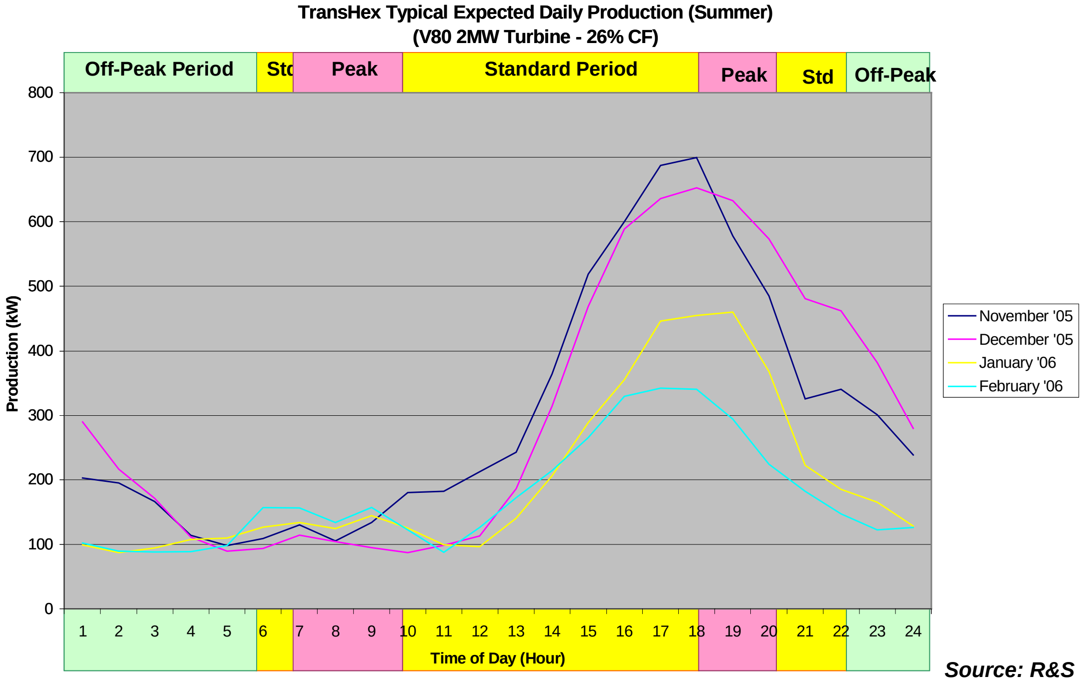


Figure 3.7: Illustration of the principle of the Betz Limit

3.4. Wind Energy as a Power Option for the West Coast

Actual wind measurements at the proposed site applied to typical wind turbine performance has indicated an energy utilisation factor of 26%. However climatic variation may impact this production figure by as much as 30% on a year-on-year basis (both negative and positive). This is based on European experience over the last 100 years. Experiences in wind at the site also indicate large variations in wind resource. This variation could potentially change the possibilities of the proposed project to 16% utilisation (18 km/hr (5 m/s) average annually) and a 36% utilisation (25 km/hr (7 m/s) average annually).

Figure 3.8 below indicates the typical expected daily production (for summer) on the West Coast site (assuming the use of a 2 MW industry standard wind turbine).



Source: R&S

Figure 3.8: Graph indicating the typical expected daily production (for summer) on a site on the West Coast north of the Olifants River