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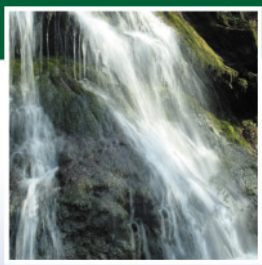

Chapter 7
Wind Energy

TIPPERARY INSTITUTE

NATIONAL DEVELOPMENT PLAN
EUROPEAN UNION STRUCTURAL FUNDS

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7 Introduction to Wind Energy

Seamus Hoyne, Tipperary Institute

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7.1 Objectives

Having completed this section of the training course and manual, learners should:

- Understand the different components and technologies involved in wind energy.
- Be familiar with the process involved in the development of a wind project
- Be familiar with the potential for wind energy development and appropriate supports and legislation in place.

7.2 Context

This section will focus primarily on large scale wind turbines i.e. those associated with electricity generation for distribution through the electricity network. Some references will be made to smaller scale wind turbines which can be used for more local use, which may or may not be independent of the electricity network or grid.

A sample project will be used for most examples throughout the project. This will have the following characteristics:

- Number of turbines: 10
- Turbine Capacity: 1.75MW
- Site Capacity Factor: 30%
- Average Annual Wind Speed: 8m/s

7.3 Wind Energy Technology

7.3.1 How Wind is Created

Wind is caused by the movement of air masses around the earth. The force and direction of the wind is influenced by:

1. the earths temperatures (which is in turn affected by the curvature of the earth)

   The earth is heated by the sun. The curvature of the earth means that the tropics i.e. closer to the equator, are considerably warmer than those regions at higher latitudes.[1] This causes air movements and depending on the position on the earth results in trade/global winds and regions of higher and lower atmospheric pressure.

2. the earths rotation

   The rotation of the earth has an additional affect which is termed the Coriolis Effect (named after Gutave-Gaspart de Coriolis who discovered the affect in 1835). This causes the winds direction to change depending on location e.g. in the Northern Hemisphere north bound winds are caused to veer to the right/west creating what are called westerlies.

A key latitude which affects the direction of wind globally is 30 degrees (North and South). At this latitude the Coriolis rotational affect prevents the hot air, which has risen from the equator and is moving north or south, from progressing further. This results in high pressure areas in this region and low pressure areas at the equator.

The presence of windy changeable weather can be assessed by the observation of atmospheric pressure in particular areas. Atmospheric pressure is measured in bar or pascals[2]. One bar is approximately normal

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[1] Latitude: the equator has latitude of 0. Regions with higher latitudes are closer to the poles (north and south).

[2] 1 Pascal = 1 Newton per square meter (N/m^2)

atmospheric pressure at sea level. Barometers, used to measure atmospheric pressure, measure the weight of air in a column above a specific surface area. Areas of high pressure indicate little wind and fine weather while areas of low pressure tend to indicate windy weather and rain.

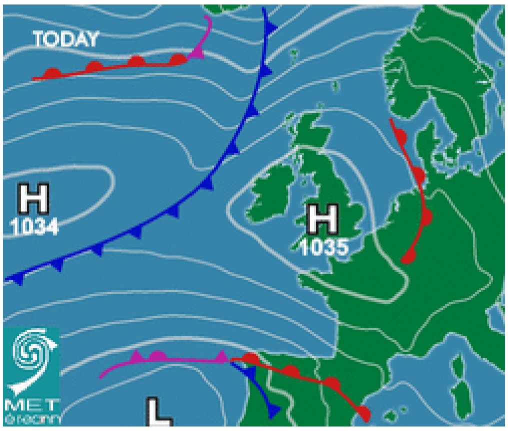

Figure 7.1 Sample weather chart with isobars
(Met Eireann, 2006)

In general, the direction of the prevailing wind i.e. the main wind direction, can be determined based on latitude as follows

Latitude	90-60°N	60-30°N	30-0°N	0-30°S	30-60°S	60-90°S
Direction	NE	SW	NE	SE	NW	SE

Table 7.1 Typical wind direction depending on latitude
(DWEA, 2006a)

Ireland is at latitude of approximately 50 degrees North which would indicate that the prevailing wind direction would be from the South West and this is the case in practise.

In addition to the above affects at a global level there are local conditions which also affect wind direction and force. These include altitude, proximity to the sea (sea breezes), topography (valley winds) etc.

7.3.2 Understanding Energy and Power in the Wind

The energy which can be captured from the wind is its kinetic energy. Kinetic energy is the energy in a moving body. The standard convention for calculating the amount of kinetic energy in a moving body is:

Kinetic Energy per Second = half of the mass of the moving body x velocity squared

$$\text{Kinetic Energy} = 0.5\ m \times V^2$$

Formula 7.1 Kinetic Energy per Second

Where:

m = mass of body (kilograms)

V = velocity (meters per second, $m\ s^{-1}$)

To calculate the energy in the wind it is necessary therefore to calculate the mass and to measure the velocity.

The mass of air can be calculated using the following formula

Mass of air per second = air density x volume of air flowing per second

= air density x area x velocity

$$m = \rho \times A \times V$$

Formula 7.2 Mass of air per second

Where:

A = swept area of the turbine blades (π x radius^2)

ρ = air density = 1.2256 kg/m^3 at sea level

By now substituting for m in figure 7.1 with the definition in Formula 7.2 it is possible to derive a final formula for calculating the energy in the wind which passes through a wind turbine every second.

$$\text{Kinetic Energy} = 0.5 \times \rho \times A \times V^3 \text{ (Joules per Second)}$$

Formula 7.3 Kinetic Energy per Second – Wind Power

Given that power is equal to the energy used per unit of time the Power in the wind (in Watts) is equal to the Kinetic Energy (Joules per second).

This is the theoretical power which can be captured from the wind. Albert Betz in 1928 calculated that the maximum fraction of power which can be extracted is 16/27 or 59.3%.

Knowing the above it is possible to calculate the power in the wind at a particular wind speed, as in the following example.

Wind at a speed of 10 meters per second passed through a wind turbine with a blade radius of 30m. What is the theoretical power available and the maximum fraction of power available? Kinetic Energy/Second = Power = 0.5 x ρ x A x V^3 (Watts) = 0.5 x 1.2256 x 3.146 x 30 x 30 x 10 x 10 x 10 = 1,735,081 W = 1,735 kW = 1.735 MW 1.735 MW is the maximum theoretical power for these conditions Applying Betz Law the maximum fraction of this which can be captured is = 1.735 x 0.593 = 1.03 MW

Example 7.1 Calculating the theoretical and maximum available power.

7.3.3 Brief History of Wind Energy Technology

7.3.3.1 Wind Mills

The power of the wind has been harnessed for centuries. The evolution of turbines for the production of electricity however is a more recent phenomenon.

Given that traditionally the first use of wind was for milling grain and pumping water a distinction between these types of machines will be drawn by calling them windmills. There is still some debate over when the first wind mills were used, and by whom. Evidence of vertical axis turbines has been discovered in 644 A.D (Hau, 2000) in the Persian-Afghan area. The horizontal axis machine (the traditional windmill) evolved in Europe and was mainly initiated in the North West. The Netherlands is often seen as a founding country of windmills in Europe with a particular increase in the use of wind mills being seen in the 16th and 17th centuries (Hau, 2000).

Figure 7.2 Traditional Windmill
(Wikipedia, 2006)

The traditional use of wind mills was for the milling of grain (and other products) and pumping of water. A range of designs and options for wind mills evolved as the industry grew. Further details on these can be found in Eldrige, 1975 and Goulding, 1995.

7.3.3.2 Wind Energy and Electricity Generation

With the developments in the production of electricity and the electricity network in the late 19th century and early 20th century experimentation into the production of electricity using wind mills started.

The major developments in this regard occurred in Denmark and were lead initially by Poul La Cour (Hau, 2000). A driver behind the development was the need to supply electricity to rural areas within Denmark. His first machine, built in 1891, powered a dynamo. Further experimentation lead to the designs being commercially developed.

Research and development in Germany and the USA up until the mid 1970s met with varying levels of success. This was primarily due to the low energy prices at the time restricting the interest, at a strategic level, in developing wind energy.

The scale of the machines that were developed in this time frame can be gauged from the following table. A concise history of the development of wind turbines can be found in Hau, 2000.

Category	Name	Year	Diameter (m)	Capacity (MW)	Location
Megawatt	Smith-Puttman	1939	53	1.25	Vermont, USA
Commercial	Gedsen	1956-57	24	0.2	Gedsen, Denmark
Lightweight	Hutter-Allgaier	1960's	34	0.1	Germany

Table 7.2 Examples of early wind turbines
(EWEA, 2006a)

7.3.4 Wind Turbine Types & Scale

Wind turbines can generally be classified into two main configurations horizontal axis and vertical axis. This section will concentrate on horizontal axis type machines with general descriptions of both types provided here.

7.3.4.1 Horizontal Axis

The large scale horizontal axis wind turbines (HAWT) have predominantly two or three blades. These types of machines dominate the wind turbines industry for the production of electricity. They have evolved from the traditional wind mills with streamlined appearances as a result of improved knowledge in the area of design, aerodynamics and availability of new materials and technologies.

With HAWT the direction of the wind is parallel to the axis of rotation. They consist of a tower on top of which is located the rotor which is connected to the blades. Generally, the position of the blades can be rotated so that they are facing into the wind, therefore capturing the maximum amount of energy from the wind.

Smaller scale HAWT typically have multiple blades to improve the ability to deal with high torque requirements. Such wind turbines are referred to as high solidity turbines with modern electricity generating wind turbines being referred to as low solidity turbines, as they have a lower number of blades.

Figure 7.3 Large HAWT, Aalborg, Denmark
(Wikipedia, 2006)

7.3.4.2 Vertical Axis

While not as dominant as the HAWT type machines Vertical Axis Wind Turbines (VAWT) present particular benefits in relation to efficiency and reduced stress loads on components.

The main VAWT type machine evolved from the 'egg beater' design developed in France by Darrieus (Boyle, 2004) and consists of a vertical shaft to which the two curved blades are attached at the top and bottom.

Vertical axis machines can capture the wind from any direction, therefore are not required to rotate to face into the wind. A variety of VAWT types have been developed including the H-Type VAWT and V-Type VAWT.

Figure 7.4 Darrieus VAWT, Magdelen Island
(Wikipedia, 2006)

7.3.4.3 Wind Turbine Size

The size of HAWT has grown considerably in the past 20 years. Due to significant developments and technological advancements the maximum size of turbine has increased to 5MW in 2006.

Typical on-shore wind turbines have a tower height in the region of 100m and rotor diameter in the region of 70m. The average capacity is now over 1.5MW per turbine. Offshore machines are larger in scale with tower heights over 100m and rotor diameters of over 100m.

7.3.5 Wind Turbine Components

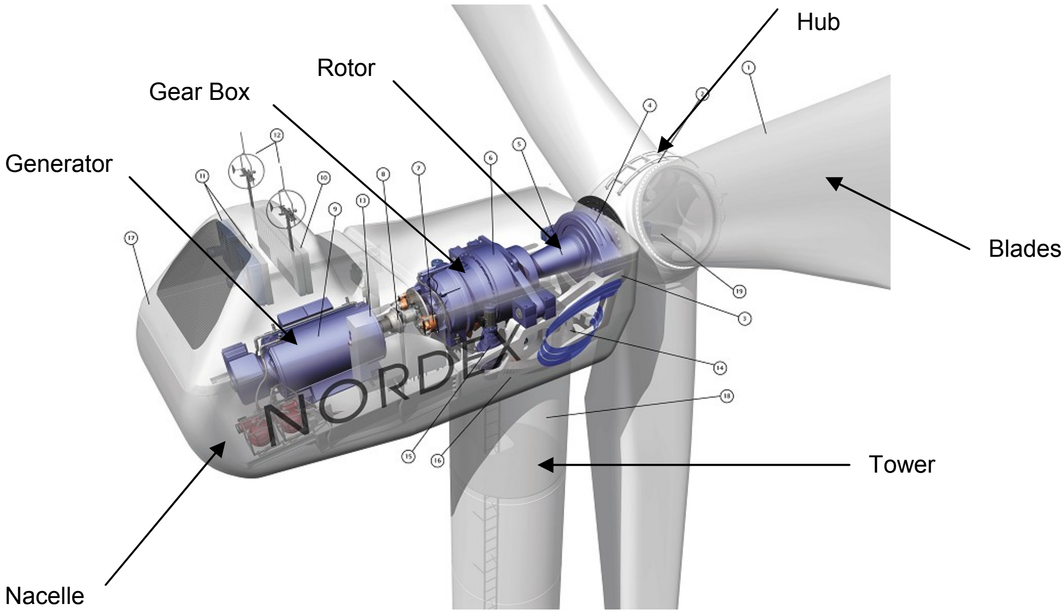

Figure 7.5 Wind Turbine Basic Components
(Nordex, 2006)

Wind turbines can essentially be divided into a number of key components.

1. Blades

The blades are responsible for capturing the energy available in the wind. Modern blades have evolved from the traditional blades used on windmills to highly designed and engineered components using modern materials. Much of the developments in the area of blade design have evolved from the aeronautical industry.

The number of blades on a modern HAWT is defined by the need to capture as much of the wind passing through the turbine, the size of the turbine and costs. A survey by the European Wind Energy Association in 2003 indicated that 74% of turbines on the market at that time were three blade machines (EWEA, 2006).

The blades on a HAWT machines with a small number of blades will rotate faster when compared to a machine with a larger number of blades. This is necessary so that they can capture the same amount of energy. While increasing the number of blades will result in a gain in power and energy the effect is limited (a few percent increase) and does not justify the additional capital cost.

Blades are typically manufactured from composite materials which provide maximum strength with reduced weight. Originally blades were constructed from wood, steel, aluminium etc.

Figure 7.6 Blade delivery and tower construction
(Tipperary Institute, 2005)

2. Hub

The blades are connected to hub. The hub provides the connection point between the blades and the rotor.

3. Rotor & Shaft

The rotor is the term used for the blades and hub combined. This is connected to a shaft to transfer the rotational force through the gearbox and generator.

4. Gearbox

Typically generators operate at high rotational speeds and therefore it is necessary to have a gear box to increase the rotational speed from the rotor to match the requirements of the generator.

5. Generator

The generator is the component of the turbine which produces the electricity. In large scale HAWT the generators are three phase AC generators, as are used in conventional power plants.

The majority of new turbines are including variable speed drives/generators in the design. Traditional generators operated efficiently at a set speed. New generator and turbine designs now allow the turbine to produce electricity at maximum efficiency at variable speeds – which suits the nature of the variable wind resource.

6. Nacelle

The rotor, gearbox and generator are all housed in the nacelle.

Figure 7.7 Turbine Nacelle
(Tipperary Institute, 2005)

7. Tower

Wind speed varies with height and therefore to capture the maximum amount of wind the blades and nacelle are hoisted on a tower. The tower typically has a slightly conical shape and is hollow internally. Normal turbine tower heights are >40m.

8. Controls

Wind is a variable resource and therefore the controls on the turbine are vital to maximise the amount of energy that can be captured from the wind. The controls required on a typical include

- Ability to start-up when the wind speed is above a certain level
- Ability to stop when wind spend exceeds safe limits
- Ability to maximise output as wind speed varies
- Ability to rotate to face into the wind direction
- Ability to monitor and control quality of electricity output to the grid

For medium/large scale turbines two main control methods are used to control energy output.

- Pitch Control: Blades regulate power delivered by pitching the blades to reduce the lifting force of aerofoil sections
- Stall - Aerofoil sections are designed to stall as wind speed and relative flow angle increases. Power is regulated by progressive loss of rotor efficiency as stall extends

As the size of wind turbines increases there is increased use of pitch control as the mechanism for control.

The turbines must also rotate the nacelle so that the blades are facing into the direction of the wind. This is controlled by the Yaw mechanism which allows the turbines to rotate the entire nacelle based on data it receives from wind direction measurements.

Turbines will also have a mechanical brake which will be used to stop the turbine as required. This generally will work in combination with the stall/pitch controls.

7.4 Power and Energy from Wind Turbines

7.4.1 Power Curves

The basic calculations for determining the amount of power in the wind were reviewed (Formulas 7.1-7.3) in earlier sections.

The power produced from a wind turbine will vary depending on wind speeds but also on the turbines particular characteristics. This variation is illustrated in the turbines Power Curve.

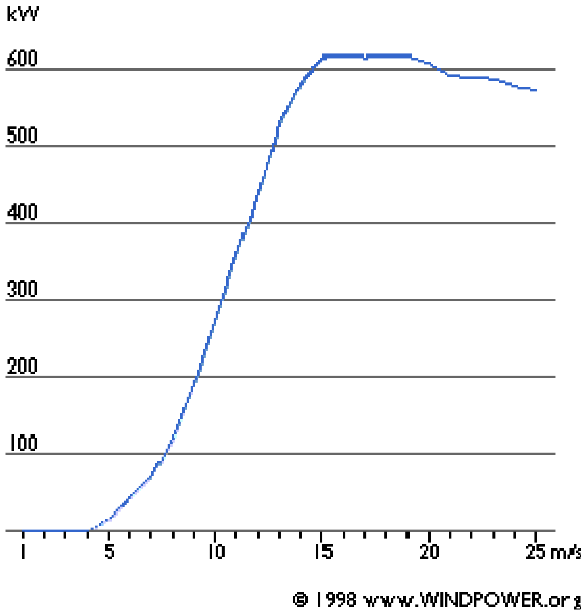

Figure 7.8 Wind Turbine Power Curve
(DWEA, 2006b)

Betz Limit sets the theoretical limit to the amount of power which can be extracted from the wind. Specific characteristics of the turbine which affect the power curve include

- Blade type and number
- Rotor diameter
- Tip speed ratio
- Speed of rotation
- Cut in, rated and shut down wind speeds
- Generator and gearbox efficiencies

Typically wind turbines power curves for HAWT will indicate cut-in wind speeds of 3-5m/s, rated power achieved at between 8-15m/s and cut-out/shut down wind speeds of 25m/s.

7.4.2 Wind Speed Distribution and Turbine Energy Production

Now that the power that the turbine will produce at different wind speeds is known it is possible to determine the energy production. To calculate this it is necessary to know the wind speed frequency distribution. This is a graph which shows the number of hours (per annum) that the wind blows at a particular wind speed.

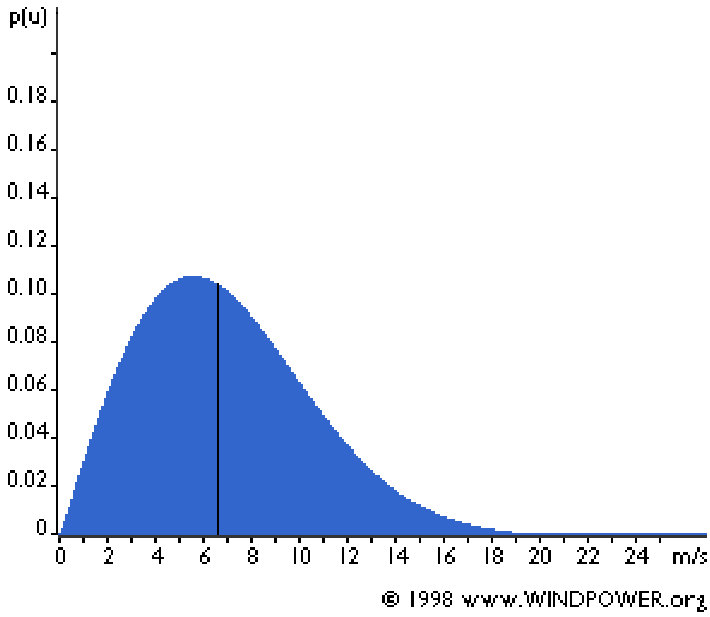

Figure 7.9 Wind Distribution Graph
(DWEA, 2006c)

Combining this data with the power curve data it is possible to produce a Wind Energy Distribution Curve. This is done by taking the number of hours for a particular wind speed and multiplying it by the power output for a particular turbine at that wind speed.

For example at 10m/s the turbine has an output of 1000kW and the wind blows at 10m/s for 500 hours per annum. The electricity produced from the turbine at 10m/s for the year is therefore:

Electricity Production at particular wind speed = Power at particular wind speed from Power Curve x No. of Hours of particular wind speed from Wind Speed Distribution

Electricity Production at 10m/s = 1000 kW x 500 hrs
= 500,000kWhrs (kilowatt hours)

Example 7.2 Calculation of wind energy production at particular wind speed/year

This calculation is done for each wind speed (between the cut-in and cut-out wind speeds) to determine the total electricity production for a particular turbine at a particular site.

Other factors affecting the electricity production will include the availability of the turbine i.e. the number of hours per annum that the turbine is available to produce energy. Availability for most HAWT is now well above 90% and often over 95% (Boyle, 2003).

7.4.3 Approximation Method 1: Using Wind Speed

There are a range of models and methods of completing initial estimates of energy/electricity production. One equation which can be used is

$$\text{Annual Electricity Production (kWh)} = K \times V^3 \times A_t \times T$$

Formula 7.4 Annual electricity production – Wind Speed Basis
(Beurskens and Jensen, 2001)

Where:

K = 3.2 (approximation factor)

V = Mean Annual Wind Speed (m/s)

A_t = Swept Area of wind turbine (m^2)

T = Number of Wind Turbines.

This equation must be treated with caution as the factor, K, is used to approximate the relationship between wind speed and distribution. This relationship will change depending on the particular site. The equation does not allow for optimisation based on particular turbine power curves either.

Using this method the annual electricity production can be then estimated for a site with the following characteristics:

- mean annual wind speed 8 m/s
- ten 1.75 MW turbines to be installed
- swept area of 3,421 m^2.

Annual Electricity Production	$= K \times V^3 \times A_t \times T$
	= 3.2 x 8 x 8 x 8 x 3,421 x 10
	= 56,049,664 kWh
	= 56 GWh

Example 7.3 Initial electricity production estimate using approximation.

7.4.4 Approximation Method 2: Capacity Factor

If no data on wind speed is available another equation can be used for calculating the annual wind energy resource. This is based on both the power of the turbines to be installed and also the expected capacity factor. The capacity factor describes the productivity of the turbine over time. A turbine will not operate at full capacity every hour of every day during the year as the wind speed and duration will vary through the year. Knowing the typical capacity factor for wind energy sites in a location can give an indication of performance. In Ireland, typical sites have capacity factors between 30-35%.

The formula to be used is:

$$\text{Annual Energy Output (kWh)} = h \times Pt \times F \times T$$

Formula 7.5 Annual Energy Output - Capacity Factor Basis

Where:

H = number of hours per year (8760)

P_t = rate power of each turbine

F = annual capacity factor

T = Number of turbines

Applying this equation to the scenario, assuming a capacity factor of 30%, used in Example 3 yields the following results:

Annual Energy Output (kWh) = h x Pt x F x T
= 8760x 1.75 x 0.30 x 10
= 45,990 MWh
= 46 GWh

Example 7.4 Annual energy output – calculation 2.

It is clear that there is some variation between the equations available. It is however, advisable to err on the side of caution when doing the initial analysis.

Another model which provides a useful way of completing pre-feasibility analysis includes RETSCreen (www.retscreen.net), an Excel based model which can be used to estimate electricity production and do initial economic feasibility.

7.5 Wind Resource Assessment

It has been shown that both the power of the wind and energy produced from a turbine are primarily dependent on the wind speed as the wind speed is cubed to calculate these figures. It is therefore vital to have an accurate assessment of the wind speed for a particular site before proceeding with project development. A number of options are available to do this.

7.5.1 Anemometers

Accurate measurement is only achievable by erecting an anemometer on site (Figure 7.10). This consists of a number of anemometers and wind vanes for measuring wind speed and directions and varying heights. This data is then stored in a data logger and routinely downloaded to a computer package for analysis. Typically, data is monitored for a minimum of 12 months.

This local data is then compared to wind speed data from nearby meteorological stations over a 20 year period to allow for accurate calculations of future wind speeds.

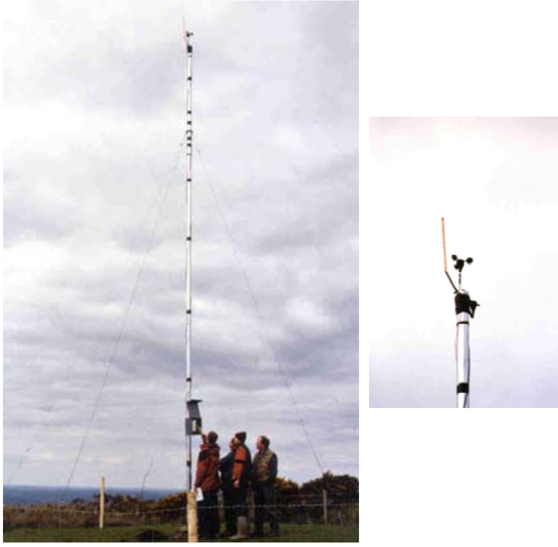

Figure 7.10 Anemometer
(Tipperary Institute, 2006)

7.5.2 Other Resource Assessment Methods

Erection of anemometers and analysis of data is expensive and time consuming. Other mechanisms exist for developing initial estimates of wind speeds, including

- Data from nearby meteorological stations:
    - This data can be used and local data derived by taken variances and local factors into account.
- Wind Speed Maps and Atlases:
    - These have been developed at a European level and also in some cases nationally. The European Wind Atlas was produced in 1989 by the Riso Institute in Denmark (www.windatlas.dk).
    - An Irish Wind Atlas was developed in 2004 by Sustainable Energy Ireland (SEI). The Wind Atlas for Ireland displays wind speed maps for the entire country and for each county, plus information about the location of the electricity network at both national and county levels. The Wind Atlas displays wind speeds at 50, 75 and 100 metres above ground level, tiled over Ordinance Survey Ireland (OSI) maps.

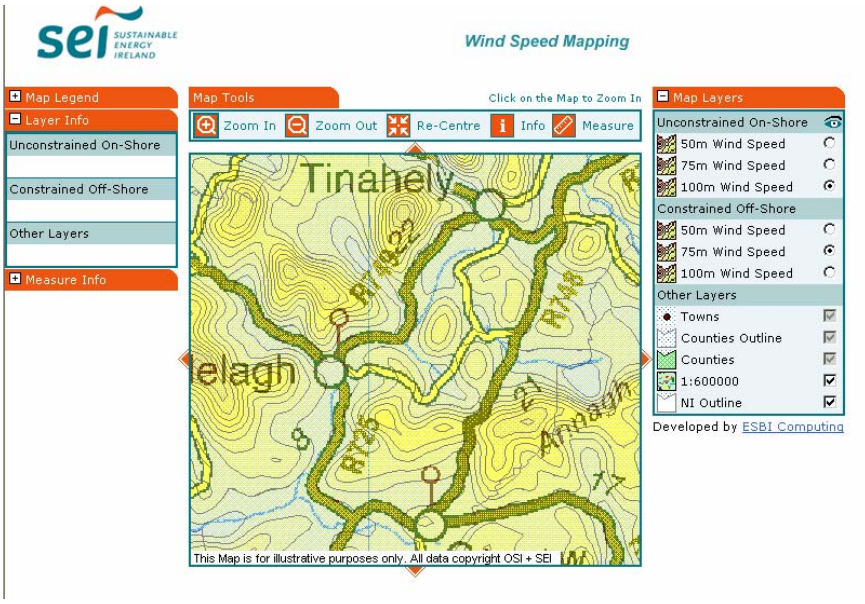

Figure 7.11 Wind speed map showing Carlow region (100m)
(SEI, 2006)

- Simulation Software
  - A number of models are available to predict wind speeds. Models include NOABL (Department of Trade and Industry Wind Speed Database, UK) and WASP (Wind Analysis and Applications Programme).

7.6 Wind Project Development Phases

The development of a large scale wind energy project has a considerable lead in time. There is a range of influencing factors which the project developer does not always have control over. The key steps in the development of a project has been summarised below:

1. Research

The project developer should begin by developing an understanding of what are the key National policies in relation to wind and prospects for development. This can be best achieved by attending relevant wind energy conferences and events and membership of wind energy associations is always beneficial. In addition, visits to other wind farms are also recommended.

2. Site Selection

The selection of the site will depend on the following key factors

a. Wind Speed: This is the primary criteria and estimates should be developed using existing data. There will be guidance on minimum wind speeds which will make a project viable. In Ireland the typical wind speeds for viability is >7.5m/s
b. Grid connection: Being able to connect to the electricity grid to export the power from the wind farm is vital. This however can have significant financial implications. Early discussions with the electricity network operator are important.
c. Development Plans: An initial review of local development plans should be completed to ensure that the site in question is not in a restricted zone in terms of planning and that there is a reasonable chance of being able to develop the project.
d. Land ownership: if the project developer is the land-owner this is not an issue but where the site involves other land owners initial agreements which allow for development of the site should be entered into.

3. Resource Assessment

Depending on the finances and timescale involved it is vital to get an accurate assessment of wind speeds on the site. This can be done using appropriate models e.g. WASP etc. or by erection of an anemometer on the site. Typically, anemometers will require permission from the local authority before they can be erected.

4. Planning

This is a vital part of the project development phase and depending on project scale will require a significant investment from the project developer. Developers should read the planning regulations carefully and a meeting with the local authority planning department before submission of a planning application is encouraged.

In Ireland all wind farms which have a capacity of greater than 5MW or have more than five turbines will require an Environmental Impact Statement (EIS) to be completed. An EIS generally needs to be completed by a qualified person and will require appropriate consultants to be engaged for different studies. The application will also need to include a Zone of Visual Impact (ZVI) Map along with photomontages.

The Department of Environment, Heritage and Local Government in Ireland published Wind Farm Planning Guidelines in 2006 which provide an example of issues to be considered (DoEHLG, 2006).

5. Grid Connection

Without a connection to the grid the wind farm will not be able to export the electricity it produces. The legislation for connection to the grid varies from country to country. Generally, the wind project developer has to apply to the electricity network operator and receive a Grid Connection Agreement.

6. Power Purchase Agreement

If the project has been successful in receiving planning permission and an agreement for connection to the electricity network has been received the next phase involves the completion of a Power Purchase Agreement (PPA) with an electricity supply company. This is essentially a contract for the sale of the electricity generated at the site for a defined period at an agreed price.

In Ireland, up until 2004/2005 this was done through Government Contracts under the Alternative Energy Requirement (AER) process. This has now changed to the REFIT programme (www.dcmnr.gov.ie)

7. Construction

The construction of the wind farm is typically carried out by specialised wind farm development companies. Design and installation of access roads and turbine foundations needs to meet specific criteria. Transport of the turbines needs a review of the road network as the scale of the equipment to be delivered may require road re-alignment in particular situations.

8. Operation and Maintenance

Once constructed the wind farm can enter into operation assuming all the necessary safety and commissioning checks are completed. The day to day operation of a wind farm may or not require specific personnel to be available on site. Annual maintenance schedules are required to ensure the turbines meet their operating parameters.

7.7 Offshore Wind Development

Offshore wind energy will not be addressed here in detail. There are significant developments in this area with a large number of installations being developed or planned.

Offshore developments offer benefits in relation to reduced visual impact, capability to install larger machines, more stable and higher speed wind regimes (in most instances) etc. However, the site and construction conditions are more difficult and result in higher investment costs. Considered research and development is being focused on this area.

7.8 Small Scale Wind

Small scale wind turbines can generally be classified as being <250kW. The use of small scale wind is primarily focused on scenarios where electricity will be used on site and not exported to the electricity grid.

There is a wide range of designs and systems available. An important design consideration for small scale wind systems is to match the size of the turbine with the electrical load profile at the site.

These applications can involve the electricity produced being used in the following ways;

- for directly heating water (through an electric immersion coil)
- being stored in batteries and used to power buildings
- being used directly in the building with excess being exported to the electricity grid.

In situations where net-metering or smart metering is available the viability of small scale wind can be considerably advanced. This is due to the fact that excess power from the turbine can be exported to displace imported electricity and batteries, invertors etc are not required. The situation with net-metering varies considerably across the EU.

Regulations regarding planning permission and grid connection vary from country to country and expert advice should be sought for an appropriate supplier or energy expert.

Figure 7.12 3000W Micro Wind Turbine
(Surface Power, 2006)

In some cases the systems can be combined with photovoltaic or other technologies to provide a full energy supply system. An important aspect of the system is the management system use to control the electricity production, load and invertors(s) (if required).

A particularly good resource to review small scale wind is the Home Power Magazine (www.homepower.com).

7.9 National Potential

A detailed study of renewable energy in Ireland was completed by ESB International. The 'Total Renewable Energy Resource in Ireland' study assessed all renewable energy technologies in detail. The section on wind energy noted that a total installed capacity of 812MW would be reasonable by 2020 (ESBI, 1996). This figure will clearly be exceeded given that there is already approximately 600MW connected to the network in Ireland.

In 2004 Sustainable Energy Ireland commissioned an update to the 1996 study. This report 'Updating the Renewable Energy Resource in Ireland (2004)' was completed by ESB International also. The wind energy section provided detailed analysis of the potential for wind energy.

GWh	2010	2020
Practicable	947,969	1,902,023
Accessible	26,202	36,701

Table 7.3 Wind energy potential production in Ireland, 2004 study (SEI, 2004)

Assessing the likely constraints in terms of planning, grid connection, social acceptance etc. the report indicated that wind energy would have to be limited to 1,250MW by 2020 based on current grid configuration. However, the true potential is 3,725MW if changes to the mix of generation plant on the system are made.

7.10 National Installed Capacity

The largest growth in renewable energy contribution in Ireland has come in the form of electricity generated from wind power. The output from wind generation increased by 44% in 2004 alone and by a further 46% in 2005 (SEI, 2004). The total installed capacity of wind farms in Ireland in December 2005 was 495 MWe. Further growth has occurred in 2006 and as of September 2006 the following was the status of wind energy projects connected to the National Grid in Ireland.

Status	TSO/DSO[3]	Capacity (MW)
Connected	TSO	263.2
Connected	DSO	335.4
	Sub Total	598.6

Table 7.4 Wind farms connected to the electricity grid, September 2006 (Eirgrid, 2006)

In addition, there are a significant number of wind farms which have been offered electricity network contracts.

Status	TSO/DSO	Capacity (MW)
Contracted	TSO	350.5
Contracted	DSO	324.7
Gate 1	DSO	17.1
Sub Total		692.3

Table 7.5 Wind farms who have been offered connection agreements, September 2006 (Eirgrid, 2006)

In addition, there is a total of 3,269.7 MW of capacity (split almost 50/50 between the DSO and TSO) of applicants to the network operator who have not yet been given grid connection agreements (Eirgrid, 2006). Under the Gate 2 process being administered by the Commission for Energy Regulation (CER) 500MW of this will be given connection agreements.

7.11 Barriers to Adoption

The further development of wind energy in Ireland will be constrained by a number of key factors.

7.11.1 Planning

Much progress has been made in relation to the planning process related to wind in Ireland. The large number of projects which have received permission are an indication of this. However, some problems remain.

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[3] TSO – Transmission System Operator; DSO – Distribution System Operator

Not all local authorities have taken the step of identifying strategic zoned areas for wind energy. Such local plans provide clarity for all participants in the planning process.

Wind farm developers need to also ensure that adequate information on the scale and type of development is provided to the local community. There have been, in some cases, considerable local opposition to wind farms being developed in particular areas. In many instances this has been due to a lack of information or incorrect information about the project being circulated.

There have been limited examples of community involvement in wind farms in Ireland as development has generally been carried out by large commercial developers who do not include community participation in the development processes.

A study in 2003 completed by SEI 'Attitudes towards wind farms and wind energy in Ireland' found that following:

- *'The study indicates that the overall attitude to wind farms is almost entirely positive. More than eight out of ten believe wind energy to be a very or fairly good thing.*
- *Encouragingly, the study highlights that two-thirds of Irish adults are either very or fairly favourable to having a wind farm built in their locality, with little evidence of a 'Not In My Back Yard' effect.*

This would seem to indicate that appropriately designed projects should be able to negotiate the planning process successfully.

7.11.2 Environmental Protection

With the increased number of wind farms being developed there may be concerns raised by particular sectors that a balance needs to be maintained in relation to the number of wind farms which are acceptable.

The planning process should adequately deal with any environmental issues that may arise. Key issues which any developers will need to address in developing their project will include:

- Visual impact
- Noise
- Electromagnetic interference
- Impact of flora and fauna etc.

7.11.3 Grid Connection

In Ireland the securing of a grid connection agreement is proving to be the main barrier to development for wind energy projects at present. In 2003 a moratorium on the connection of wind energy projects to the grid was put in place by the CER due to concerns over the stability of the grid and its ability to deal with the increased number of wind projects being connected. This moratorium was lifted in 2004 but there is now a considerable backlog of projects seeking connection agreements.

A grouping process is now in place and projects are being processed through a 'gate' or staged system. However, scenarios are now developing where planning permission for projects awaiting connection is expiring (permission is typically for a period of 5 years).

Any potential developer will need to clearly review the options for development in the context of the grid system in the project location.

7.11.4 Policy and National Supports

A lack of consistent policy and support programme for renewable energy in Ireland has caused problems for the industry. The inconsistent manner of the support programmes has resulted in a stop/start programme of development which has affected confidence in investment.

7.12 Relevant Policy and Legislation

There are a number of key policy and legislative issues which are relevant to the wind energy sector in Ireland. In the policy area these include:

- Green Paper on Sustainable Energy (1999): set a target of an additional 500MW of renewable energy by 2005
- Green Paper on Energy – Towards a Sustainable Energy Future for Ireland (2006): proposes targets of 30% electricity consumption from renewables by 2020
- National Climate Change Strategy (2000 and review in 2007): Highlights the impact renewables can make in terms of emission reductions
- All-Island Energy Market: Renewable Electricity – A '2020 Vision': Identifies the need for additional capacity in the Republic and Northern Ireland.

Key legislation relevant to the wind sector is primarily related to the electricity network and its regulation. This is related primarily to the establishment of the Commission for Energy Regulation and liberalisation of the electricity network. Details of relevant legislation are available at www.cer.ie.

7.13 Government Supports

Ireland used a programme called the Alternative Energy Requirement (AER) Programme to support wind, and other renewables, since 1993. The AER was a competition based programme where project developers applied to secure a Power Purchase Agreement (PPA) with the ESB, through the Government. While this delivered projects at least cost it was delivered in a stop/start fashion and provided no certainty within the sector. In addition, some projects which secured contracts were never built as the bid price was too low to ensure project viability.

In 2005, the Government changed to a fixed feed in price system called REFIT. The initial capacity which will be offered contracts under the current

REFIT has been limited to 400MW. The supports for wind energy projects under the REFIT programme are

i. Large Scale Wind category (>5MW) – 5.7 eurocents per kWh.
ii. Small Scale Wind category (<5MW) – 5.9 eurocents per kWh.

The Sustainable Energy Ireland RD&D programme has supported a range of projects in relation to wind energy. Some examples include:

- Riso Laboratories: "Offshore Wind and Industry Development"
- Aertech - Evaluation of wind turbine foundation behaviour.
- Veelite Lighting Ltd - Feasibility study on small Vertical Axis Wind Turbine.
- CENER - Definition of a Monitoring Programme for Irish Wind Farms.
- ERC, University College Dublin - The development of benchmarked dynamic wind-turbine and wind-farm models suitable for use within the power system community of the Republic of Ireland.
- Dundalk Institute of Technology - Development of a 1.2 kW Domestic Wind Turbine
- Participation in IEA R&D Wind Implementing Agreement

Future priorities for further projects are stated as being in the following areas:

Onshore

- Demonstration Projects of innovative wind energy applications (including auto-production)
- Data monitoring of energy production
- SCADA systems for wind farms
- System modelling
- Integration of large scale wind farm energy penetration into electricity grids
- Wind Energy Forecasting

Offshore:

- O&M of wind turbines and farms,

- Integration of offshore wind energy into Ireland's electrical infrastructure and
- Data monitoring.

7.14 Financial Viability

The financial viability of a wind project will largely depend on the cost at which a unit of electricity will be produced at. This will generally affect the ability of the project to secure a PPA. To calculate the financial viability/unit cost of a particular wind project the following information is required:

- Annual energy production from the wind turbine/farm (see Formula 7.2)
- Capital Cost of installation
- Rate at which the capital needs to be recovered
- Operation and Maintenance Costs
- Length of contract for the sale of electricity
- Length of time over which investment in the project is to be recovered

Boyle, 2004 provides a number of equations for the calculation of the cost per unit of electricity. These are:

$$\text{Unit price of electricity cost} = ((C \times R) + M) / (E)$$

Formula 7.6 Unit price calculation for wind energy project

Where

C = Capital cost of the wind farm

R = Capital Recovery Factor/Annuity Factor

E = Annual electricity production

M = Operation and Maintenance Cost

R is calculated by using the following formula

$$R = x / (1 - (1+x)-n)$$

Formula 7.7 Capital Recovery Factor/Annuity Factor

Where

X = required annual rate of return

N = number of years over which investment is to be recovered

This is just one of many methodologies which can be used. The RETScreen Model (www.retscreen.net) provides a more comprehensive method for producing a feasibility study of the costs and financial viability of a wind project.

Investors will have their own methodologies for checking both financial and project viability.

7.15 Case Studies

7.15.1 Sample Project

Using the project which has been used throughout this section it is possible to draw together the key information. The project has the following characteristics

- Number of turbines: 10
- Turbine Capacity: 1.75MW
- Site Capacity Factor: 30%
- Average Annual Wind Speed: 8m/s

It is necessary to assess the potential for the project to get a PPA under the Irish REFIT programme. It would therefore need to be able to produce electricity at or below 5.7 cent per kilowatt hour.

Using Formula 7.2 the annual energy output has been calculated at 46GWh.
To use Formula 7.6 it is necessary to make a number of assumptions as follows:

- Capital cost: €1,200 per kW
- Annual Rate of Return: 10%
- Operation and Maintenance Costs: 2.5% of capital costs
- Number of years to recover investment: 10

Using Formula 7.7 the Capital Rate of Return is calculated to be 0.167

Entering this and other data into Formula 7.6 the average annual unit price of electricity for the site is €0.08571/kWh. This is above the potential price which could be received under the REFIT programme. The mechanisms to reduce this figure would be to increase the capacity factor or increase the size of the turbines installed.

7.15.2 Existing Project

7.15.2.1 Project Development

In County Tipperary a wind farm was developed consisting of three 850kW Vestas machines. This project was the first wind farm installed in County Tipperary and the most inland wind farm in Ireland. The first phase of the project had no objections when it went through the planning process. The project is planned to expand in the future with the addition of one more turbine. The second phase of planning received 17 objections, mainly based on visual impact grounds.

The project is connected to the electricity grid via a 10kV line which had to be constructed between the site and the nearest sub-station (9km away). The cost of the grid connection was €300,000 with the total project development costs estimated to be €400,000. The developers were successful in agreeing a contract under the Irish Government AER IV programme. The second phase of the project will have a contract under the REFIT Programme.

7.15.2.2 Technology

Figure 7.13 Turbines at Aelous Wind Farm, Co. Tipperary
(Tipperary Institute, 2006)

The project uses Vestas V52/850kW wind turbines. The turbines have a 49 m hub height, 26 m blades (52 m diameter, 75 m overall height) with the rotor rotating at 25 rpm.

The turbines generate electricity at 690V which is then transformed to 10,000V (10kV) at the substation. The turbines have twin generators. One generator is used to operate at lower wind speeds and at higher wind speeds (>6m/s) it switches to the other generator. This improves the overall efficiency of the turbines.

The turbines uses pitch control to regulate power and the cut-out speed is 20m/s and the towers are spaced 150m apart (1.5 times the rotor diameter).

7.15.2.3 Operation

The project has been in operation since early 2004. The developers monitoring wind data for 18 months before constructing the project. Average annual wind speeds are 8m/s. The project has had little downtime outside of normal maintenance requirements. The majority of downtime has been due to problems with the grid although these are normally rectified in a number of hours.

The developers have an O&M contract with Vestas, with an annual cost of €150,000. This is seen as being good value for money by the developers.

The project operation can be monitoring remotely and problems are notified by Short Message Service (SMS) to the appropriate person.

7.15.2.4 Financial Analysis

This project has been analysed using the RETScreen model. A number of assumptions were made in relation to costs and other factors. The key data for the project is as follows:

- Turbine Type: Vestas V52/850kW
- Number of Turbines: Three
- Average wind speed at hub height: 8.0m/s
- Annual energy production per turbine: 2,946 MWh
- Cost per Turbine: €850,000
- Total Project Costs: €3,250,000
- AER VI Income/kWh: 5.742 Eurocent/kWh
- Debt Ratio: 80%
- Discount Rate: 8%

Using this data the project analysis returned the following economic data:

- Simple Payback: 8.5 years
- Internal Rate of Return: 14%
- Net Present Value: 801,000

The developers noted that raising the finance for the project was particularly challenging and personal assets were required to match the debt raised. If the initial development costs can be overcome it is clear that a wind energy project at the correct site is financially viable.

7.15.2.5 Environmental Analysis

In Ireland, the average CO_2 emissions per kWh of electricity was 0.68kg/kWh in 2004 (SEI, 2005). This project would therefore avoid 6000 Tonnes of CO_2 per annum.

7.16 Sources of further information

- EU Commission:
  - DG Transport and Energy (New and Renewable Energies)
    - http://ec.europa.eu/energy/res/sectors/wind_energy_en.htm
  - ATLAS Web Site
    - http://ec.europa.eu/energy/atlas/home.html
- EWEA (www.ewea.org)
  - Wind Energy – The Facts
  - Wind Force 12
- Sustainable Energy Ireland
  - Http://(www.sei.ie)
- RES-E Regions Project
  - http://www.res-regions.info
- Danish Wind Energy Association (DWEA) (2006a) Wind Know-How/Guided Tour/Wind/Global Wind.
  - http://www.windpower.org
- Wind Works
  - http://www.wind-works.org

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