Training Unit on MiniWind

Supported by INTELLIGENT ENERGY EUROPE

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INTRODUCTORY DOCUMENT ON MINIWIND ENERGY

MAIN DOCUMENT- TRAINING PACKAGE ON MINIWIND ENERGY SYSTEM

(PART OF DELIVERABLE D4.4)

Rural-RES

PROMOTION OF SMALL-SCALE HYDRO AND WIND SYSTEMS IN MOUNTAIN AND RURAL TERRITORIES

Intelligent Energy Europe Programme

IEE/07/797/SI2.499715

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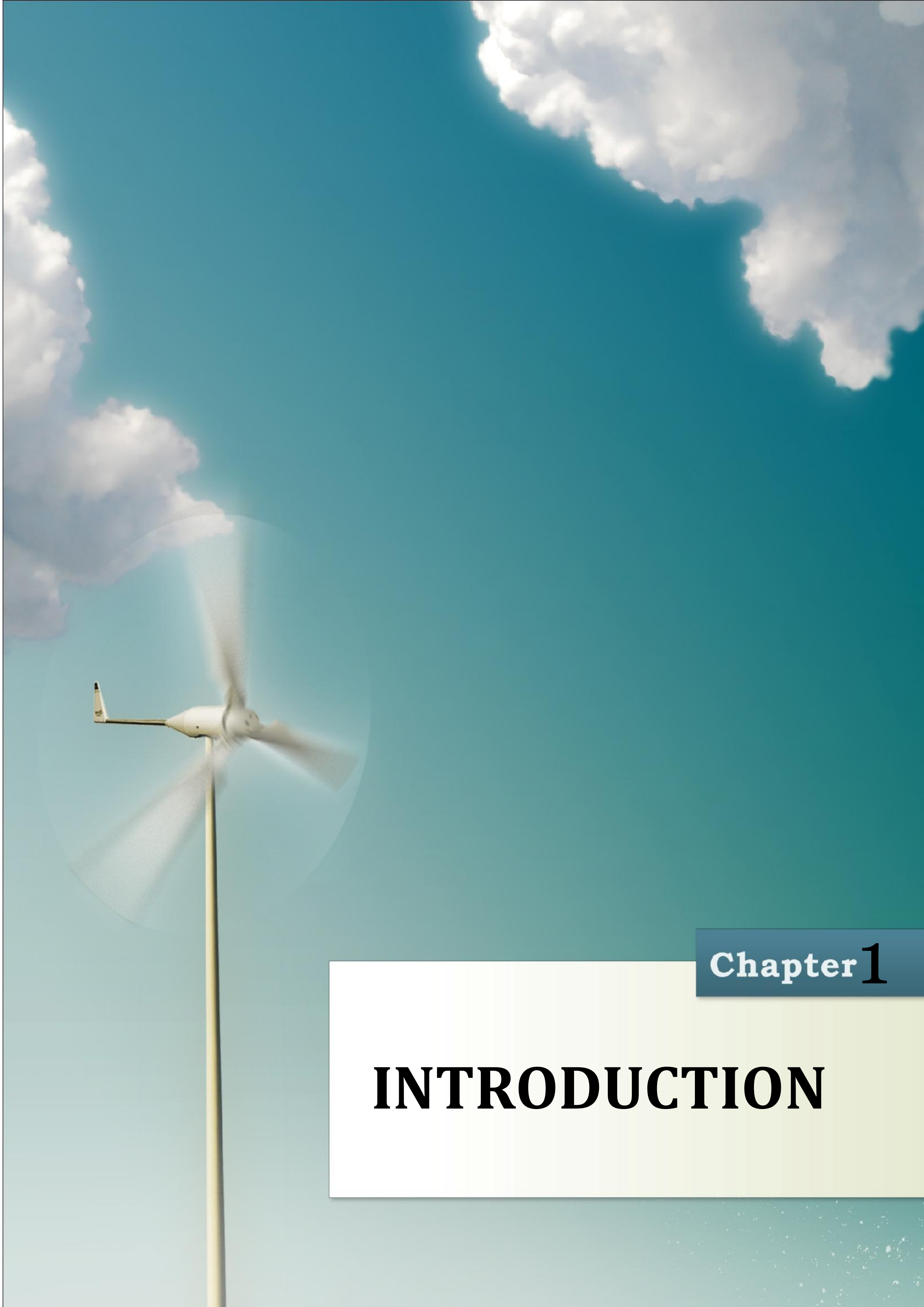


Chapter 1

INTRODUCTION

1. INTRODUCTION

In the last two decades, with concerns over both climate change and security of supply becoming more and more acute, larger wind turbines and wind farms are becoming part of everyday life. The problems associated with these new clean methods for electricity production are being overcome rapidly year by year. However, currently big wind´s success is not being mirrored in its smaller sister industry. The installation of small wind turbines is far from commonplace, in fact it is more or less limited to rural off-grid applications, where photovoltaic installations still take preference. Although the potential for electricity generation from small wind turbines does not reach the same impressive levels of that for large wind, the benefits that it can provide in terms of locally produced renewable energy, distributed energy generation, security of Energy Supply and very easy installation, it must be considered as a vital contribution to our energy future.

The categorisation of miniwind, or small wind varies very much from country to country, from administrative body to administrative body, and sometimes from planning authority to planning authority. For having said that, the general range for turbine power does not vary very much as it is mainly common sense. Therefore generalising according to for all the various definitions that there are, we can state the following:

- micro wind: of less than 1.5 kW of nominal power
- small/mini wind: 1.5 kW to 100 kW
- medium wind: 100 kW to 600 kW
- Large wind: greater than 600 kW

For the RuralRES project, miniwind was specified to be any power rating below 50kW, although relevance will most likely apply to all types up to 100 KW nominal power.

There is no international legislation that specifies that wind turbines which nominal power is less than 100 kW as low power wind technology. There is just one manufacturing norm for small wind turbines by the International Electrical Commission but it is not a compulsory order. This Commission defines a wind turbine of low power as that one which swept area of its rotor is less than 200 m^2.[1]

The following table shows which parameters are adequate to describe the small wind turbines according to the IEC 61400-2 standard (International Electrotechnical Commission).

[2] *CEI Standard IEC-61400-2 Ed.* ***2****. 2006*

IEC 61400-2
Área less than 200 m²
Nominal power 0-65 kW
Blade diameter < 15 m

Table 01: Description of small wind turbines[2].

1.1 BACKGROUND

1.1.1 Historical background

Sailing boats were the most probably the first use of wind power by mankind and the first references to the use of sailing ship come from Egypt dated around 5000 years b.c. The first powered machines were however actually hydropowered using the mechanical energy provided by the movement of water. Wind machines came to light later, due to the technical difficulties presented; notably the random behaviour of wind of intensity and direction which require a regulation and direction mechanism more complex than those needed in watermills.

The Chinese were the first to use windmills, also called panemones (all winds), (see figure 1), which were used to pump water from the salines. They were vertical axis and their blades were made with fabrics on wooden beams. The position of the blades could be modified to adjust the action of the wind turbine. Some historians think that these machines could be the precursor to persian mills.

The spread of windmills in Europe in the 11th and 12th centuries spread due to the Mediterranean influence, extended by the islamic civilization, to the southern half of the Iberian Peninsula, leading to a Mediterranean type windmill. At the same time a triangle of innovation was formed by Brittany, England and Netherlands.

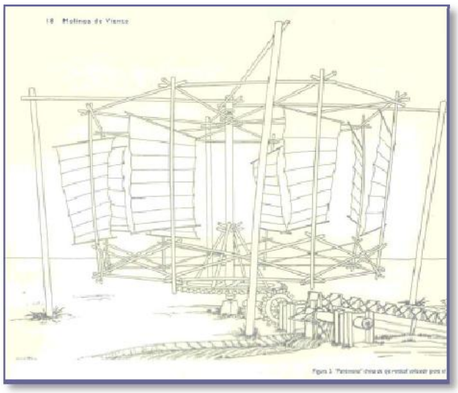


Figure 01. Chinese panemones

Whatever the origin of these machines in various European countries, there are abundant examples of the importance of windmills with various application, such as the Castellano mills used for grinding and the Dutch windmills, used since 1430 for draining, all of them being of horizontal design.

In the 16th Century, Holland improved the design of mills which were used for drainage between the years 1609 and 1612. Beemster Polder was drained with the help of these machines. The mills were used to drain water and to extract oilseed, to grind grain, etc: the name of these mills comes from this type of applications. We can see the

[3] *LA TECNOLOGÍA MINIEÓLICA:RETOS Y POTENCIAL DE DESARROLLO. Enrique Soria Lascorz. División de Energías Renovables. CIEMAT*

importance wind power acquired in the past when in the 18th century, the Dutch had installed and brought into operation 20.000 mills which provided an estimated of 20 kW each. It was a very large quantity of energy in that period.

Figure 2. is an example of Dutch mill called Kat and located in the Zaanse Schans town. It is from 1646 and ground materials to create pigments for paints.

In the 17th century, there were scientific and technological advances with improvements in the direction and regulation systems that had been a problem.

Figure 02: Kat mill in Zaanse Schans. Holland.

1.1.2 Origin of wind turbines

Windmills were developed in Europe reaching their maximum technological development in the mid-nineteenth century. Moreover, new designs for new applications were emerging. In 1724, Leopold Jacob designed an eight-bladed windmill which moved a rotor pump. The first wind pumps appeared in 1854 in USA. They consisted of a rotor of multiple blades attached to a rotor pump through a rod-crank system.

Figure 03: Details of metal blades.

In 1883, based on this development, the American multi blade turbine designed by Steward Perry appeared; this mill with metal blades (figure 3) has a 3 m of diameter rotor and between 18 and 24 blades.

The American Charles F. Brush (1849-1929) in 1888 built the first automatic turbine to produce electricity, based in the American multi blade mill, with a diameter of 14m and 144 blades of cedar wood. Although, it was a big turbine, it only moved a 12 kW dynamo. The American-type slow rotation turbines did not have a high efficiency. Figure 4 shows this turbine in Cleveland (Ohio).

Figure 04: wind turbine of Brush in 1888

A wind development program of Danish government resulted that in 1892, professor Poul la Cour developed the first electric wind turbine prototype. Moreover, to conducting his experiments, he built his own wind tunnel and is considered one of the pioneers in modern aerodynamics. La Cour also researched energy storage, using the electricity of its wind turbines to obtain hydrogen to fuel gas lamps through electrolysis. In the figure 5 there are two test wind turbines in La Cour in 1897, in the institute Askov Folk, AsKov (Denmark).

Figure 05: wind turbines in La Cour in 1897

During the first decades of the 20th Century is when the aerodynamic theory developed allowing us to understand the nature and behaviour of the forces that act around the turbine blades. The same scientists who developed it for aeronautical applications Joukowski, Drzewiechy and Sabinin in Russia, Prandtl and Betz in Germany, Constantin and Enfield in France, etc, established the basic criteria that the new generations of wind turbines would follow.

1.1.3 Evolution of wind turbines

The advance in the aerodynamic theory in the 1920's, started to be applied to the rotors for wind turbines which had been previously focused on designs for wings and propellers of aeroplanes. In 1927, the Dutch A.J.Dekker built the first aerodynamic rotor obtaining a tipspeed of four or five times higher than the incidental wind. The theory showed that the higher speeds of rotation have less influence on the performance of the system than the number of blades, so wind turbines of two or three blades appeared.

In 1924 the Finnish engineer Sigurd J. Savonius designed a rotor consisting of two half cylinders around a vertical axis that works with low wind speeds and are the basis of current developments in the production of electricity in isolated systems with low power. Figure 6 represents a Savonius rotor, where it indicates the incidence of wind and its rotation.

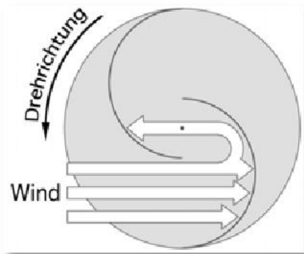
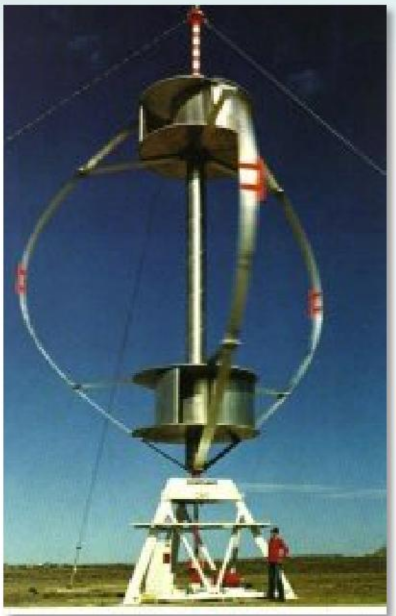


Figure 06: *Rotor Savonius in plant*

The French engineer Darrieus also designed a vertical-axis turbine formed by two blades with profile of an aeroplane wing joined to the axis at its two extremes. The curve formed by the two joints of the axis is designed for maximum performance.



This type of rotor cannot start by itself. Due to this, it needs an auxiliary start device as we can see in the figure 7 which has a Darrieus rotor with a Savonius start. This set up is able to keep the its blades moving whilst achieving speeds higher than the Savonius rotor but lower than the horizontal axis rotors.

Figure 07: Rotor Darrieus with Savonius start

Between 1940 and 1950 the Danish engineering company FL Smidth built several two-and three-bladed wind turbines, based on the idea that fewer bladed turbines are more efficient than mutli-blades. When they discovered that three-bladed wind turbines provide greater stability than the two-turbine blades, the Danish concept of wind turbines appeared, which is referred to a three-bladed machine. Figure 8 shows Smidth three-bladed wind turbines on the island of Bogo, built in 1942, which was part of a wind-diesel system that provided electricity on the island.

Figure 08: wind turbine Smidth in 1942

Since the end of the World War II to 1973, there was a period of low oil prices. For this reason developed countries abandoned the research in wind technology, with the exception of Denmark that had a wind energy development program. As a result of the ongoing research activity Denmark has always been a world leader in wind technology.

After the energy crisis in 1973, some countries such as Sweden, Great Britain, USA, Germany and Denmark created research and development plans which would be the origin of the current wind technology. Among the events to highlight, USA started a program whose first result was the installation in 1975 of the MOD-0 100 kW wind turbine.

In the early 1980's wind turbines that will be the basis of the current designs were being trialled, such as Danish wind turbine Bonus of 30 kW (figure 9), which improved in a short time increasing the power up to 55 kW. Due to the industrial and technological advances for modern wind turbines the cost per kWh of electricity fell by about 50%.

Figure 09: 30kW wind turbines, Bonus.

In the 1990's, there was a rapid development in wind energy putting this source of renewable energy in a competitive position with respect to conventional energy production. Between the end of 1990's and the early part of this decade, wind turbines were installed for mass production of electricity in wind farms, with power ratings of between 600 kW and 850 kW. The market for megawatt wind turbines began in 1998.

The advance that wind power has seen in the 20th century came from the application of the aerodynamic theory which established the basic principles of operation of the new wind turbines. This advance also came from the development of mechanical, electric, electronics and material technologies, which have allowed the building of very high power wind turbines with good regulation and great reliability.[3]

1.2 CURRENT SITUATION OF SMALL WIND ENERGY

In the last decade mini wind turbines connected to the grid have become a real option, especially in the developed world where the conventional grid reaches most areas. However, its implementation depends on financial incentives that need to be enough attractive to offset the long and complicated process of dealing with local electric companies. For example, in Denmark, the feed-in-tariff for small wind energy is the double that of the big wind energy. This rate is applied to systems up to 25 kW of installed power. The USA has the remuneration system called "net metering", which provides individuals who have renewable energy generation in their homes to deduct their excess from energy bills when they generate more than they use or they draw from the grid in times of insufficient production.[4] [5] [6]

Despite the success of the big wind turbines industry, small wind turbines (ie, less than 100 kW rated power) are a distinct market for themselves. The main differences in these markets are:

- Small wind generators are usually installed as individual units, and;
- Small wind turbines include a much wider technologic range.[7]

There are a growing number of small wind turbines manufacturers and at present, the big wind turbines manufacturers are starting to see possibilities for the new market. The world leader in this market is USA ant the most of the companies outside the USA which built wind turbines of less than 1 kW, sell within their countries. The few companies which are present in the american market are from UK, Canada and Germany.

[3] *Manuel I. Bahamonde. Module of wind power. Master of renewable energy and energy efficiency. Department of Applied Physics of the University of Huelva.*
[5] *American Wind Energy Association. Global Wind Energy Market Report, USA. 2001. Available in http://www.awea.gov*
[6] *PRADAS POVEDA, José Ignacio. Análisis comparativo de las tarifas eléctricas en la Unión Europea. BOLETIN ECONOMICO DE ICE N° 2669. 2008*
[7] *European Wind Energy Association, EWEA. Available in: http://www.ewea.gov*
[7] *Canadian Wind Energy Association http://www.smallwindenergy.ca/en/Overview/History.html*

One of the markets with a possible future for this type of energy are urban areas. There is a new type of wind turbine that is developed for the urban environment. These wind turbines are safe, have a low noise level, have an aesthetic scenic value of landscape and an easy installation in buildings. Germany, Finland and Denmark have started to use these small wind turbines. But Holland is the true pioneer in this technology due to the lack of space.[8]

1.3 PERSPECTIVES

Wind power is seen as one of the key measures to reduce and reverse the increase of non-renewable energy consumption and CO_2 emissions according to a report of the International Energy Agency (IEA).

In the following graph, we can see the partial and total cumulated increases expected from 1980 to 2030 for each known energy source or currently used if there were not measures to promote renewable energy and energy efficiency. This is the reference framework.

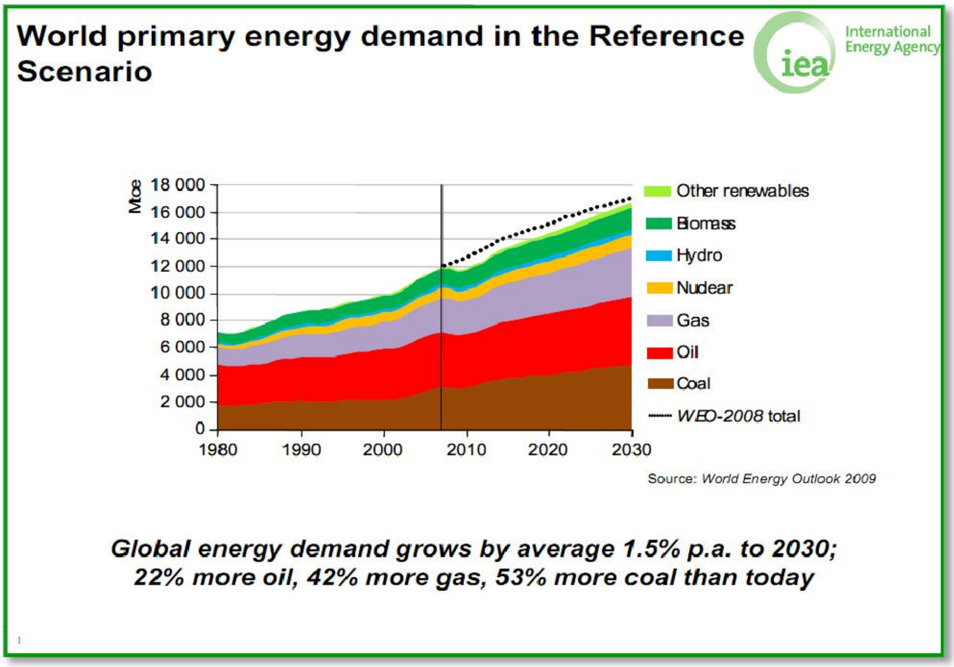


Figure 10: energy demand estimated in the period 1980-2030.[9]

As we can see in figure 10, there will be an increase of three times the consumption in 1980 in the year 2030.

[8] *CIEMAT. Prospectiva y vigilancia tecnológica. Aerogeneradores de potencia inferior a 100 kW. [electronically transmitted document] July 2008.*

[9] *International Energy Agency (IEA. Image form the presentation of IDAE "La mini eólica en España. Marco regulatorio, situación y perspectivas. Juan José RomeroZamora. 21 May 2010.*

The IEA carried out a "450 Scenario" which establishes an aggressive timetable to implement the necessary actions to limit the concentration of greenhouse gas in the atmosphere to 450 parts per million of carbon dioxide equivalent. By maintaining the atmospheric concentrations of greenhouse gas at this level, will limit the global temperature increase to about 2° C above pre-industrial levels.

This implies a strong development and application of energy efficient technologies. According to the 450 Scenario, energy efficiency 2030 is more than half of greenhouse gas emissions reduction and the promotion of renewable energy is about 20% as we can see in figure 11.

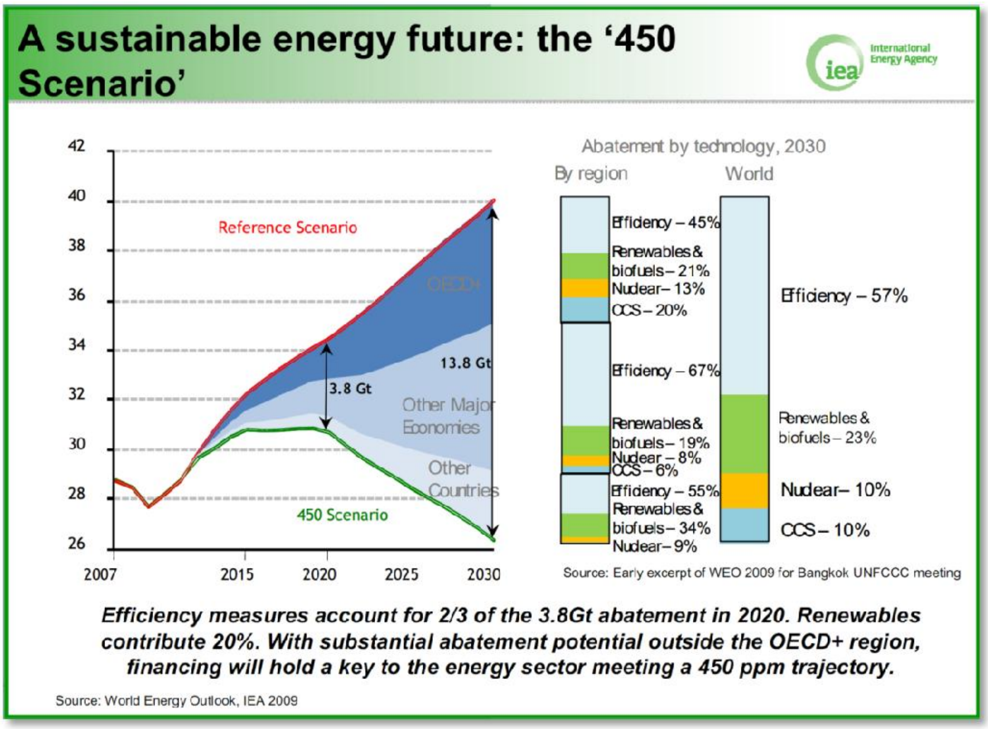


Figure 11: the future sustainable energy "450 Scenario"[10]

The reduction of CO2 derived from the implementation of the plan requires contributions of the various key technologies, both to avoid CO2 emissions and to capture them, from 2010 to 2050. In this scenario, the total of renewable energy is 16%.

The result of these technologies will be, as the IEA called, the Blue Map Emissions.[11]

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[10] *Presentation of IDAE "La mini eólica en España. Marco regulatorio, situación y perspectivas. Juan José Romero Zamora. 21 May 2010.*

[11] *Source: IEA, Energy Technology Perspectives 2008 : Scenarios and strategies to 2050, Executive Summary. (2008).*

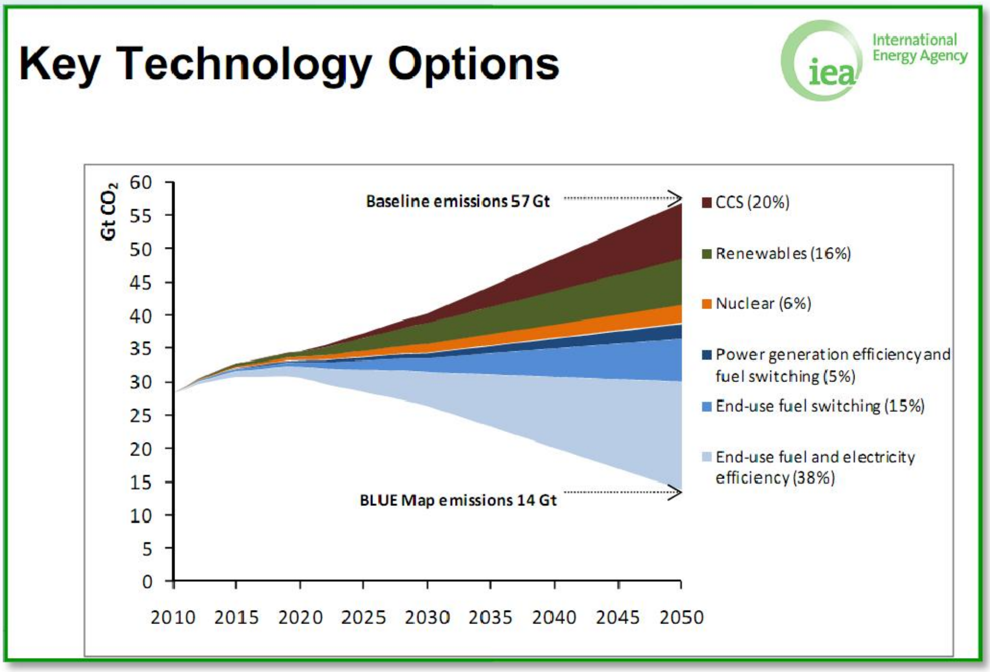

Figure 12: technological options to reduce the CO2 emissions.[12]

Figure 13 shows a comparison between the different scenarios from now to 2050 in accordance with the primacy or non-primacy of non-renewable energy sources.

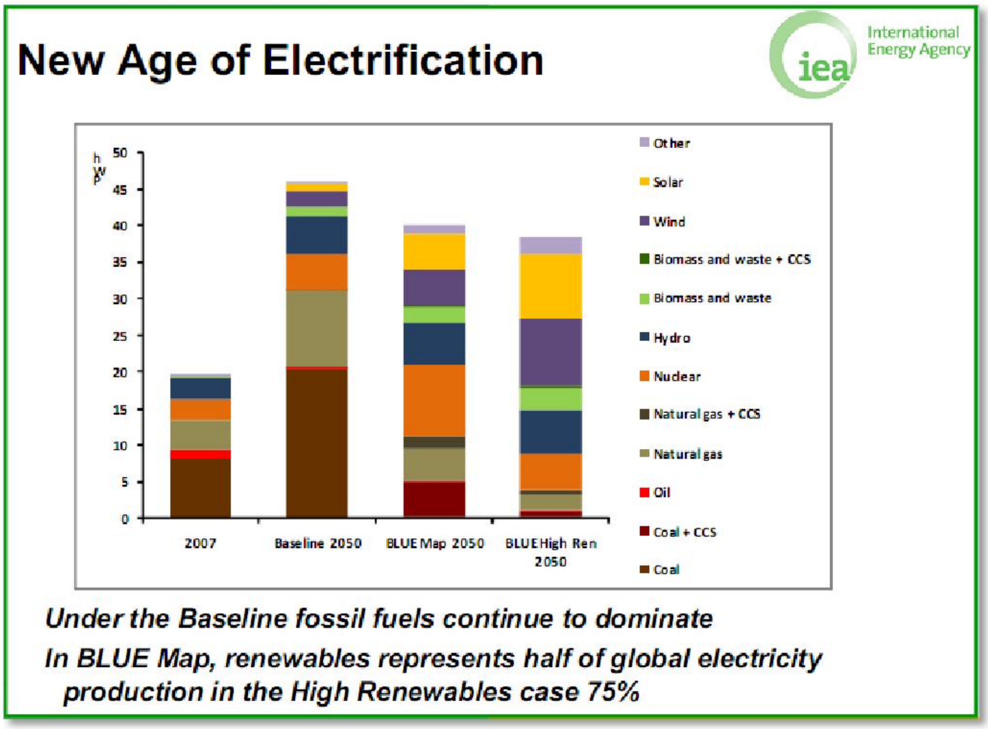

Figure 13: Perspective on the new era of the electrification.[13]

[12] *Presentation of IDAE "La mini eólica en España. Marco regulatorio, situación y perspectivas. Juan José Romero Zamora. 21 May 2010.*

[13] *Presentation of IDAE "La mini eólica en España. Marco regulatorio, situación y perspectivas. Juan José Romero Zamora. 21 May 2010.*

The success in these Blue scenarios, which would mean a reduction of at least 85% of CO_2 emissions in 2050 will lead to enormous efforts in technological development and reduction in renewable technology unit costs.

1.4 WIND ENERGY RESOURCE AND ITS POTENTIAL

The energy in wind, like most land energy sources, comes from the sun. The energy that the sun radiates, between 1 and 2% becomes wind[14]. We are only able to take advantage of a small part of this but it is estimated that the wind potential is twenty times the current world energy consumption.[15]

Figure 14 shows the relation between the consumption of primary energy in 2007 and the amount of energy that could be obtained worldwide through renewable energy sources. Also, this graph shows that any of the potential of renewable energy fully exploited could satisfy global energy demand.

In the legend we can see, for example, that the energy released by the sun's radiation directly on the continent is 1800 times the necessary world's primary energy in 2007.

In this graph, we can see that the wind energy is in the second place from renewable sources exploited to date, and can provide an equivalent of 200 times the energy needed to satisfy global demand in 2007.

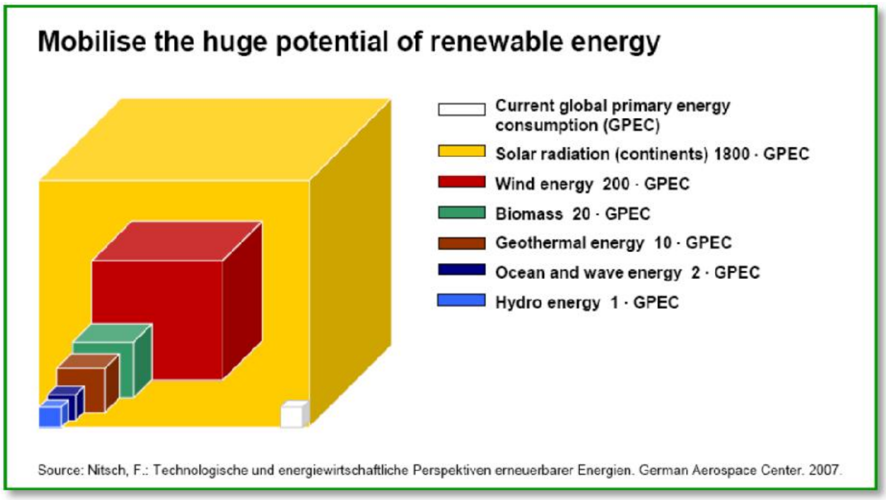

Figure 14: distribution of the global renewable energy.[16]

One of the characteristic of wind resource is its randomness and variability depending on the atmospheric conditions. Moreover, adequate wind for generating electricity are usually only found in specific areas, so the first step for its exploitation is

[15] *CIEMAT. Principios de Conversión de Energía eólica. Edit. CIEMAT. España: 2001.*
[16] *Master in Environmental technology. University of Huelva and UNIA Renewable Energy and energy saving. Wind energy. © Manuel I. Bahamonde García.*
[16] *Presentation of IDAE "La mini eólica en España. Marco regulatorio, situación y perspectivas. Juan José Romero Zamora. 21 May 2010.*

the evaluation of wind[17] characteristics. For this purpose, there are different techniques. The technical and economic feasibility study of a wind project, requires a detailed knowledge of wind behaviour and it is indispensable to carry out anemometric measurements "in situ ".[18]

The exact estimations of the wind speed are important to evaluate the useful potential in any location. Wind resources are characterized by a scale of wind types according to their speed that is from the type 1 (lowest) to type 7 (highest).[19]

Height	*10 m*		*30 m*		*50 m*	
	Wind Speed m/s	*Wind Power Density W/m²*	*Wind speed m/s*	*Wind Power Density W/m²*	*Wind speed m/s*	*Wind Power Density W/m²*
1	0-4.4	0-100	0-5.1	0-160	0-5.6	0-200
2	4.4-5.1	100-150	5.1-5.9	160-240	5.6-6.4	200-300
3	5.1-5.6	150-200	5.9-6.5	240-320	6.4-7.0	300-400
4	5.6-6.0	200-250	6.5-7.0	320-400	7.0-7.5	400-500
5	6.0-6.4	250-300	7.0-7.4	400-480	7.5-8.0	500-600
6	6.4-7.0	300-400	7.4-8.2	480-640	8.0-8.8	600-800
7	7.0-9.4	400-1000	8.2-11.0	640-1600	8.8-11.9	800-2000

Table 02. wind power available in accordance with the speed and height.

The amount of energy that a wind turbine can generate depends on wind characteristics. Wind is a movement of air and carries the energy associated with it. Wind turbines use that energy to generate electricity directly. Therefore, before installing a wind turbine should know the potential of wind in the right location, a value that is given by the following equation:[20]

$$Pd = \frac{1}{2} \cdot \rho \cdot A \cdot v^3$$

From the analysis of this equation, we can obtain the following conclusions:

The speed at which the air passes through the blades is extremely important, because wind power is proportional to the cube of the speed at which it moves. For example, if the speed is doubled, the energy will be eight times higher.

There are other important factors in the wind speed:[21]

Relief. Hills devoid of trees or obstacles and rounded tops, are interesting sites for the installation of wind turbines because they can take advantage of the accelerating effect of the relief. But cliffs, etc, are worse due to the formation of turbulence areas,

[18] *ARAUS. Maria E , Massa. Aldo A y Solelti. Alfredo J; Energía Eólica. Universidad Católica de Córdova. 1983.*
[19] *VON DOENHOFF, Abbott. Theory Of Wing Sections; Dover Publ. United States: 1959.*
[20] *GÓMEZ ROCHA, Luis Martín. Aspectos relevantes de energía eólica "WINDPOWER 2001". Comisión Nacional para el Ahorro de Energía (CONAE). Mexico: 2002.*
[21] *CIEMAT. Prospectiva y vigilancia tecnológica. Aerogeneradores de potencia inferior a 100 kW. [electronically transmitted document] July 2008.*
[22] *MOYO. Condiciones de Contorno. [electronically transmitted document] 2000. available in: http://usuarios.arnet.com.as/marman/Proyecto.Final.html*

which not only reduce the energy produced, but also produce strain of fatigue on the machine reducing its operating life. The presence of obstacles causes two negative effects: reduction of wind speed and increase of turbulences.[22]

Roughness. The variation of speed with respect to the height depends essentially on the roughness of the surface land. A very rough surface like a forest or a group of houses will cause turbulences and slow wind down, while another smoother areas open water or an airport runway will encourage air flow. Therefore, for a better exploitation of wind power, smooth and clear terrain is ideal.

Height. It is the height of the turbine hub above the ground. At higher altitudes the wind is faster and less turbulent. This is one of the factors that determine the variability of small wind facilities against large wind installations that tend be around 80 m. Small wind power facilities as a general rule not exceed 25 m in height. The most common height in a residential installation are between 12 and 20 m. At this height the wind speed is much more affected by the roughness, type of ground cover and obstacles making it more turbulent wind flow and mathematical estimates become less precise, requiring a specific study for each site.

Swept Area of the turbine is also crucial to the power generated by the turbine. It is result from the following equation $A = pi R^2$. Therefore, another important factor is the radius of the rotor. A small increase in rotor diameter produces a significant increase in power.

Power also depends linearly on the air density, the heavier the air more energy will receive the wind. The air density varies with **temperature and altitude**. Hot air is less dense than cold, so the production of energy is less during the summer than during the winter with the same wind speed. Also at the same temperature a location close to the sea will have a higher power density than a high elevation location as the density of air decreases with height.

The power Pd is the maximum power that could be extracted from the wind, if all the kinetic energy of wind could become used. But with aerodynamic and mechanical limitations as aerodynamic and mechanical friction, efficiency of the electric generator etc., means that in practice it is only possible to take 40% of the available wind power.[23]

A wind turbine slows down the wind alter it passes through the rotor to 2/3 of its beginning speed. This means that the wind turbine does not take all the kinetic energy of the wind as the Betz's Law says: “you can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy using a wind turbine.”[24]

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[23] *COMISIÓN NACIONAL DE INVESTIGACIONES ESPACIALES. Consideraciones Generales Sobre Aspectos Relacionados a la Transformación del Viento con la Altura. Fuerza Aérea Argentina-Centro Espacial San Miguel, Argentina; July 1983.*

[23] *ALATALO. Mikael; Permanent magnet machines with air gap windings and integrated teeth windings, Doctoral thesis. Göteborg, Sweden, Chalmers University of Technology, School of Electrical and Computer Engineering, Technical Report No. 288, May 2002.*

[24] *HENGELVELD-LYSEN-PAULISSEN. Matching of Wind Rotors to Low Power Electrical Generators. PUBLICATION CWD 78-3. CWD: Netherlands. 1998.*

The wind power extracted or captured from the wind by the rotor of the machine is known as wind power output. The conversion efficiency is described by the power coefficient (Cp) defined as the relation between output and available power (Cp = Pa / Pd). This maximum would be the Betz limit and depends on the type of generator, its area, its rotational speed and wind speed. Therefore, the wind power delivered can be calculated from the following equation:

$$Pa = Cp \cdot \left(1/2 \cdot \rho \cdot A \cdot v^3 \right)$$

Wind power output = Cp x swept area of wind turbine x $^{1}/_{2}$ *du*^{3}

Figure 1 shows the variation of the power coefficient Cp as a function of windspeed for different types of horizontal and vertical axis wind turbines.

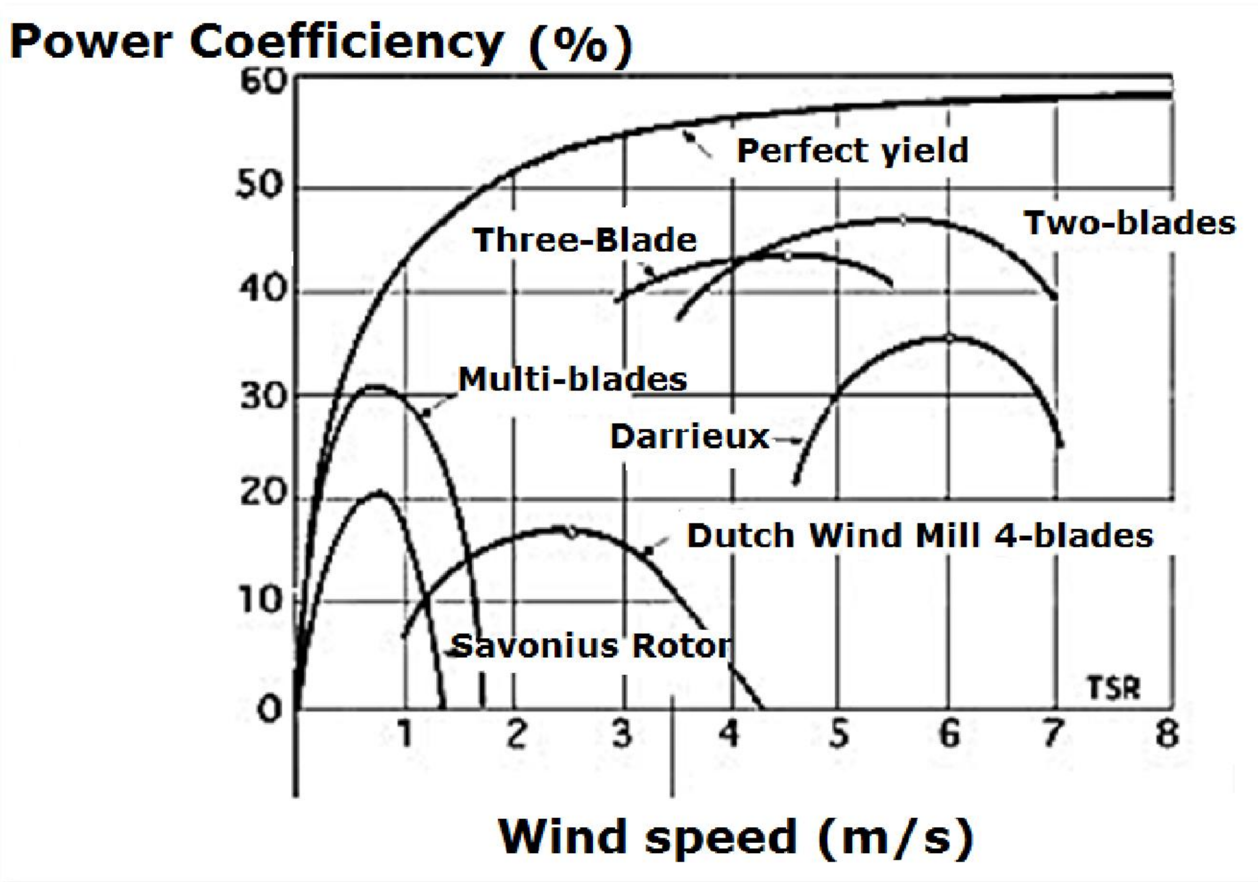


Figure 15: Variation of the power coefficient (Cp) for different types of wind turbines.[25]

1.4.1 Topography and terrain

[25] *BILBAO, Armando y Zarraoa, Amaia. Diseño estructural de un aerogenerador. IDOM*

Topographic inclinations such as hills and valleys influence local wind acceleration. For example, a hill with gentle gradient speeds up the wind though the slope giving the maximum speed at the top of the hill.

However, an abrupt topographic inclination dissipates wind energy due to the turbulences generated. Thus in the case of an installation of a wind turbine on a cliff or in a building, to give it enough height to pass this area of turbulence.

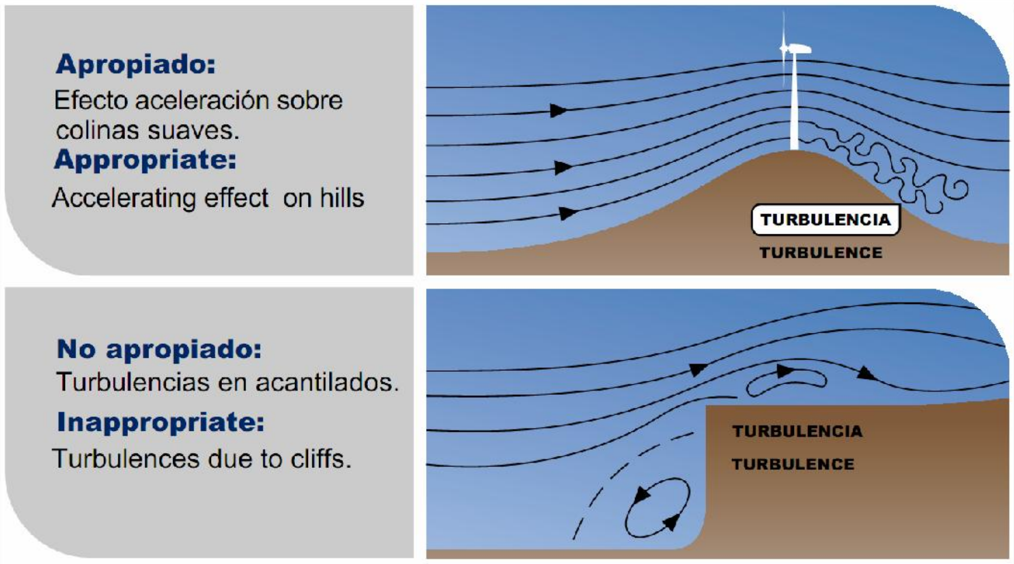


Figure 16: Behaviour of the air flow depending on the terrain.[26]

The following image in figure 17 shows graphically how the air flow changes when it is brought to an abrupt obstacle item such as a building in a city, and which should be the approximate location of the wind turbine.

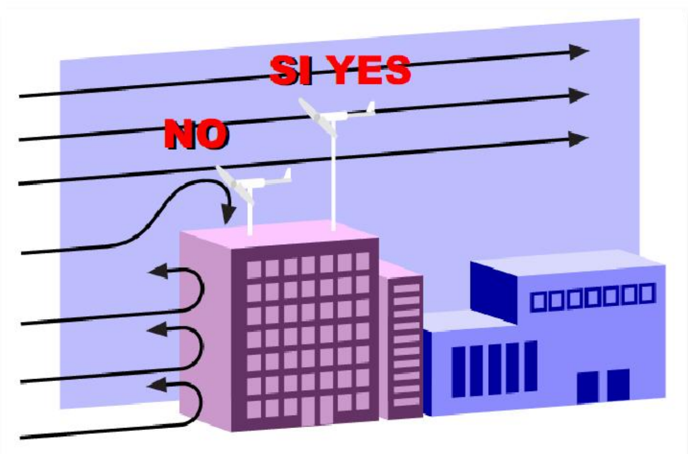


Figure 17: location of a wind turbine on the roof of a building [35]

[26] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*

1.4.2 Obstacles

Buildings and trees are obstacles which alter the course of wind and produce turbulences (air disturbed, usually low speed), so they should be taken into account and avoided for seeking the best location.

There are two types of obstacles, that let the wind passes (porous) and that don´t (non porous).

1.4.2.1. Porous obstacles

In this type of obstacles, are shrubs, trees, gates, fences, lattice towers and even other wind turbines.

It is advisable to install the wind tower between 7 and 10 times the diameter of the obstacle.

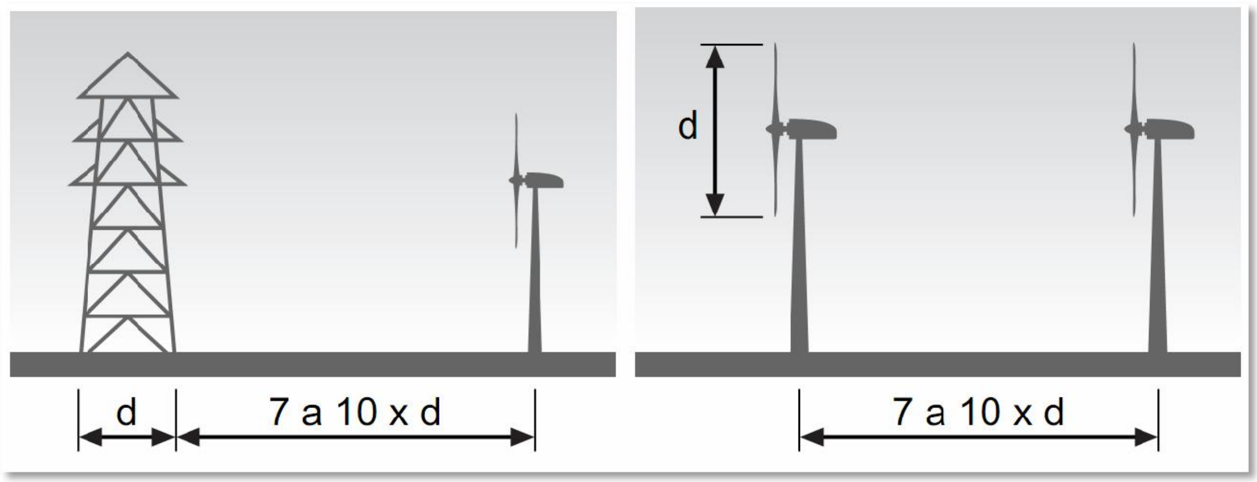


Figure 18: wind turbine separation distance for porous obstacles.[27]

1.4.2.2. Non-porous obstacles

The non-porous obstacles such as buildings and trees which do not let the wind passes make it flow over them, causing turbulence. After meeting with isolated obstacles, wind does quickly return to its speed and flow uniformity. But where are the nearby obstacles, the wind is not able to recover the normal flow behaviour and can form complex flows.

In general, the effects of non porous obstacles depend on their distance to the wind generator and their relative heights (for example, houses, walls, fences or dense trees which do not let wind pass). It is advisable to always install the wind turbine in front of the obstacle.

[27] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*

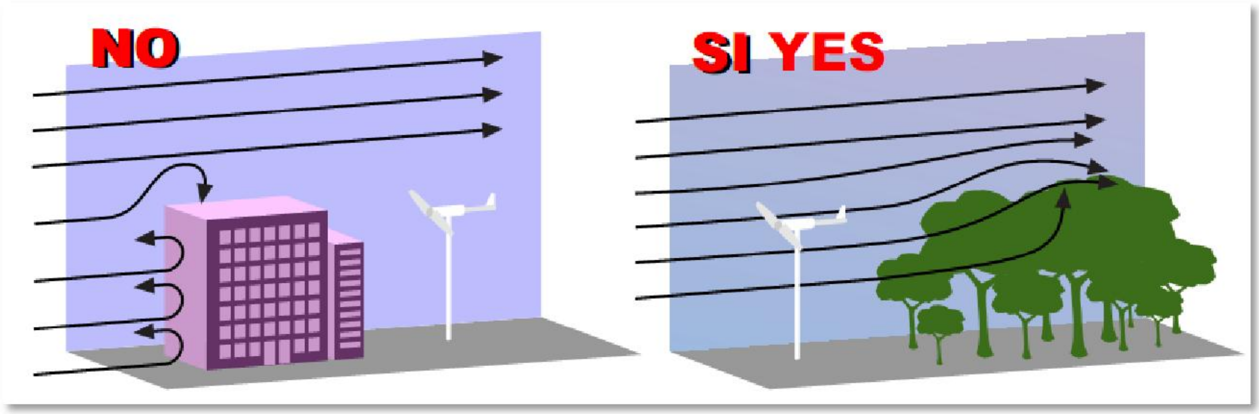


Figure 19: Small wind turbine location. [28]

If it is not possible to install in this way, the height and distance to the obstacle must be optimised to avoid the turbulent flow caused as can be seen in figure 20.

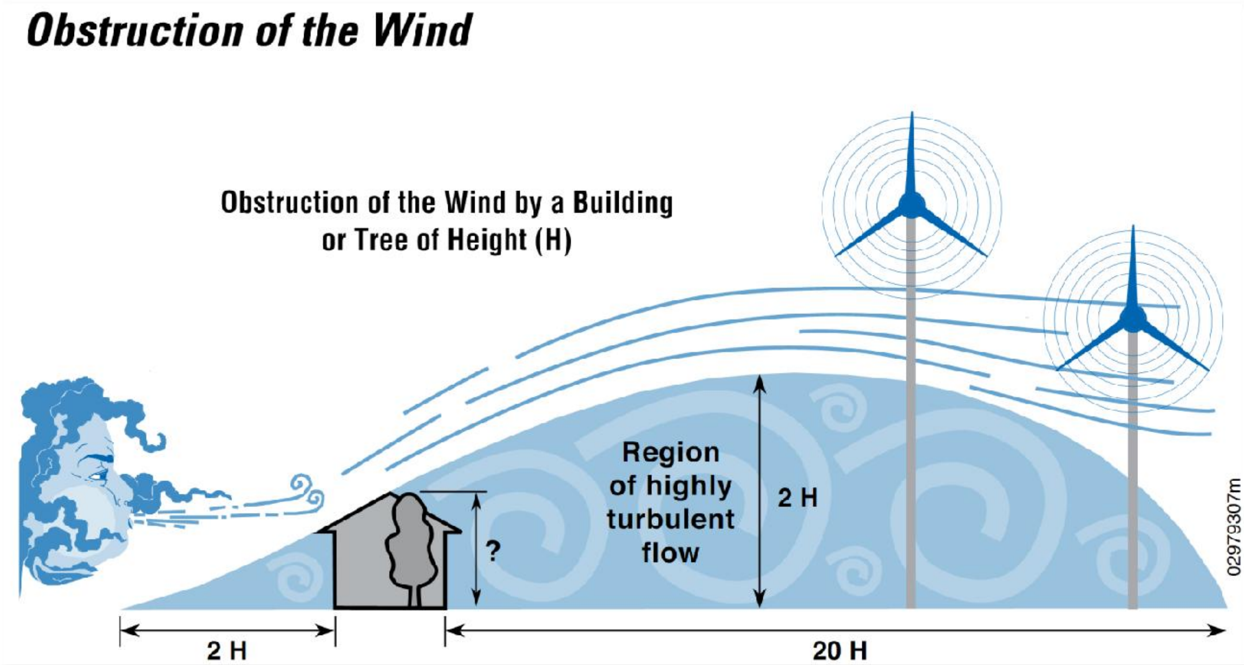


Figure 20: Required distance for the location and height recommended to avoid the turbulent flow caused by an obstacle of height H.[29]

If we know the height (H), we can estimate the horizontal and vertical distance of the wind turbine location.

[28] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*
[29] *CanWEA. Small Wind Turbine Purchasing Guide. Off-grid, Residential, Farm & Small Business Applications*

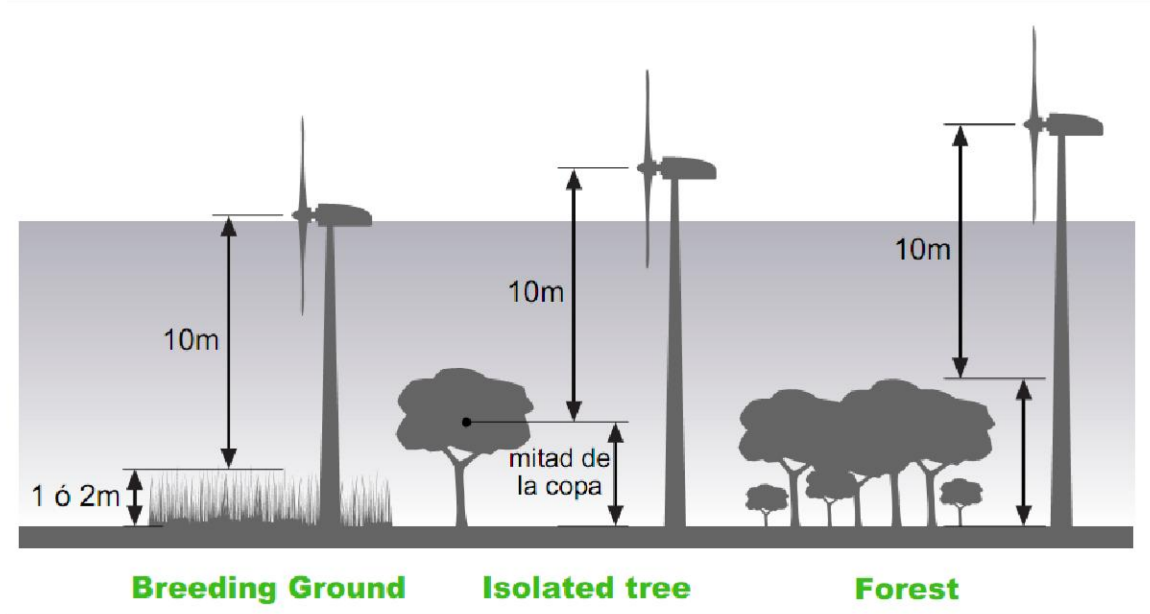


Figure 21:Height of hub according to type of obstacle.[30]

In built-up and urban areas, there are more obstacles which change the wind flow causing vertical and horizontal currents of varying speeds. Figure 23 and 24 show three usual situations and behaviour of air currents if more of one obstacle is present and depending on the distance between them

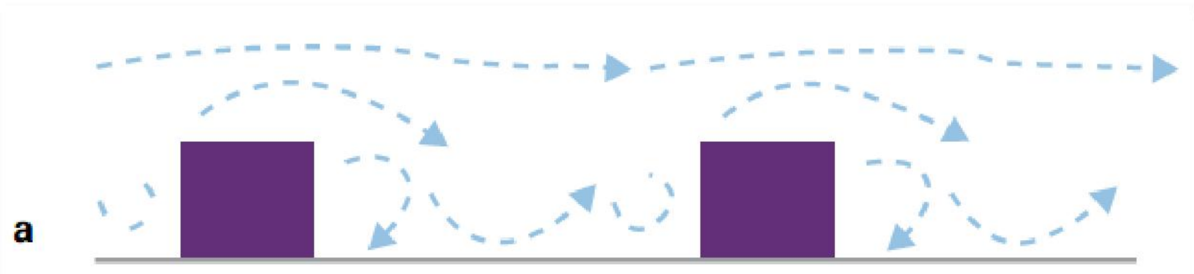


Figure 22: Buildings act as isolated obstacles. Source: Met Office (from Oke) [31]

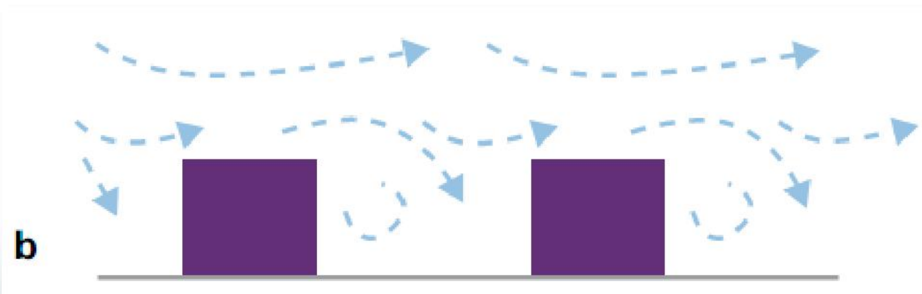
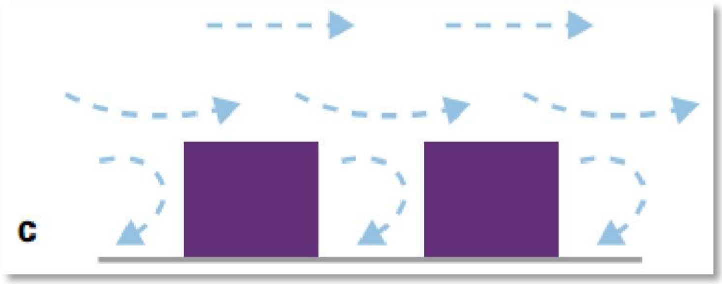


Figure 23: Flow around the downstream building is affected by the wake of the upstream building.

[30] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*
[31] *Carbon Trust. Small-scale wind energy. Policy insights and practical guidance.*

This is known as wake interference. Source: Met Office (from Oke) [32]

Figure 24: Buildings are sufficiently close that the flow above rooftop level skims over the tops of the buildings;



it appears that the ground level has been raised. Source: Met Office (after Oke).[33]

There are many studies and mathematical simulations about how wind flows around obstacles. These studies have a great complexity and diversity of situations, especially in urban environments. The following figures from one of these studies show the modelling of wind behaviour in two most common scenarios that we can find, urban areas with obstacles and rural environment with isolated obstacles.

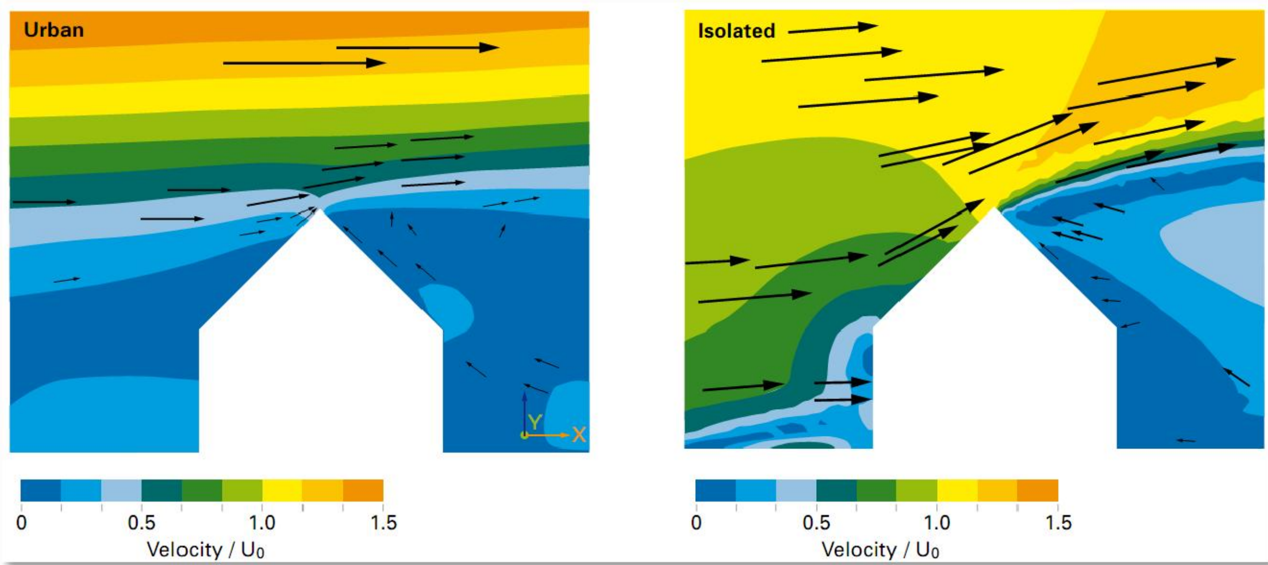


Figure 25: Results of CFD modelling of wind flows around buildings.[34]

Where there are obstacles, the wind flow passes above buildings as it were the ground. Whereas in the case of isolated obstacles the wind flow becomes more turbulent and irregular increasing its speed in certain regions according to the shape of the obstacle overcome.

In urban areas, there are two special situations:

[32] *Carbon Trust. Small-scale wind energy. Policy insights and practical guidance.*
[33] *Carbon Trust. Small-scale wind energy. Policy insights and practical guidance.*
[34] *Carbon Trust. Small-scale wind energy. Policy insights and practical guidance.*

1. When a tall building among much smaller consecutive ones. In this case the wind behaviour may be similar to that when faced with an isolated obstacle in rural environment

2. At the edge of a built up area. In this case, there are transition effects that affect the wind flow, displacing the profiles up and changing the shape. These effects generally occur in very short distances, approximately three blocks. In these cases, wind speeds decrease as one moves further toward the centre of town.

1.4.3 Influence of terrain roughness and height.

The terrain roughness, expressed in the letter "α", indicates how the wind speed increases with the height with respect to the ground. There is a logarithmic relation between the roughness and wind speed with different wind profiles for each soil.

In general, the wind speed increases with the height. In addition, the wind speed profile is more pronounced with the increase of the roughness and as the speed decreases.

The minimum roughness, or type 0 is present in aquatic environments such as the sea, while the type 3 implies near forests, urban areas, etc[35].

As the roughness and terrain of soil, the height is another defining factor in the selection and placement of wind turbines. If the terrain is rough, wind turbines will require higher height to reach the same wind speed than other smoother locations.

The increase of the wind speed with height, uncomplex terrains can be assessed by the following expression:

$$V(h) = Vo * (h/ho)^{\alpha}$$

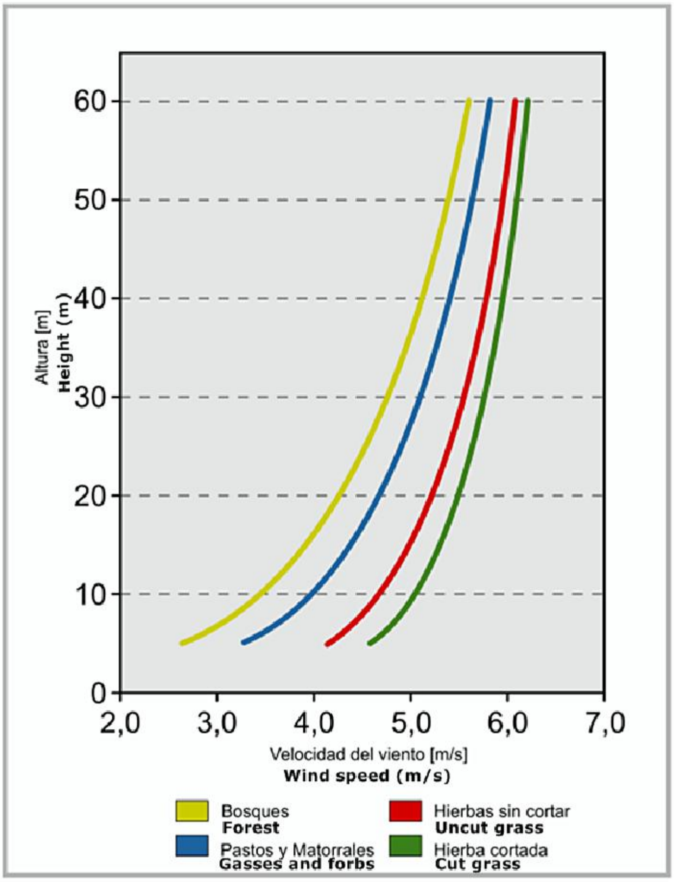


Figure 26.1: Influence of terrain roughness on wind speed [36]

V(h) = Wind speed to be estimated, at the hub height h

Vo = Known wind speed at a height ho

h = Height to which you want to estimate the wind speed

[35] *Energía Eólica.Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación, Ciencia y Empresa*

ho = Reference height
α= Value depends on the roughness is on the site (see coefficients)

Estimation of the α value for different terrains.

Type of terrain:	α
Smooth (sea, sand, snow) from	0,10-0,13
Moderate roughness (grass, crops) from	0,13-0,20
Rough (forests, buildings) from	0,20-0,27
Very rough (cities) from	0,27-0,40

Table 3 shows some examples of the type of surface compared to its roughness class and associated energy index.

ROUGHNESS CLASS	LENGTH OF ROUGHNESS [M]	ENERGY INDEX	TYPE OF SURFACE
0	**0,0002**	100	**Open water**
0,5	**0,0024**	73	**Open terrain such as airport runways, mown lawn etc**
1	**0,03**	62	**Open agricultural land, with dispersed buildings, and very smooth hills**
1,5	**0,055**	45	**Agricultural land with some plants and houses, but no higher than 8 meters and 1250m apart.**
2	**0,1**	39	**Agricultural land with some plants and houses of 8m and 500m apart.**
2,5	**0,2**	31	**Agricultural land with some plants and houses of 8m and 250m apart.**
3	**0,4**	24	**Villages, small towns, agricultural land with uneven surface**
3,5	**0,8**	18	**Large towns with high buildings**
4	**1,6**	13	**Large towns with skyscrapers**

Table 03: Wind roughness classes.[36]

To consider speed increase when the height of the tower is increased from 0 to 20 m or 30 to 60m:

$$V = (20/10)^{0.14} V_0 = 2^{0.14} V_0 = 1.1 V_0$$

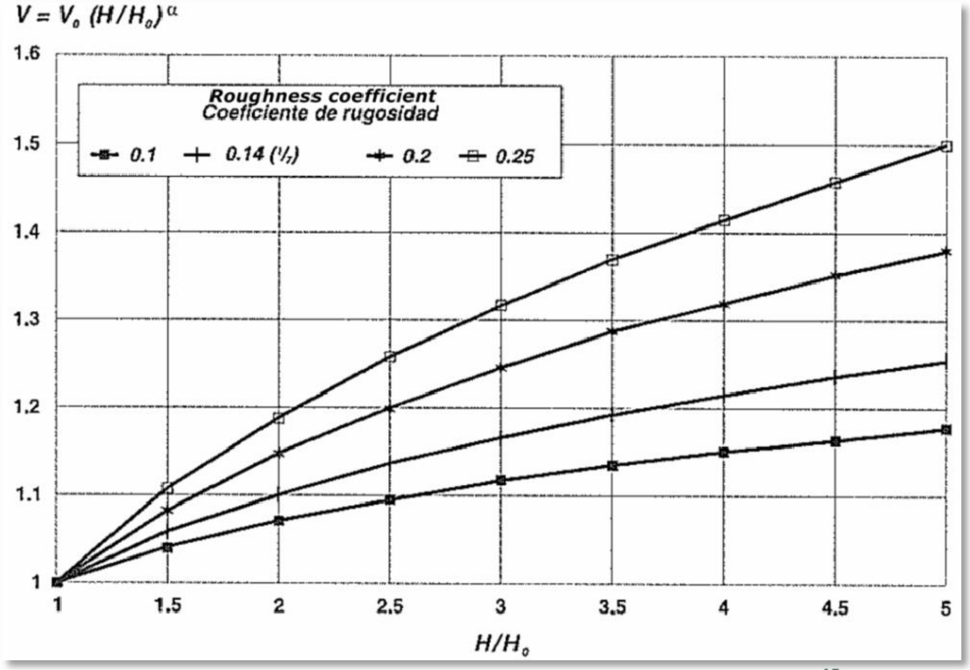
This means that in terrains where the exponential law is fulfilled, if the height of the tower is doubled, the wind speed will be increased about 10%, and wind power will also increase exponentially with the relationship being cubed:

$$P = (h/h_0)^{3\alpha} P_0 = 2^{3(0.14)} P_0 = 1.34 P_0$$

[36] *Atlas Eólico Europeo, WaSP, Risoe National Laboratory, Dinamarca. Documento "ENERGÍAS RENOVABLES. Conceptos y Aplicaciones". Santiago J. Sánchez Miño M.Sc. Energías Renovables M.E.E. Master Electrical Engineering Ingeniero Eléctrico.*

Thus wind power will increase about 34 %.

The following graphics show how to vary the speed and power in accordance with the Exponential Law and the relation of increased height (h/h_0)) for different terrain roughness coefficients:



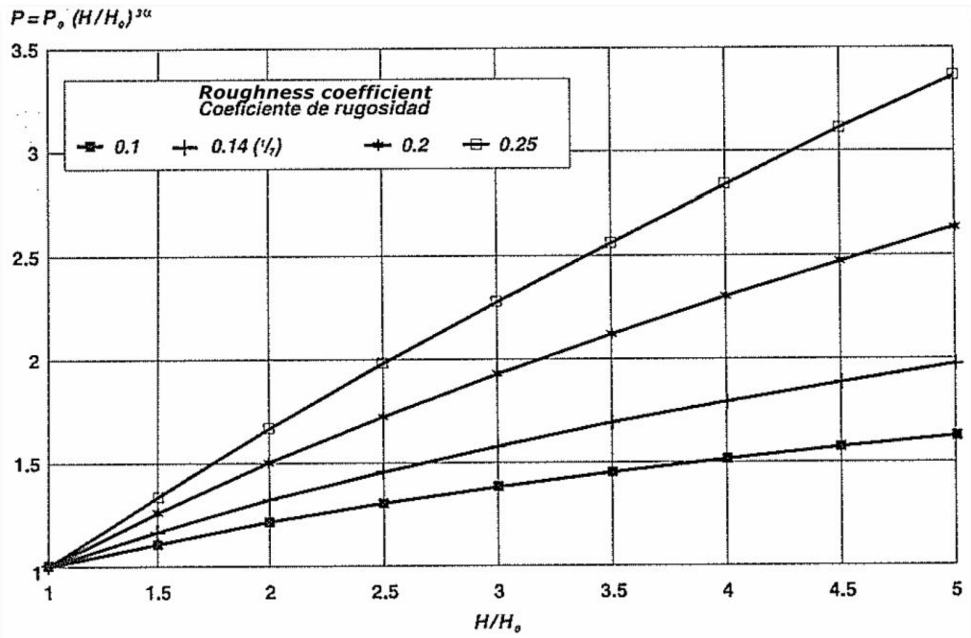


Figure 28: Increase of the power based on the relative height of the tower[38]

As we can see in the above formula, the change in wind speed based on height is dependent on terrain roughness factor. However, for small turbines, in the presence of many obstacles this law is not valid or is too inaccurate due to turbulent regimes of the wind.

[37] *Energía Eólica Práctica. Paul Gipe*
[38] *Energía Eólica Práctica. Paul Gipe*

To see how the height influences in the final production of electricity for a small turbine, with a roughness value of α = 0.14 corresponding to a moderate roughness, see table 4:

Tower Height		Wind Speed at Hub Height		Annual Output
Meters	Feet	Meters/Sec.	Miles/Hour	kWh
18	60	4.8	10.8	11,000
24	80	5.0	11.2	12,200
30	100	5.2	11.6	13,300
37	120	5.3	11.9	14,300
43	140	5.4	12.2	15,000

BERGEY WINDPOWER BWC EXCEL 10 kW

Table 04: Annual production of a 10kW generator according to the installation height.[39]

We can see that the height of the tower is multiplied by 2, from 18 to 36 m, while wind speed increased by 10% and the final electricity generation by 30%.

On the other hand, in this other picture from the web Oy Nordic AC Ltd. Focused on larger turbines, a step from 18 to 36 m in the height of the tower means an increase of 50% in the wind speed and up to 59% on increased energy production. In order to this case taken place α = 0.585 (a high value of roughness) so, in presence of obstacles the exponential relation between power and height is not fulfilled.

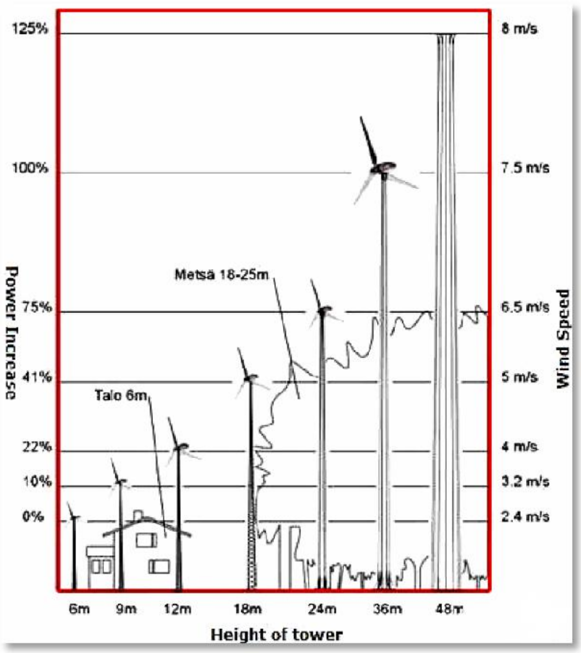


Figure 29: Variation of wind speed and energy production with height[40]

In the following figure 30, we can see how the wind speed changed with respect to the height in the two most common sceneries, rural, marine or urban environment. In urban areas the effect is that the ground level is “displaced” to the rooftops of the houses. All these factors must be considered when deciding on wind turbine placement.

[39] *IDAE “Manuales de Energías Renovables. Energía Eólica”. Pág 25. Ministerio de Industria Turismo y Comercio.*
[40] *Oy Nordic AC Ltd. http://www.nac.fi/index.htm*

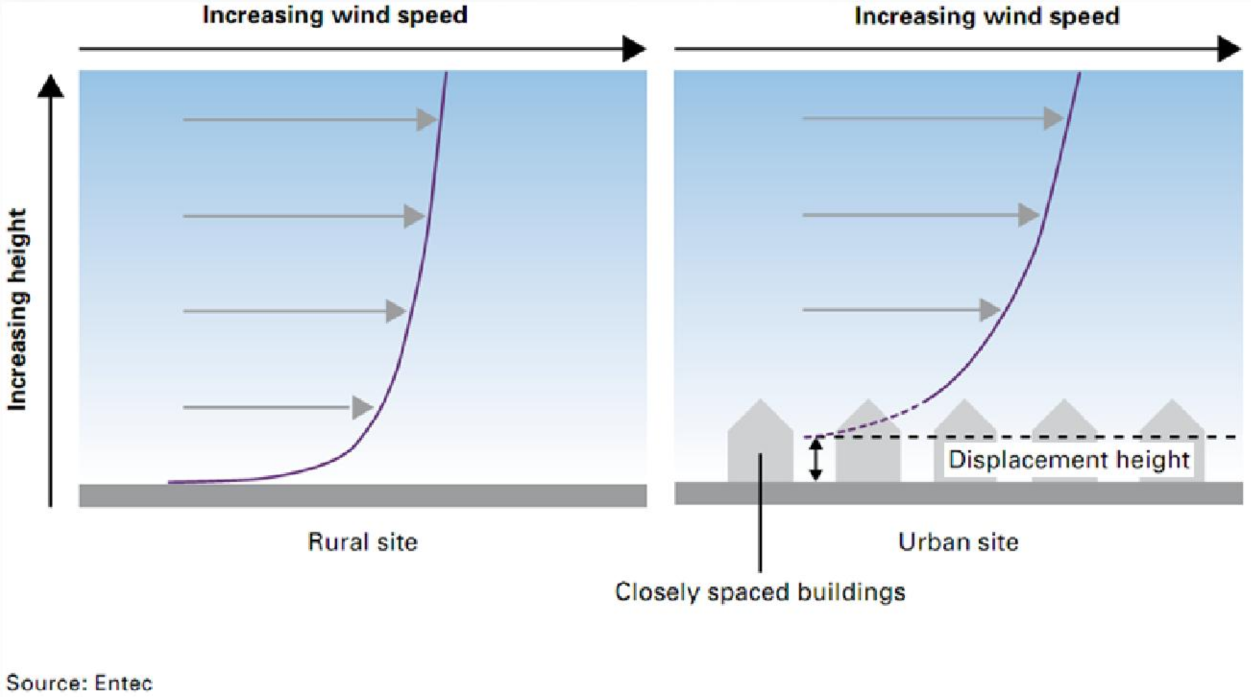


Figure 30: height variation in rural and urban environments[41]

1.4.4 Wind Roses

A wind rose is a way to express the two main datas of wind speed which are: the speed in meters per second [m/s] and the direction in degrees [°].

The wind rose is essential to determine the installation location.

1.4.4.1. Wind rose of directions

Its main use is to provide the direction or main directions with their frequency in a circular diagram. This allows to place the wind turbine in the best location. In the example, the dominant direction is NNE which must be free of obstacles.

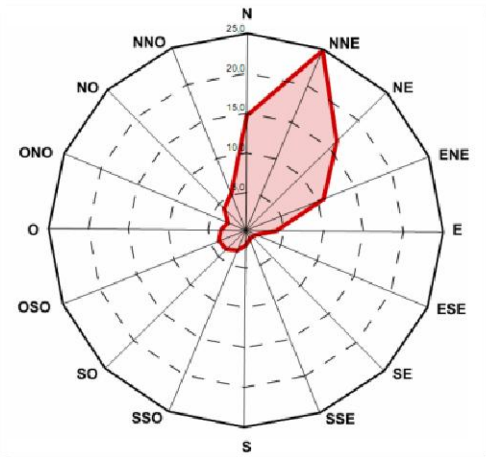


Figure 31: Wind rose example

[41] *Carbon Trust. Small-scale wind energy. Policy insights and practical guidance.*

1.4.4.2. Wind rose of power

If is not clear which is the prevailing wind, we can use a diagram that shows the main directions of maximum power, being the power proportional to the cube of wind speed.

In this case, although there are two dominant wind directions, NNE and SE, is the second one which provides greater power. However, one must take into account the NNE in the final location of the wind turbine.[42]

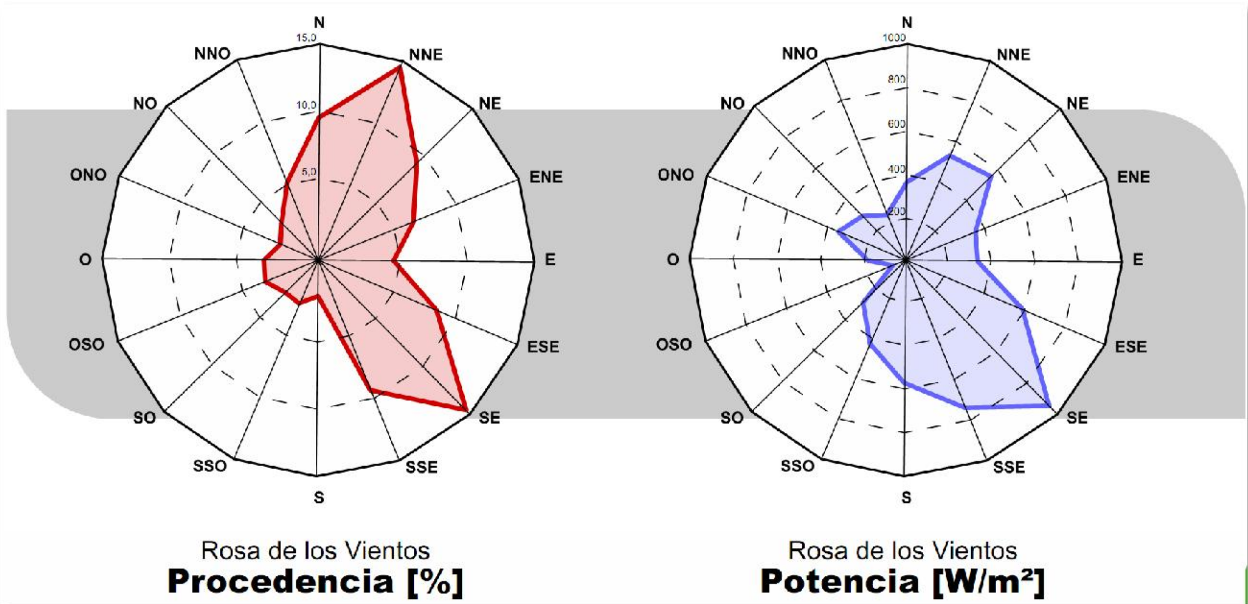


Figure 32: Power rose example[43]

1.4.5 Weibull distribution.

It is important to know the wind direction and power in a location, the possibility or frequency of repetition in a specific wind speed within a period (day, week, month or year).

Figure 33 shows the measurements of wind for a day with an interval of 10 minutes:

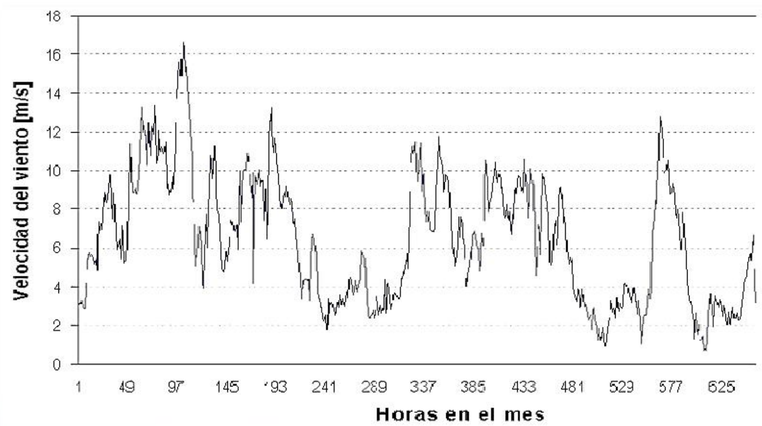


Figure 33: Measurements of wind speed during a month[44]

[42] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*
[43] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*
[44] *ENERGÍAS RENOVABLES. Conceptos y Aplicaciones. Santiago J. Sánchez Miño M.Sc. Energías Renovables M.E.E. Master Electrical Engineering Ingeniero Eléctrico.*

If we count the number of times in which the speed during this period is between 0.5 and 1.5 m/s, between 1.5 and 2.5 m/s we obtain a velocity distribution curve that is shown in figure 34 below where the vertical axis indicates the frequency or percentage possibility and the horizontal axis, the velocity ranges or "bins". The sum of the percentages of each range is 100% (of the measurements).

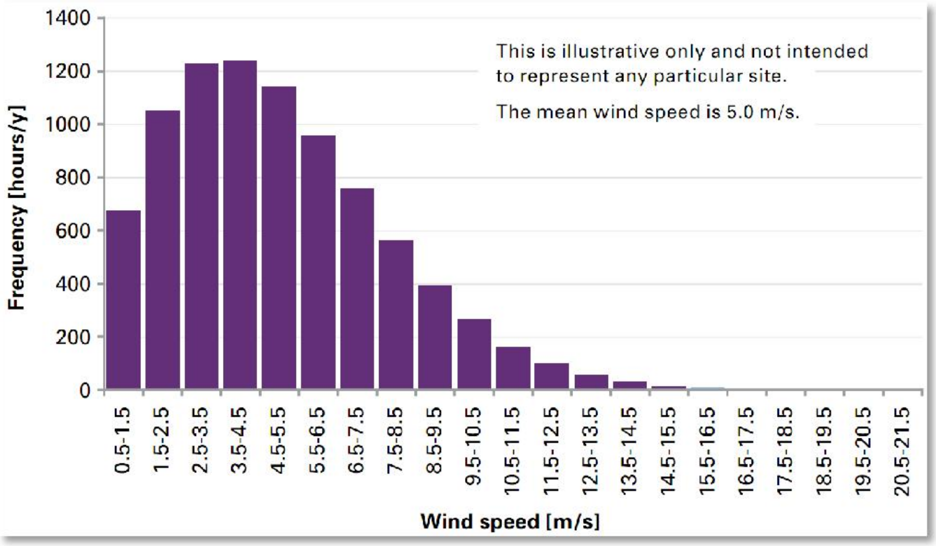


Figure 34: Distribution of wind speeds for intervals of 1 m / s for a year.[45]

This is the way to represent the wind potential of a specified location depending on the wind speed and the frequency of occurrence of each value through the **wind frequency distribution curve**. This curve represents the **Weibull distribution** curves so it is usual to find the definition of the wind resources at a site.

Weibull distribution is defined by two parameters, the scale factor c (or A in some texts) that gives us the value of average speed and the shape factor k that gives us an idea of how narrow or biased to the left (towards zero) is the curve and can vary between 1 and 3.

If k = 3 the curve is a normal distribution of probabilities.

When k = 2 is also known as Rayleigh distribution.

The left figure shows the Weibull curves of probability distribution for three sites where you can see the different behaviour of the wind and whose parameters of the Weibull distribution.

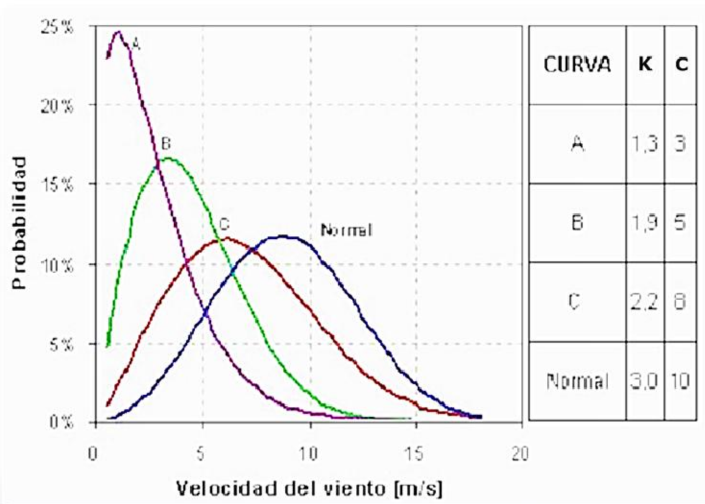


Figure 35: Weibull distribution for three sites and Normal distribution curve [46]

[45] *ENERGÍAS RENOVABLES. Conceptos y Aplicaciones. Santiago J. Sánchez Miño M.Sc. Energías Renovables M.E.E. Master Electrical Engineering Ingeniero Eléctrico.*

Figure 36 shows the effects of a change the form of the curve maintaining C=1 and changing the value of K.

When we carry out a study about wind resource for a site, we obtain a Weibull distribution typical of this site. If the conditions of the site are similar to another, they can have similar Weibull distributions but the values can change, so it is advisable to carry out a study of every site.

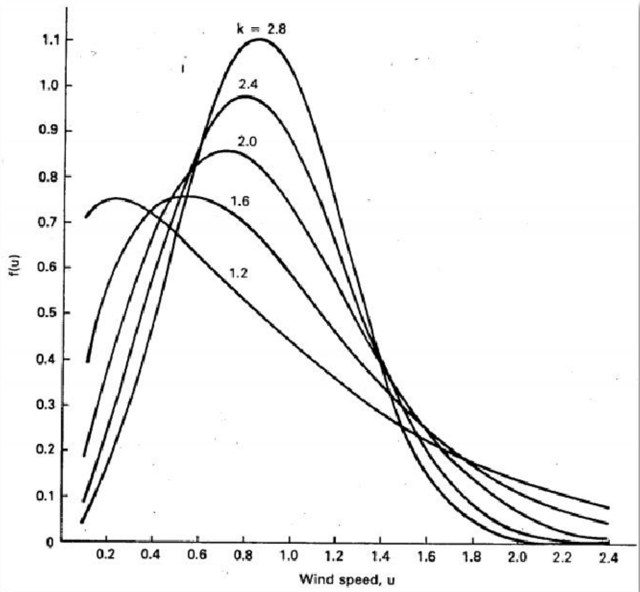


Figure 36: Weibull distribution for C=1[47]

1.4.6 Wind potential studies and maps

The idea of a wind study and maps is to predict and evaluate what will be the potential of wind at any point of the earth's surface by direct measurements or mathematical estimations.

A wind study is a detailed study of the atmospheric conditions related to the wind potential, maximum and minimal speed, averages, direction, frequencies, regime, density, etc … of a certain location or region; and the wind maps, therefore, are the graphical representations of information obtained in this study which identify and locate the wind potentials depending on the predominant or average windspeed at a certain height. The ranges of the considered speeds and the geographical resolution will be defined by the precision and factors considered in the mathematical estimations and/or the field measurements.

1.4.6.1. Relevant Studies and projects on miniwind.

This paragraph will show some of the interesting projects that are implemented in the European territory in relation to the development, promotion and integration of the small wind technologies.

a) First of all, it is necessary to mention the WICO project. The complementarity between Rural-RES and this project is particularly interesting because both projects develop the implementation of wind energy in different territorial areas: those of mountain and rural (Rural-RES Project); coastal areas (WICO Project). WICO project is

[46] *ENERGÍAS RENOVABLES. Conceptos y Aplicaciones. Santiago J. Sánchez Miño M.Sc. Energías Renovables M.E.E. Master Electrical Engineering Ingeniero Eléctrico.*

[47] *Wind Energy Systems by Dr. Gary L. Johnson*

part of the POWER programme which is dependent on the European Programme of Territorial Cooperation INTERREG IVC.

b) In relation to other projects carried out in the European territory, it is interesting to highlight the **Warwick Microwind Trial Project**, whose main aim was the evaluation and monitoring of 23 small wind installations during an approximate period of 12 months placed in roofs in different territories of United Kingdom.

The main aim in this project was to obtain information in field of the wind turbines operation in real cases by measurements of variables such as the wind speed, direction and actual power output. These details provide reliable information about the real performance of this technology and allow checking that the installations and applications for each type of wind turbine are appropriate.[48]

Among other projects about the small wind energy we can highlight these:

c) In Spain, and in the small wind sector, there are projects being carried out by CIEMAT (Energy, Environment and Technology Research Centre) and specifically PSE-MINIEÓLICA Project[49]

This project is a multi-year project of research and development focused on the improvement of the domestic sector dedicated to the development of small wind power technology, both for isolated applications and electrical grid connection, considering that small power turbine technology has a rated power less than 100 kW. It is expected to last five years (2005-2010) and in its development involves up to 20 participants between the consortium partners, manufacturers, technological and research centres.

1.4.6.2. Regional and National project

For your regional and national project see the Training Package section in the Training section of the RuralRES website. For example the Andalusian Energy Agency has developed a new initiative called SEDAMIS. It is a useful web application for installers and users of isolated mixed facilities, which provides information on the operation of their monitored installations, creating a network of installations that provide online information on production data and real wind data in the different locations.

[48] *Available in: http://www.warwickwindtrials.org.uk/3.html*
[49] *Available in: http://minieolica.ciemat.es/MINIEOLICAportal/*

Figure 37: Screenshot of the tool / wind map of the AAE (Andalusian Agency of the Energy) [50]

In the following image there is an example of the public information that can be visualized of each installation. In this case it corresponds to the red circle in the previous image:

[50] http://www.agenciaandaluzadelaenergia.es/sedamis2/libre/index_libre.html

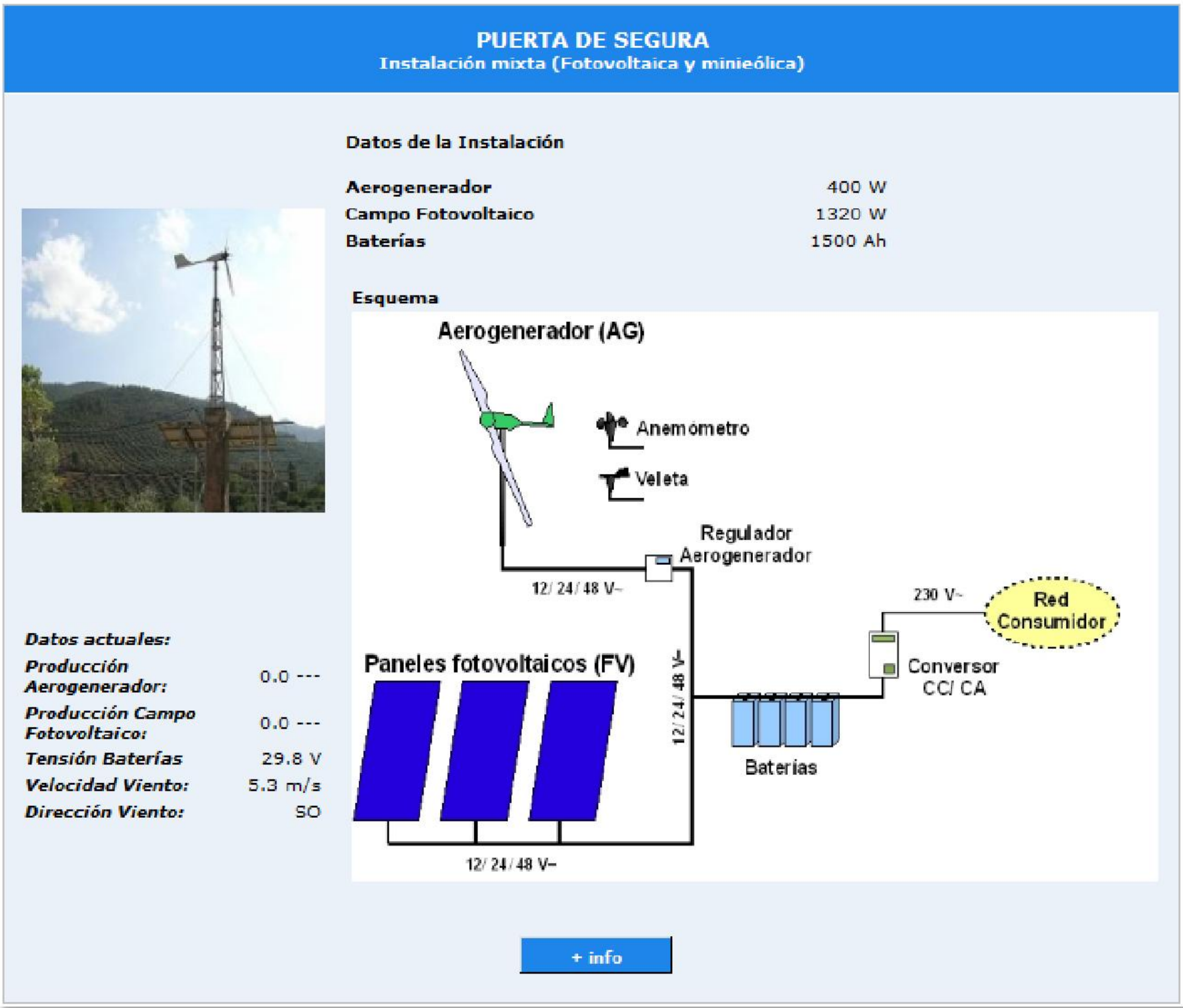


Figure 38: Screenshot of the tool SEDAMIS of the AAE (Andalusian Agency of the Energy).[51]

[51] http://www.agenciaandaluzadelaenergia.es/sedamis2/libre/datos/informe_instalacion.jsp

1.5 REGULATORY FRAMEWORK.

1.5.1 At European and International level

The European Directive 2009/28/EC on the promotion of the use of energy from renewable sources, this Directive establishes the obligation to rationalize and accelerate administrative procedures of authorization and connection to distribution networks and electricity transmission, urging simplified authorization procedures. It regulates the general rules for grid access and their operation in relation to renewable energy, taking into account their future development. This directive revokes the previous one which set the aim of achieving 12% in the contribution of primary energy in the EU for 2010, establishing that at European level 20% of final energy consumption for the year 2020 will come from renewable energy sources .

Directive 2009/72/EC concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC

Art. 2.31. Distributed generation means generation plants connected to the distribution system.

Art, 36.d. The regulatory authority will help to achieve, in the most cost-effective way, the development of secure, reliable and efficient non-discriminatory systems that are consumer oriented, and promoting system adequacy and, in line with general energy policy objectives, energy efficiency as well as the integration of large and small-scale production of electricity from renewable energy sources and distributed generation in both transmission and distribution networks[52]

Directive 2004/8/EC on the promotion of cogeneration, whose aim is to increase energy efficiency and improve security of supply by creating a framework for the promotion and cogeneration development of high efficiency of heat and power based on useful heat demand and primary energy savings, taking into account specific national circumstances. One of the aims cited in this Directive, is the promotion of small installations.

With regard to international standards, is the International Electrotechnical Commission (IEC) standards relating to wind turbines:

IEC 61400-1 – Technical requirements for the security and design of wind turbines. This rule applies to all types of wind turbines located on land.

IEC 61400-2 – Applicable to small wind turbines: those with area less than 200 m² rotor (radius <8 m) and lower voltage generation to 1,000 V for alternating current and 1,500 V direct current.

IEC 61400-12 – Related to power curves.

[52] *www.mityc.es/energia/.../Propuesta_RD_Conexion_instalaciones_pequeña_potencia.pdf*

IEC 61400-11 – Related to noise measurement.

IEC 61400-13 – Related to measurement of mechanical loads.

IEC 61400-22 – Related to certification of the wind turbines.

IEC 61400-23 – Related to structural testing of rotor blades

IEC 61400-21 – Related to power quality.

1.5.1. At national level

Legislation and Regulations varies greatly between countries with the European Union, despite efforts for harmonisation. Each RuralRES partner has uploaded in the Training part of the RuralRES website (http://ruralres.diphuelva.es/index.php) a training package relevant to each partner country, which contains peritent national legislation and norms.

1.5.2. At regional level

Similarly at regional level there will be even more variations, although most of the legilsation is national. For RuralRES territories, this information is also available in the Training section of the RuralRES website. (http://ruralres.diphuelva.es/index.php)

1.6 MAIN BARRIERS TO DEVELOP MINIWIND TECHNOLOGIES

The barriers to the development of small wind differ widely from one country to another. While the technological development is similar in all cases, the cost per kWh produced differs significantly between them as well as market development, implementation and policy and administrative regulation. For example, domestic manufacturers in Spain are having big difficulties with the local market due to difficulty in grid connection, at a time and when business incentives are emerging in other countries with high growth potential (especially in USA, where there are 66 manufacturers, Japan, Canada, UK, Germany and China have more than a dozen).[53]

There follows some of the general barriers common to most countries that can arise in the case of miniwind turbine installations. Depending on the national legislation, social environmental awareness and quality of turbines mounted in your country, these will vary in importance from country to country.

1.5.3. Legislative and Administrative Barriers

[53] *Presentación del IDAE "La mini eólica en España. Marco regulatorio, situación y perspectivas. Juan José Romero Zamora. 21 de mayo de 2010*

In many instances the legal process is excessively complicated and lengthy. In some countries (such as Spain) there is currently no differentiation between small-wind turbine installations and large wind turbine installations. What this means is that the same legal process needs to be followed to obtain permission for a 1 kW turbine as for are wind park of 20 MW. In other countries (such as Italy and UK), there is a differentiation between the two for planning purposes with deadlines to which the local authority should adhere. But the reality is that these deadlines are not met. In others such as the UK and Sweden the planning procedures are usually quite quick and various small-wind specific legislation, however the requirements to qualify for feed-in tariffs some consider excessively strict.

Each country will have its own pitfalls either insufficient legislation, excessive legislation, or simply that the legislation is not being correctly and intelligently implemented.

Planning law will clearly very distinctly between countries and regions and locally. However more or less the same issues will always have to be addressed so. For example: the permitted height of the turbine; the length of time to process an application; the limit for turbine capacity; certificates from the installer; certificates for the wind turbine; noise nuisance; flicker issues; social impact; current designated land use category; building regulations.

Dealing with planning permission for small-wind turbines is a particularly sticky subject especially when there is no specific reference in local planning law to small-wind. Some countries are introducing specific guidance and legislation to take this technology into account, however in most cases it is the local municipal officers that must resolve the issues. This brings up a significant issue that there is a real lack of training and information on small-wind for local and regional municipal officers.

Again environmental law will be different depending on your locality. However the environmental laws are usually national, the majority of which will have been drawn up following European Directives. The environmental impacts of a small wind turbine installation are minimal yet such installations often get confused with larger wind Parks due to a lack of knowledge and misperception. Where there are no specific inclusions or articles regarding small-wind turbines in environmental regulations, it's categorisation alongside its larger sister can result in failed applications or very long delays which may render the investment unviable. For example, in Andalusia, the same environmental law (GICA) applies to both small and large turbines when they are to be connected to the grid. As a result, there are no cases of legally installed small-wind turbines connected to the grid in Andalusia. Requiring an environmental impact assessment for a small installation is clearly ridiculous but without laws that differentiate between the two types it it is inevitable that environmental officers and planning officers will find decision-making extremely difficult.

1.5.4. Financial

In general the price per kWh of electricity from a miniwind installation is considerably higher than the cost of electricity form the grid today. Therefore in order to be viable, some form of financial incentive is usually necessary to compensate for its comparate expense when compared to conventional sources of energy.

One of the biggest financial barriers to the uptake of small renewable installations is the high up-front capital investment costs. This is particularly poignant when Net Present Value and Internal Rate of Return financial studies are performed with significant discount rates. The up-front cost has a higher weighting than the future benefits. Therefore financial assistance is justified to facilitate deployment of renewable energy technologies, and various innovative financial mechanisms can be developed to reduce the cost differential between conventional and renewable technologies, and address investor concern about high initial capital costs.

1.5.5. Social perception

Society's perception is a key aspect in the introduction of any new technology. It must be met with favour, in particular by local people, if its development and success are to be assured. Much of Society today has a relatively high environmental awareness, thanks to many years of campaigns and the media coverage that Climate Change receives. Very few people would consider themselves "against" renewable energy. However, despite this Wind power is not without its critics and is often victim of a significant degree of negative perceptions. This is due to various reasons, for example: genuine issues; lack of knowledge; negative propaganda by vested interest; lack of compromise. Main criticisms of wind turbines:

- **Visual Impact**

Visibility of miniwind turbines, because they will be mounted on tall towers for performance reasons, is unavoidable. However, this is not the same as visual impact. Society is used to seeing electricity and telephone pylons, water towers, mobile phone transmitters dotted all over the countryside and towns. The relative impact of small wind turbine installations, will be minimal. However, as it is perception that we are dealing with, care must be taken, especially in visually sensitive areas, for example protected areas, ridgelines etc. Inappropriate siting of an installation could generate conflicts between residents, municipal officials and small wind turbine owners.

- **Noise**

Noise impacts from miniwind turbines is only usually an issue on roof-mounted turbines. Any turbine producing over 60dB in normal wind conditions probably has a technical problem. The majority of modern small wind turbines have been designed to be very quiet, for instance by having direct drive systems to avoid gear box noise and to increase efficiency. In general, the wind itself makes more noise than a wind turbine. It is most unlikely that any noise from miniwind turbines will be heard at more than 50 m.

- **Threat to wildlife**

Large wind turbines have had bad press regarding their impacts on birdlife, particularly migratory birds. Quoted from the RSPB website:

"Poorly sited wind farms have caused some major bird casualties, particularly in Tarifa and Navarra in Spain, and the Altamont Pass in California. At these sites, planners failed to consider adequately the likely impact of putting hundreds, or even thousands, of turbines in areas that are important for birds of prey. Tragically, killing many hundreds of birds as a result. If wind farms are located away from major migration routes and important feeding, breeding and roosting areas of those bird species known or suspected to be at risk, there is a strong possibility that they will have minimal impact on wildlife."
(http://www.rspb.org.uk/ourwork/policy/windfarms/index.aspx)

1.5.6. Safety and Reliability

Due to the lack of accreditation and international standards for small wind turbines, the industry is plagued by certain issues, as highlighted by R&D experts of the International Energy Agency 49th Topical Expert Meeting:

Although turbines should be designed to last for at least 10 years service and often much more, many do not live long due to technical failures or excessive need for maintenance.

They frequently have misleading or non-existent noise data and are not designed according to existing safety standards and have caused accidents.

Some may even be illegal to use, because they do not fulfil legal product requirements.

Chapter 2

MINIWIND ENERGY SYSTEMS

2. MINIWIND ENERGY SYSTEMS

2.1 STATE OF THE ART: SMALL WIND TURBINES

Wind turbines are devices which transform the kinetic energy of the wind into mechanical energy. The aerodynamic principle for which a set of blades turns is similar to the one that makes the planes fly. According to this principle, the air is forced to flow through the top and bottom sides of the low profile, generating a difference of pressures between its two sides which gives rise to as a resultant force that acts on the profile.[54]

If we separate this force into two directions, we get:

- Lift force, or this force that is perpendicular to the oncoming flow direction.
- Drag force, parallel to the wind direction

Depending on how the blades are assembled to the wind and axis of rotation, the force that will produce the torque motor will be drag or lift force. With the exception of vertical axis windmills, nowadays in all wind turbines the dominant force is that of lift due to allows to obtain, with less weight and cost, higher power per unit of rotor area.

In order for a wind turbine to switch on, a minimum value wind speed is necessary to overcome friction and to begin to produce useful work. This minimum value is called cut-in wind speed without which, typically between between 3-5 m/s. From this point the rotation begins becoming the kinetic energy into mechanics, until it reaches the nominal power, usually the maximum that it can deliver. Then it will begin to perform active or passive mechanisms of regulation to ensure the machine works under conditions for which it was conceived. It will continue to operate until it reaches the cut out wind speed, where for security reasons, it stops normally around 25 m/s. [55] [56]

[54] *BASTIANON, Ricardo. Energía del Viento y Diseño de Generadores Eólicos de Electricidad e Turbinas Eólicas. Edit. Tiempo de Cultura: Argentina. 1992.*
[55] *Solarpedia. Energía eólica*
[56] *WARNE D.F; Generation of electricity from wind. I.E.E. review, vol. 124,numero 11 R, nov 2002*

2.2 ADVANTAGES AND DRAWBACKS OF SMALL WIND ENERGY SYSTEM

Advantages

- *As with large wind turbines, the energy source is renewable and inexhaustible.*
- *It is a clean and green technology so it does not generate CO2 and toxic emissions in the generation of energy*
- *It works at ambient temperature: refrigeration systems and boilers are not necessary.*
- *It supplies electricity in isolated and remote places away from the power grid and can pump water providing the necessary mechanical energy without the need to for electricity.*
- *It causes less visual impact than in the large wind turbines generally rising to maximum heights of about 30 m in wind turbines of more than 100 kW. It can be installed in rural, industrial and urban areas through existing infrastructure, without deteriorating natural landscapes.*
- *It generates energy close to the point of consumption, and hence reduces the losses of transport and transformation estimated to reduce by over 10 % of final energy supplied.*
- *It is accessible to many users, hardly without civil works and its installation is simple. It can be considered that installations with wind turbines with power of less than 100W can be installed by anyone with minimal technical knowledges.*
- *It encourages the awareness at personal level of the energetic problem providing energy self-sufficiency. It produces clean energy, on a small scale in a distributed and sustainable way.*
- *The technical requirements, of planning and administrative processing are minor compared to those of large wind generators, except exceptional cases in which specific regulation does not exist.*
- *It can generate local employment in manufacturing, installation and maintenance. It encourages the development of a wide market-scope, from manufacturers and developers, dealers, installers and designers. It promotes scientific, technological, industrial and economic activities.*
- *It connects to LT (low tension), similar to photovoltaics. In the hybridisation, the small wind-photovoltaic energy complement each other perfectly: the peaks of operation both happen in different stages of the year and of the day.*
- *In developed countries, where the conventional network has a majority implementation, the application of the small wind is glimpsed as a great possibility for worldwide market.*
- *In developing countries there is a high percentage of areas without access to conventional network, so it is possible in both applications: grid connection wherever there is conventional network and isolated hybrid systems where there is no such access.*
- *Its development is modular allowing its growth depending on the demand without requiring large initial investments.*

Disadvantages

- *It is normally used in places with low annual average wind speeds because the installation site is often not optimal.*
- *The price of the technology is high due to lack of mass production.*
- *It is installed at low altitudes where wind speeds are lower and is submitted to a more turbulent flow regime.*
- *In the case of installations in urban areas, as well as turbulent flow, roofs are often inclined, and there are usually multiple obstacles around.*
- *The emission of acoustic noise and the vibrations must be low due to the nearness to the point of end use.*
- *Accreditation, certification and quality control are not well developed in many countries.*
- *There is an uncertainty when estimating the appropriate size of a small wind installation with accumulation due to the several factors and elements involved.*

2.3 THEORETICAL BACKGROUND

Although the miniwind systems in terms of their characteristics, elements and applications are different from the big wind, they share the same basic physical concepts and design parameters.

One of the most interesting links that publishes detailed information on all technical aspects of wind turbines is http://guidedtour.windpower.org/en/core.htm. This page is not specific in small wind turbines, but you can do a technical tour in 5 different languages (Danish, German, English, Spanish and French).

2.4 TYPES OF WIND TURBINES

Depending on the position of the axis of rotation of the wind turbines with regard to the wind direction, there are two big groups:

Horizontal axis wind turbines (HAWT) Rotation axis parallel to the direction of the wind. This type of wind turbines can be classified according to their rotational speed which is: slow, fast and medium speed.

Vertical axis wind turbine (VAWT) Rotation axis perpendicular to the direction of the wind and there are two basic designs: Savonius and Darrieus (see Figure 39).

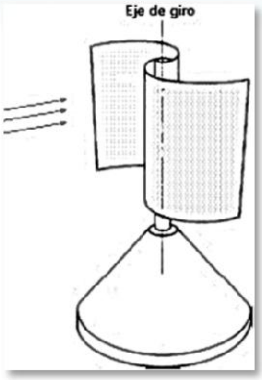
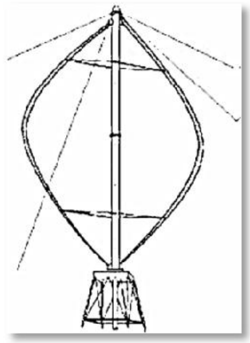
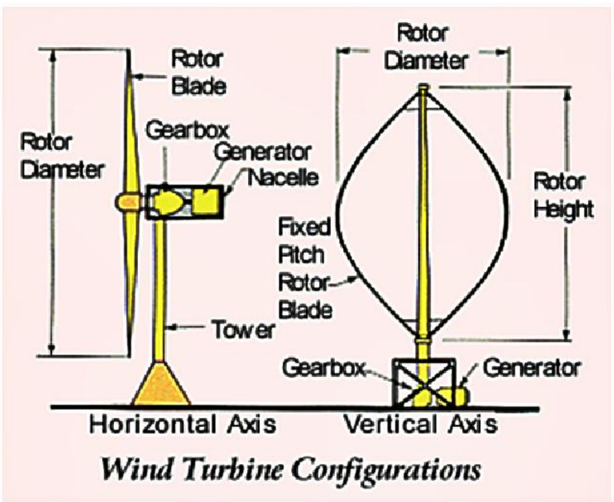
a)  b) 

Figure 39: Types of vertical axis wind turbines (a) Savonius and (b) Darrieus.[57]

Vertical axis wind turbines have some advantages over horizontal axis ones. Due to their vertical symmetry, they do not need a guidance system to align the axis of the turbine with the wind direction. Its maintenance is easier due to his lack of height from the ground and for ones that work at a constant speed, it is not necessary to include any mechanism for pitch change and has a lower cost of installation. But not all are advantages because some need a starter motor, have lower rotation speed and in general their efficiency is much less than the horizontal axis machines of the same power.[58] [59]



The technological improvements which have been developed in horizontal axis wind turbines have not been mirrored in the development of vertical axis wind turbines. However, on a small scale, these wind turbines are becoming competitive with the horizontal axis wind turbines considering the advantages mentioned above. They are particularly interesting for urban applications.

Figure 40. Possible configurations of the wind turbines.

[57] *Instituto Para la Diversificación y Ahorro de la Energía (IDAE);* ***Manuales de Energías Renovables (Energía Eólica)*** *Edición Especial Cinco Dias; 1992.*
[58] *SPERA David.* ***WIND TURBINE TECHNOLOGY.*** *Edit. ASME press; United States; 1994.*
[59] ***Aerogeneradores: ¿Cuántas palas?****; Actualizado el 3 de enero 2001; disponible en: http://www.windpower.org/es/tour/design/concepts.htm*

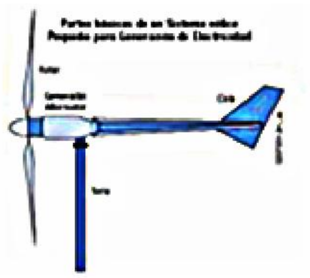
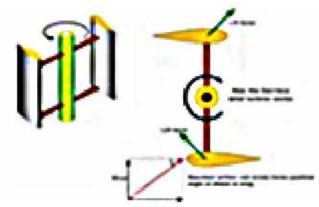
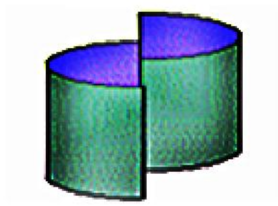
	HAWT	VAWT	VAWT
		 DARIEUS.	 SAVONIUS.
ADVANTAGES	*Efficient* *Tested and widely used* *Cheaper* *Wide variety of products*	*Low efficiency* *Orientation without wind* *Less sensitive to turbulence* *It produces less vibration*	*Product tested* *Silent* *Reliable and Robust* *Orientation without wind* *Less sensitive to turbulence than the horizontal axis* *Produces less vibration*
DISADVANTAGES	*difficulty to withstand the frequent yawing and shaking of turbulance*	*Insufficiently tested* *Much more sensitive to turbulence than the Savonius*	*Low efficiency* *Comparatively uneconomical*

Table 05. Comparison between different types of wind turbines[60]

The following tables show a comparison between the different models and technologies according to an analysis carried out by the loopwing wind turbines producers:

Comparison of Wind Turbine

Turbine Type	Blade Shape	Start	Max Efficiency	Tip Speed	Noise (tip vortex)	Shaft Vibration (torque imbalance)	Tower Vibration (Gyroscopic moments)
Propeller	Knife	Power Assist	High	High	Large	None	Large
Multiple	Knife	Self Start	Mid	Mid	Small	None	Large
Vertical	Knife	Power Assist	Mid	High	Large	Large	None
Svonius	Knife	Self Start	Very Low	Low	None	Large	None
Loopwing	Globe	Self Start	High	Mid	None	None	None

[60] Ciemat. ***Sistemas Eólicos de pequeña potencia: I+d+i***. 2008

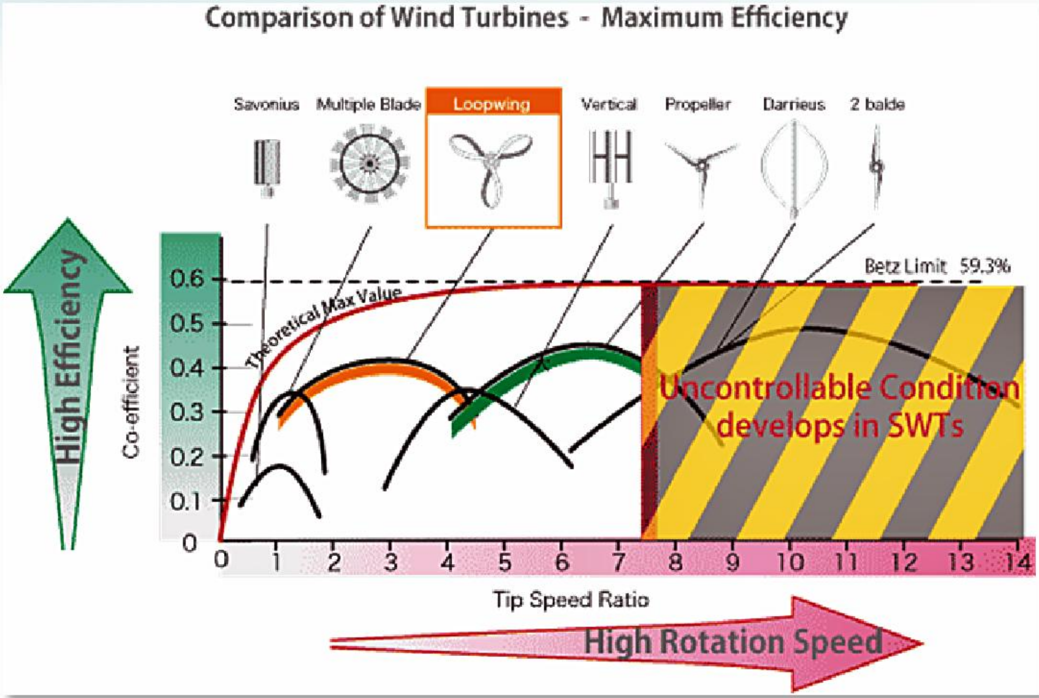


Table 06. Comparison between types of wind turbines.[61]

2.5 WIND TURBINE COMPONENTS.

The low potential wind turbines have a similar structure to the big ones, just that their design is more simple. As in general, the most used wind turbine is horizontal axis type, there follows a description of the major components of this type of wind turbines[62] [63](Figure 41).

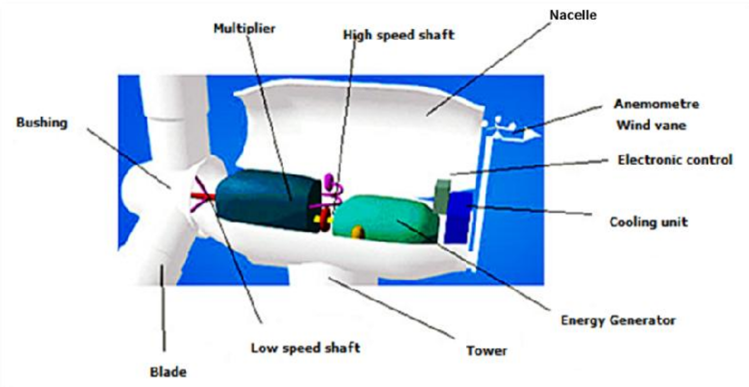


Figure 41: Components of a horizontal axis wind turbines.[64]
Anemometer and wind vane

[61] *http://www.loopwing.co.jp/en/entop.html*

[62] *BASTIANON. Ricardo. Diseño de un Aerogenerador: Adaptación Óptima Entre la Velocidad de Giro de la Hélice y el del Alternador. F.I.U.B.A. – CITEFA; Argentina; 1998.*

[63] *BURGOS PAYAN. Manuel; Gonzalez Rodríguez. Angel G. & Vallejo Saura. Manuel A. Generadores De Inducción en las Prácticas de Laboratorio; Dto. de Ingeniería Eléctrica, Escuela Superior de Ingenieros Industriales; Sevilla, España*

[64] *Instituto para la Diversificación y Ahorro de la Energía (IDAE). Energía eólica. Madrid: 2006. (Manuales de Energías Renovables; 3*

These wind turbines have external rotors, triphase, with dynamic magnets and 10-pole generator.

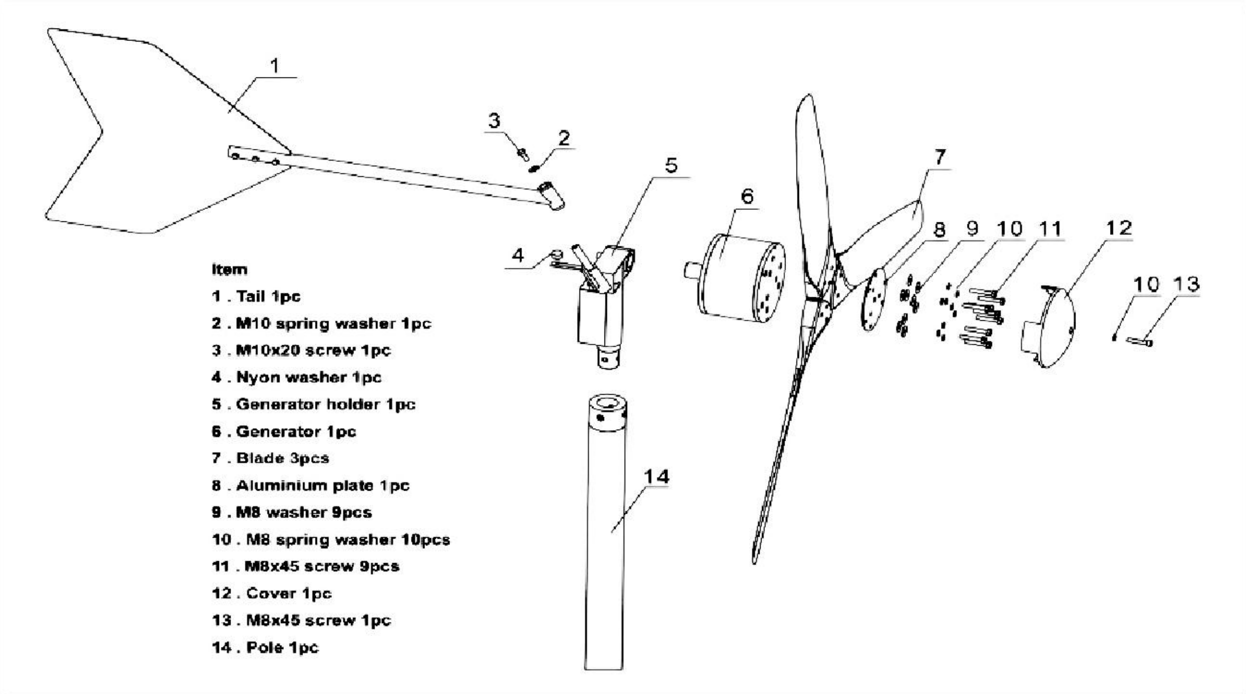


Figure 42: Horizontal axis wind turbine components Black 6001.[65]

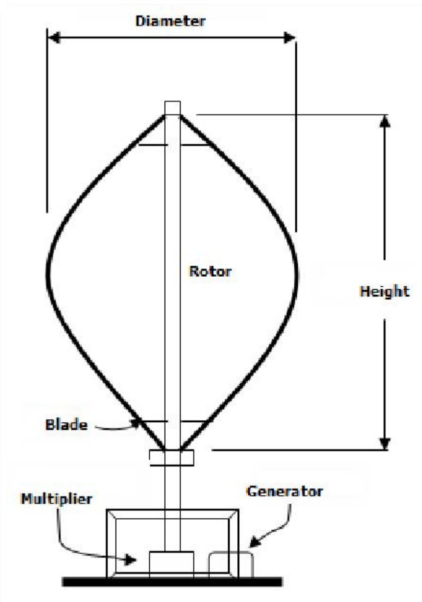


Figure 43: Components of a Darieus vertical wind turbine [66]

[65] *Assembly instructions and manual for the wind turbine Black 600. p r e V e n t GmbH*
[66] *www.monografias.com*

2.5.1 Rotor

The function of the rotor is to transform the kinetic power of the wind into mechanical energy. The larger the swept area by the rotor the greater the production of energy. For example a 10 kW wind turbine has a diameter of about seven meters, while a 750 kW wind turbine has a diameter of 24 meters.

There are two types of wind turbines according to the rotor layout:

- **Upwind**: Also called bow. Most of the wind turbines have this type of design. The rotor faces into the wind. Its main advantage is that it avoids the wind shade behind the tower. The drawback is that it needs a yaw mechanism for direction control, and is situated some distance from the tower.

- **Downwind**: also called stern. It presents as advantage that the rotor can be more flexible and does not need a guidance mechanism. Its main drawback is the fluctuation of wind power due to the passage of the rotor by the tower shade, so this creates more fatigue loads on the turbine than with the upwind design.

The rotor has two different parts: the blades (one, two, three or mutiblades) and the hub (element to which the blades are attached and through it the wind power capted by the rotor is transmitted to the gearbox).

2.5.2 Nacelle

The nacelle is the compartment where the electrical generator is housed along with the gearbox and the systems of control, regulation, orientation and breaking. Generally it is formed by a metallic structure constructed with steel, which is at the top of the tower.

2.5.3 Generator

The function of the generator is to transform the mechanical energy proceeding from the rotor into electric power. There are different types of generators:

a) Direct current generator
b) Alternative current generator

and

a) Synchronous generator of variable speed
b) Asynchronous which uses electricity to create a magnetic field.

For further information about the differences between these two types of wind turbines, visit the web http://guidedtour.windpower.org/en/core.htm (Danes, Alemán, Inglés, Español y Francés).

The most used generator in the miniwind turbines is the permanent magnet alternator that it is the ideal model for small wind turbines.

2.5.4 Multiplier

The coupling between the wind rotor and the generator, in the most cases, is done by a gearbox and its function is to multiply the rotational speed which comes from the rotor to adapt it to the generator needs. Its use is necessary while the diameter of the rotor is large because the r.p.m of the rotor must be limited to avoid that the blades tips work at speeds that compromise the strength of the materials used or induce harmful vibrations. But in the case of the turbines with a low power of 10 kW, generally, a multiplier is not used and the rotor is connected directly to the generator.

2.5.5 Control and braking system

Any wind turbine needs a control system that allows it to stop the machine, to limit its speed for safety reasons and to optimize its operation. Moreover, in case of electrical generation at constant frequency, it is necessary to maintain the rotational speed of the rotor to certain limits to obtain a high performance. The system of control is different depending on the size of the wind turbine.

- Systems with fixed pitch angle and variation of the catchment area "Furling". The wind turbine moves around a pivot sideways.
- Systems with fixed pitch angle controlled by aerodynamic loss in “stall regulation”. The profile of the blade has been designed in an aerodynamic way to assure that, if windspeed is too high, the turbine pitches up (or down) which create a loss in the lift.
- Systems with variable pitch angle or “pitch regulation”. When the direction of the blade varies, its aerodynamic qualities decrease.
- Systems of active stall regulation. They are like pitch control in the sense that both have blades that can rotate, adjusting for low and high speeds.

2.5.6 Guidance system

To optimize the exploiting of wind energy, the plane of rotation of the rotor must be perpendicular to the direction of the wind. In the event that the rotor is located downwind a guidance system is not necessary since through the taper of the blades the system is self-aligning.

In contrast, the upwind rotors which are in front of the tower, must incorporate some guidance system. There are different wind systems as auxiliary (tail mills), fantail (small turbines) and upwind rotor with assisted orientation (big or large wind turbines).

Due to their size, small wind turbines can not accommodate transmission mechanisms and the orientation engines which are used in the larger turbines. Almost all small turbines use fantails, although there are some exceptions.[67]

2.5.7 Tower

The wind machines must be located on a support structure capable of withstanding the wind force. There are different types of towers such as the followings:

a) Steel tubular tower
b) Lattice tower
c) Wind turbine guyed tower
d) Hybrid tower

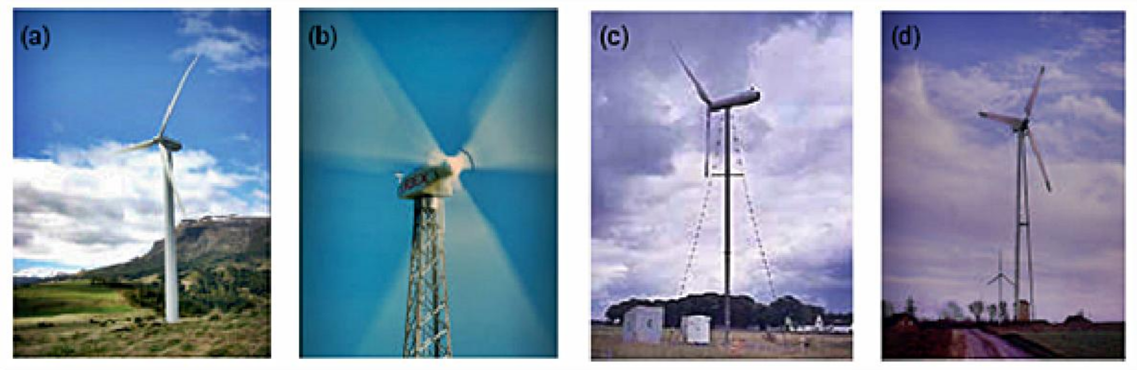


Figure 44: Types of tower: (a) tubular, (b) lattice, (c) guyed tower and (d) hybrid.[68]

In accordance with its location and installation there are four different types:

a) Ground
b) Rooftop
c) Anchored to a wall
d) On a floating platform

Ekhamba-Sweden

Mikulasovice, Czech Republic

Scuola verde, Italy

Hydrada,Grecia

The height of these towers and their position are fundamental aspects at the moment of implementing a miniwind installation. On these aspects will depend the

[67] *CIEMAT. Prospectiva y vigilancia tecnológica. Aerogeneradores de potencia inferior a 100 kW. [Documento electrónico] Julio 2008*
[68] *Danish Wind Industry Association.* ***Torres de aerogeneradores****. Windpower.org. 1999*

correct exploitation of the wind potential of the zone. These aspects will be studied in more detail in later paragraphs.

2.6 OTHER COMPONENTS OF A WIND ENERGY SYSTEM

To build a miniwind system, besides the wind turbine, additional equipment constituted by several components is necessary, depending on the exact type of installation.

2.6.1 Storage systems

Generally, in systems that are not connected to grid, there is some from storage system in order to have energy in periods of gentle breeze or calmness.

- *Batteries*

Batteries are the system most used to store the electricity generated by the turbines, the most usual is lead-acid batteries for their relatively high efficiency and adaptability to deep-cycle discharge cycles. They should allow a depth of discharge of up to 80%, although 50% will maximise battery life. Their longevity depends on duty cycle but is usually between 5 and 10 years. They are not suitable for large loads due to its size, high cost and difficulties of maintenance.

- *Thermal storage*

The energy from the wind is used to heat water, directly by a hydraulic brake or electrical resistance heating through the electricity conversion. The water is stored and hot water used on demand.

- *Water pumping*

During periods with an excess of energy production the electricity can be used to pump water to a large tank. During periods of insufficient wind load a mini hydraulic turbine could be connected in parallel with the wind turbine through a protection and control system. This method provides a power efficiency recovered between 50% and 80%. It is the solution found for wind power to wind electrify the island of El Hierro, Spain.

- *Generation of hydrogen and fuel cell*

The excess of produced electricity is used to split water into hydrogen and oxygen. The hydrogen is stored, later to be used directly as fuel or to generate direct current electricity through a fuel cell. The recovery efficiency varies between 50% and 70%.

- *Flywheel*

The energy is stored in a flywheel capable of rotating at high rate in a vacuum enclosure, to prevent drag. It is a convenient system for strong fluctuations in wind power because it is capable of absorbing high instantaneous powers. It gets very high recovery performances of around 80%. This storage system is not normally found in small wind systems, although it is being investigated.

- *Water Desalination*

In places where the demand of drinking water coincides with the availability of wind power and its ecological impact is acceptable, it is possible to use the remaining energy for water desalination, which is easily storable and has a high usage value.[69]

2.6.2 Inverters

Inverters are use for turning the direct current (DC) generated by the wind turbines, solar photovoltaic panels, accumulators or batteries, etc., in alternating current (AC) and to be injected into the grid or used in isolated electric installations. There are different types of inverters:

- Sinusoidal inverters (for systems that there are not connected to the grid).
- Synchronous inverters (which use RSC switchboards)
- Self-commutated inverters.

In the new systems, when electricity demand exceeds the supply and the batteries are close to the total discharge, the inverter automatically takes power from the grid until they are charged. However, when there is an excess of generation over demand and the batteries are fully charged, the inverter can also supply the excess of power to the grid (only if law of the country allows). Even if the power system of the grid fails, for example during a storm, the inverter and the batteries can provide uninterrupted power supply. The inverter automatically changes to a closed system with conventional batteries.[70]

2.6.3 Rectifiers and battery chargers.

Rectifiers are opposite to the inverters because they turn the energy of alternating current into direct current. In addition, if the generator doesn't have an output for battery load, a battery charger is obligatory.

[69] *CIEMAT. Prospectiva y vigilancia tecnológica. Aerogeneradores de potencia inferior a 100 kW. [Documento electrónico] Julio 2008.*
[70] *UPME; **ENERGÍAS RENOVABLES: DESCRIPCIÓN, TECNOLOGÍAS Y USOS FINALES**; en: Unidad de Planeamiento Minero Energética (UPME)-MINISTERIO DE ENERGÍA; Bogotá D.C.; Colombia.*

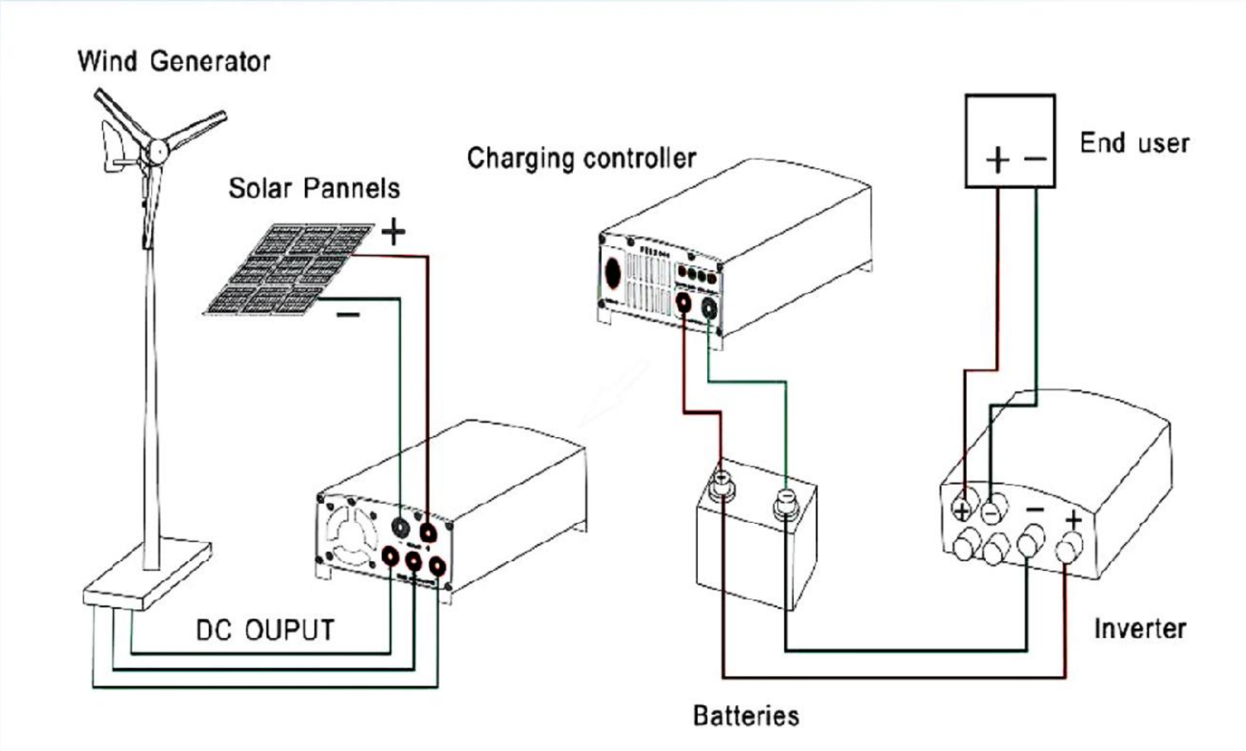


Figure 45.1: Framework of a hybrid system installation without group of support generator.[71]

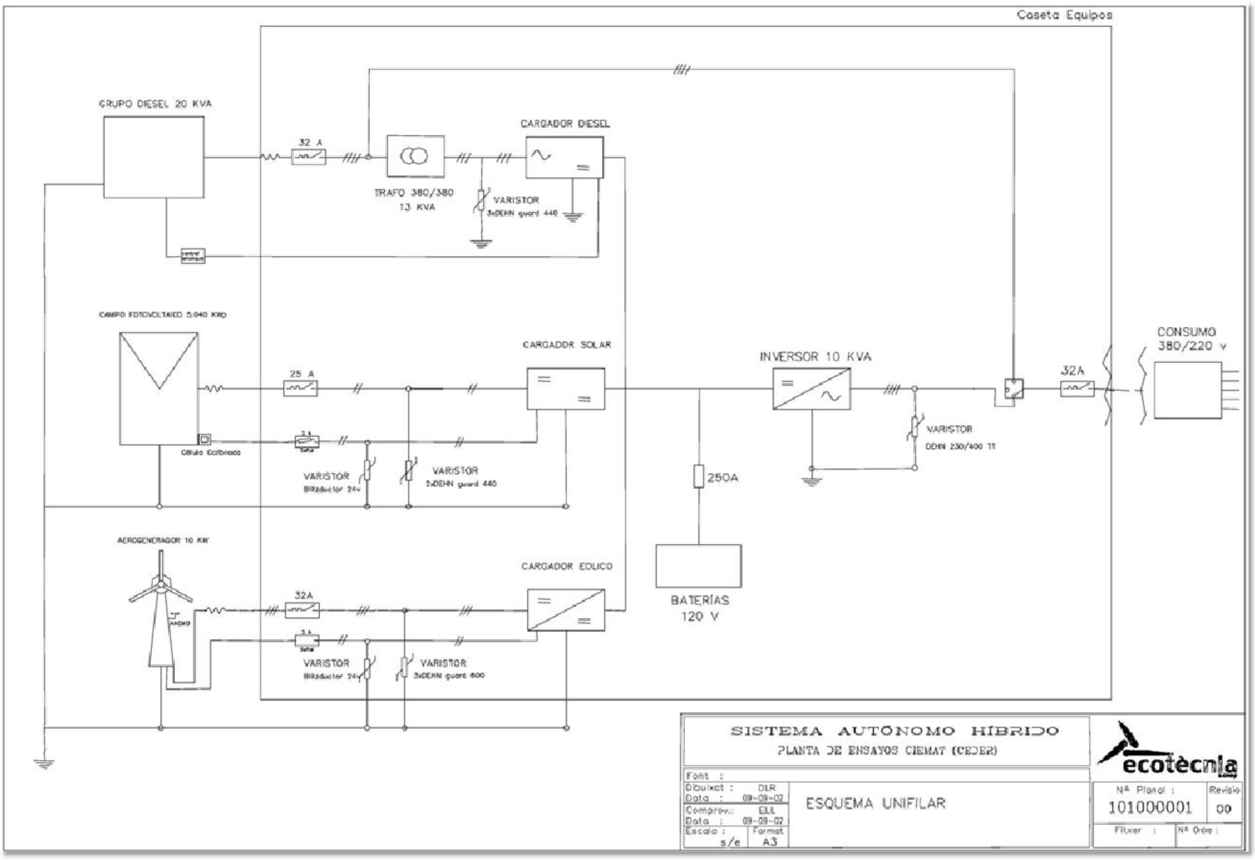


Figure 45.2: Electric framework of a hybrid system installation without support generator.[72]

[71] *Assembly instructions and manual for the wind turbine Black 600. p r e V e n t GmbH*

In the following two figures we can observe the interconnection of the components of a small wind installation in two possible setups: the case of an isolated installation of the grid, and a case of grid-connection.

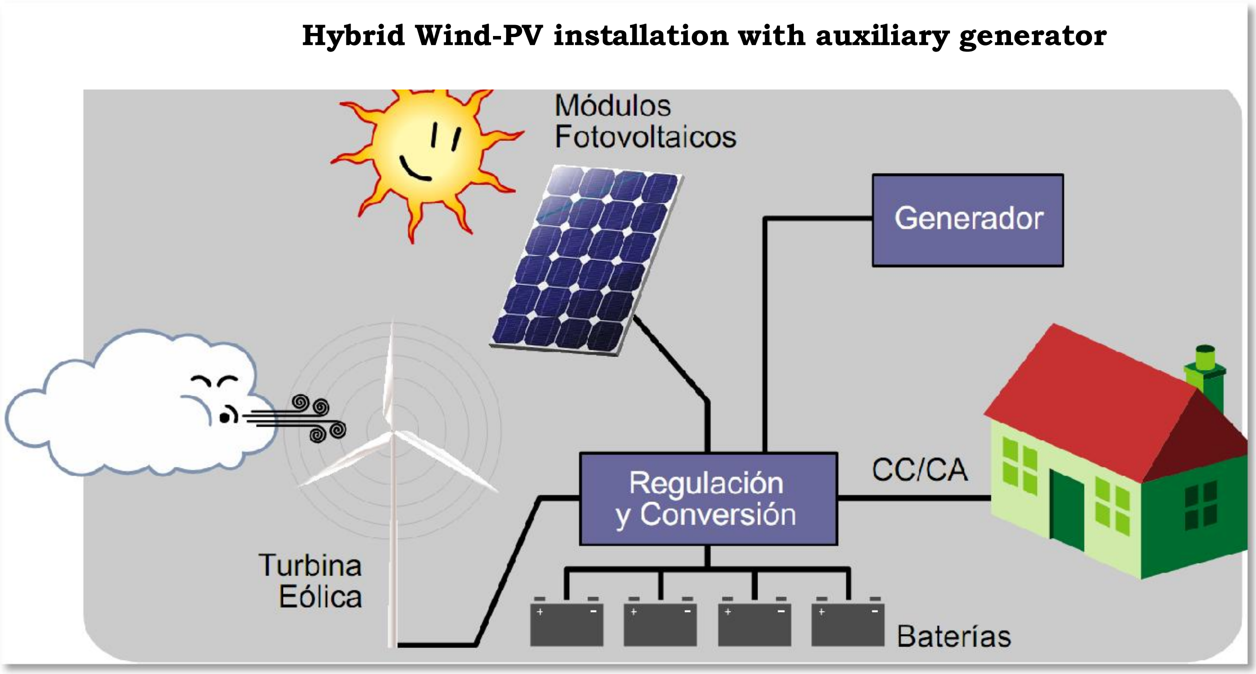


Figure 46: Framework of a hybrid system installation without generator.[73]

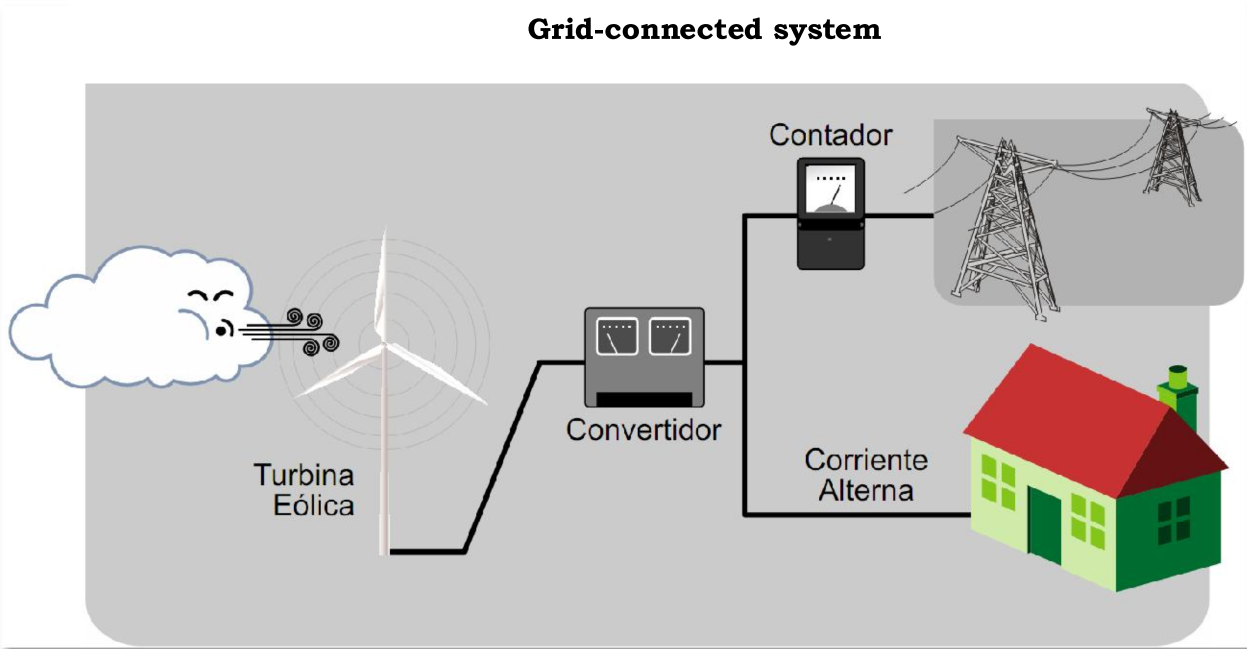


Figure 47: framework of a grid connection[74]

[72] *Sistemas Eólicos de Pequeña Potencia: I+D+i. Jornada Técnica "Energía Mini Eólica: una tecnología madura con un gran potencial*
[73] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*
[74] *Energía Eólica. Guía Técnica. Agencia Andaluza de la Energía. Consejería de Innovación Ciencia y Empresa.*

2.7 ENERGY PRODUCED BY WIND TURBINE

The energy produced by wind turbine is determined by three factors:

a) **The power curve**
b) **The wind speed**
c) **Weibull distribution**

While the first variable depends exclusively on the wind turbine, the second and third are directly related to the location and potential location of the installation.

The calculation of the final production of the wind turbine is a complex procedure even for experts. There are many factors which influence in the production of energy from the turbine, and it is a complicated estimation if we take into account the complete system losses, inverters, batteries, cabling, controllers, etc. ...

If we focus on the generation of the wind generator, there are three methods or sources to determine the amount of energy produced:

1. Based on the calculations in the power curve provided by the manufacturer.
2. Information based on the capacity factor of wind turbines.
3. Depending on the swept area of the wind turbine.

2.7.1 Power curve.

The power curve is one of the most significant characteristics of wind turbines because each type has their own power curve. This shows the simple relation between wind speed measured in m/s and the real power which will be generated by the wind turbine in kW.

The following figure shows a typical curve of wind turbines of low power , in this case, a wind turbine with rated power of about 11 kW. As you can see, the wind turbine is characterized by four speeds:[75]

[75] ***Programa de Cálculo de la Potencia de un Aerogenerador****; Actualizado el 5 de diciembre 2001; disponible en:* http://www.windpower.org/es/tour/wres/pow/index.htm

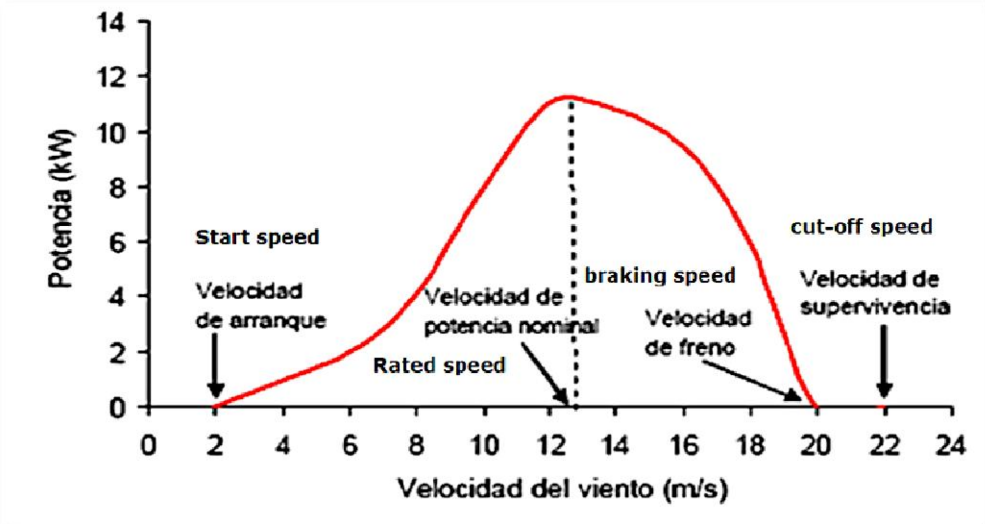


Figure 48: Power curve for a 11 kW wind turbine.[76]

- **Start-up wind speed:** Wind speed from which the wind turbine produces or generates electricity.
- **Rated speed:** it is the wind speed for which the rated power is reached. The stretch of the curve between the start-up wind and the rated speed follows a nonlinear law regarding speed.
- **Braking speed**: wind speed at which the rotor is stopped by the action of the regulation and control systems to avoid the risk of harm due to the high wind speed.
- **Speed of survival**: speed of the wind over which the wind generator can be damaged although it is stopped.[77]

The start-up wind speed is generally about 3 m/s for the equipments of hundreds of kW or MW and from 2 to 3 m/s in smaller machines. The rated power is generally reached between 12 to 15 m/s and for speeds from 25 to 30 m/s the power production is cut.[78]

In case of the miniwind turbines at low heights, the start up wind speed is the most important because on this depends whether the wind turbines works during more or less time. The following comparative graph (figure 49) shows the same model of wind turbine working in two different locations: one with a speed average of 3 m/s and the other one with 4.5 m/s. In the second case, we can observe that the functioning time increases is double and its annual production multiplies by 7.

[76] *SÁNCHEZ MIÑO, Santiago J.* ***ENERGÍAS RENOVABLES. Conceptos y aplicaciones.*** *WWF - Fundación Natura: 2003.*
[77] *CIEMAT.* ***Prospectiva y vigilancia tecnológica. Aerogeneradores de potencia inferior a 100 kW.*** *[Documento electrónico] Julio 2008.*
[78] *BASTIANON, Ricardo. Energía del Viento y Diseño de Generadores Eólicos de Electricidad e Turbinas Eólicas. Edit. Tiempo de Cultura: Argentina. 1992.*

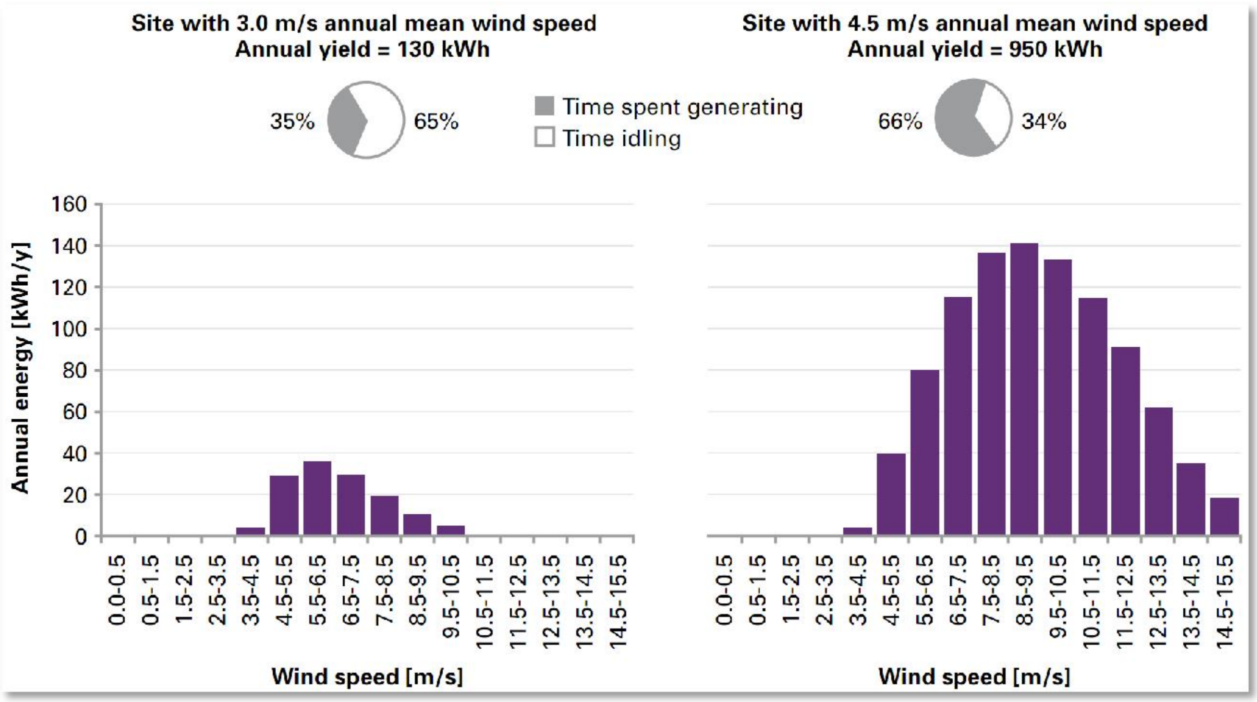


Figure 49: Production of the same wind turbine in two different locations (3 y 4,5 m/s).[79]

According to some studies developed by CIEMAT, we can see that the maximum efficiency power is between 4 and 9 m/s, as we can see in the following table.

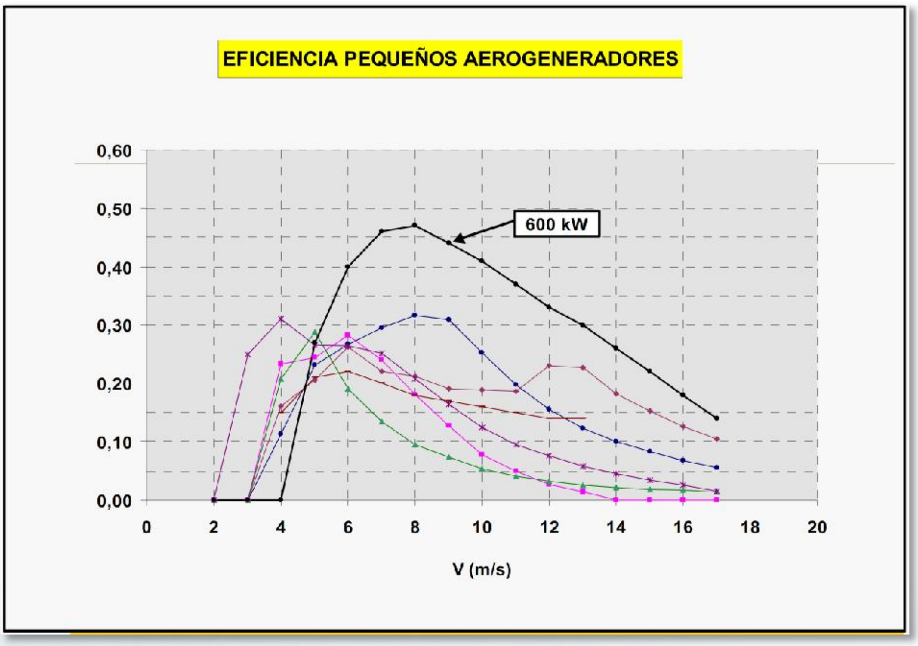


Figure 50: efficiency curves for wind turbines of low power.[80]

[79] *Carbon Trust. Small-scale wind energy. Policy insights and practical guidance.*

This curve, provided by the manufacturers should have been calculated from either wind tunnels or in real installations in field. However experience and studies reveal (like the study carried out by the project Warwick, in England and SPS-minieólica in Spain) that there are significant mistakes in these curves. This can be due to the diversity of situations, locations and regimes of operating of the different installations. Therefore, it is a theoretical curve of energy production and the most cases is found to be oversized.

The diversion or mistake in the predictions of power generation using the power curve is most acute in installations in buildings, on roofs or urban zones, where the fluctuations and turbulences of the wind are greater. The following table from a UK study shows a comparison between the predictions of production according to a model of wind estimation (the NOABL[81]), the predictions according to real measurements of wind and the measurement of the final production measured:

Site	Predicted energy output using manufacturer supplied power curves			Measured energy output (kWh)
	Using NOABL wind speeds (kWh)	Using scaled NOABL wind speed (kWh)	Using measured wind speeds (kWh)	
Lillington Road	819	127	88	52
Birds Hill	574	114	135	48
Leicester	1101	157	217	64
Daventry Town Hall	650	129	166	69

Table 07: Comparative table between estimated and actual production.[82]

[80] *Sistemas Eólicos de Pequeña Potencia: I+D+i. Jornada Técnica "Energía Mini Eólica: una tecnología madura con un gran potencial*

[81] *NOABL is based on observations for the 10 year period 1975-1984 for 56 stations, while NCIC takes into account 30 years of readings between 1971 and 2000 for approximately 220 sites. The longer time period implies that the NCIC data are more representative of long-term conditions, and the higher number of stations means the data are also less reliant on interpolation.*

[82] *Microwind - the Complete PictureResults of the Encraft Warwick Wind Trial*

The following figures show the previous results in a graph for the different places and installed equipments:

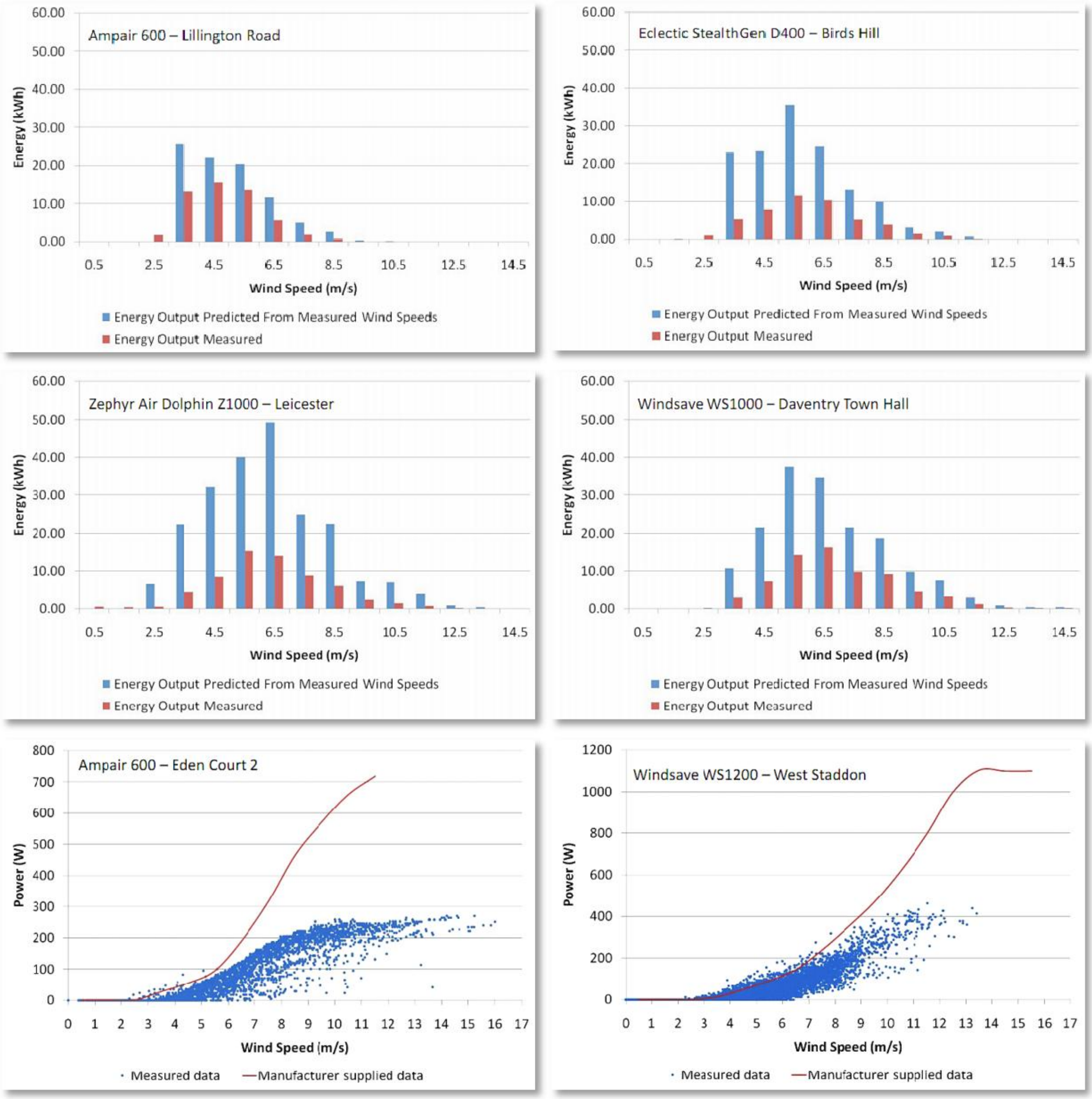


Figure 51: Comparative table between measurements of production and power curves provided by manufacturers .[83]

The difference between real measurements in field and energy produced differs enormously from the estimations using the power curves provided by manufacturers as reference. In this sense it is advisable to verify at the moment of selecting a wind turbine that it fulfils with the international standard IEC 61400-12 (on the power curves).

2.7.2 Capacity Factor

The Capacity Factor, is another method for representing the efficiency of a turbine. It is related to the nominal power of the turbine. The Capacity Factor is

[83] *Microwind - the Complete PictureResults of the Encraft Warwick Wind Trial*

expressed as a percentage of a theoretical value, that supposes that the turbine were operating at its full nominal power all year round, 24 hours per day. Thus you multiply its power in kW by the number of hours in a year (8760 or 8766 to be exact) and the result is a theoretical energy production value, usually of several thousand kWh per year. For example, a 2 kW nominal power turbine, will have a theoretical annual production of 2kW*8760h= 17520kWh/year. Obviously this value is unrealistic because the turbine is only functioning in certain wind conditions, and often well below its nominal power. Thus, once the theoretical annual production is calculate, an estimate, or measurement is then performed on the real production that the turbine will give, in the specific site wind conditions.

The real production is then divided by the theoretical figure and a percentage is the result, which is called the Capacity Factor. Therefore if the 2kW turbine actually gives us 3504 kWh/year, the Capacity Factor would be 20% (3504/17520). Large wind farms, due to their optimal locations, and ability to operate at their nominal power rating, give Capacity Factors around 30%, whereas small wind turbines, if incorrectly sited, have Capacity Factors lower than 5%. If correctly sited, a small wind turbine should give a Capacity Factor of between 10-20%.

The main Caveat for this form of measurement, is that it depends heavily on the nominal kW rating that the turbine manufacturer has given, which in many cases is somewhat arbitrary. If their nominal rating is unrealistic, or mistaken, then the Capacity Factor too will be inaccurate. For this reason it is advisable to compare the two results with the measurement using the Coefficient of Power, and verify the Capacity Factor figure. Comparison with other forms of energy are as follows (Capacity Factor is a theoretical concept and is not to be confused with efficiency):

- Large wind 20-40%
- Small wind 10-20%
- Hydro 30-80%
- Photovoltaic cells 12-15%
- Nuclear energy 60-100%
- Thermal energy 70-90%
- Combined Cycle Gas up to 60%
- Biomass up to 80%

2.7.3 Main factors influencing the energy produced by a wind turbine

Although each generator is characterized by an energy generation capacity dependent on its unique design (horizontal or vertical, blade diameter, type of generator, etc ...) and that is reflected in its power curve, this production is also dependent on the resource and wind regime of installation site. Due to this, there are other variables that must be taken into account in the real final production of the wind turbine and which are directly related to a proper installation. There are two basic parameters that can be considered more fundamental in the installation:

2.7.3.1. Height of wind turbine

The installation height is a factor that influences final production as the wind speed and flow rates vary significantly.

The following figure show the approximate relation between the height that the tower should have based on the power of the generator.

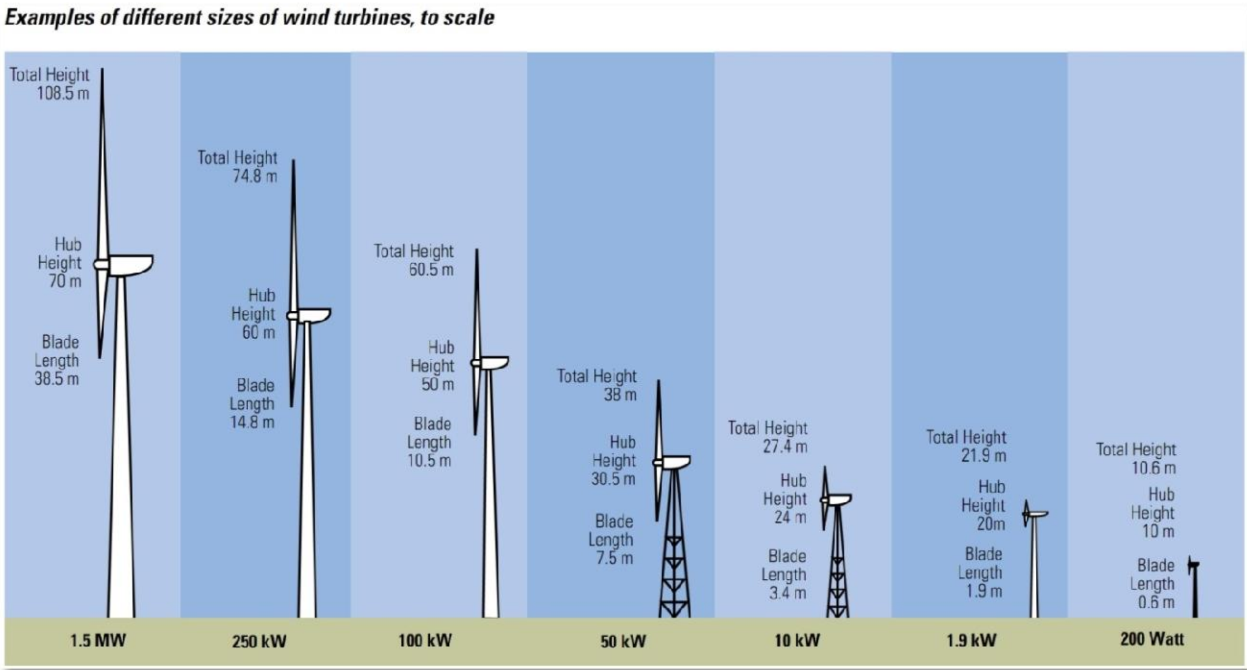


Figure 52: Approximate height of the tower based on the power of wind turbine.[84]

The height of the tower does not only depend on wind power, other factors such as nearby obstacles, type of installation (ground, roof or anchored on a wall) and environment (rural or urban) also have signficant.

2.7.3.2. Obstacles and location

It is important to find a correct location of the wind turbine avoiding obstacles that intervene in the wind flow and cause turbulence.

The obstacles and the location will change from one site to another. This must be studied closely each of them if there were obstacles thoroughly for every case. Depending on the types of obstacles and possible locations, basically we can differentiate two clearly environments:

- Rural, marine or mountainous environment: characterized for being more open spaces more homogeneous and with greater possibilities for choosing for one or another location for the placement of the wind turbine.

[84] *Small Wind Turbine Purchasing Guide.Off-grid, Residential, Farm and Small Business Applications. Canadian Wind Energy Asociation (CANWEA)*

- And the urban environment: more heterogeneous, with a huge diversity of possible arrangements of the obstacles, variable typologies of the same ones, complex formation of air currents and sometimes limited opportunities for placement of the generator.

The study of the urban environment is complex as shown in more detail in the document "Small-Sacle Wind Energy Technical Report of Carbon Trust", creating complex computerized predictive models for the study of wind potential and to predict its behaviour to deal with obstacles such as buildings.

In either case, whether there are or are not predictive models, it is always advisable to take measurements of wind on the ground in different locations selected as ideal at a suitable height for a period of 6 or more months, to have real and reliable information.

2.8 FINANCIAL ASPECTS

The relative cost of a miniwind installation can be between 4 and 7 times greater that the cost of an installation of large wind. The specific cost (€/kW) is going to depend on the type of installation to undertake but it is usually equivalent around the 6.000 € for kW installed.

For a miniwind installation connected to the grid and an applied capacity factor of 20 % that corresponds with 1.752 hours per year the production estimated is shown in Table 8. It shows a breakdown of the characteristics, the costs and the performance of the small wind turbines for different powers.

	Rated Power				
	150 W	**3000 W**	**5 kW**	**10 kW**	**50 kW**
Features					
Rotor diameter (m)	2,7	3,7	5	6,7	15
Tower height (m)	12	12	12	24	25
Rotor configuration	windward	windward	windward	windward	iee
Number of Blades	2	2	3	3	3
Costs					
Wind generator cost (€)	3.800	9.000	17.000	35.000	110.000
Installation and auxiliar costs (€)	4.000	6.000	7.000	15.000	55.000
Total costs (€)	7.800	15.000	24.000	45.000	165.000
€/kW	5.200	5.000	4.800	4.500	3.300
Performance					
Annual Energy (kWh/year)	2.500	5.250	8.750	17.500	87.500
Avoided emissions (tCO_2/year)	1,4	2,8	5,0	9,8	47,75
Production costs ($/kWh)	0,346	0,333	0,32	0,3	0,22

Table 08. characteristics, costs and performance of small wind turbines. Capacity Factor applied: 20% (1752 hours equivalent). Systems connected to grid.[85]

[85] *Ciemat, Small wind technology*

As for payback for a system one must differentiate between isolated installations and grid-connected ones. In the last case with current electricity prices it is difficult to payback the investment, whereas in the former the need for electricity can make it viable. When grants and support schemes such as feed-in-tarriffs are available, however, it can be made feasible.

Figure 53 shows the specific costs €/m2 of swept area, for miniwind turbines of less than 30kW. In general it shows a slight tendency for decrease in costs for larger turbines, but there is so much difference in prices between generators it is hard to see trends.

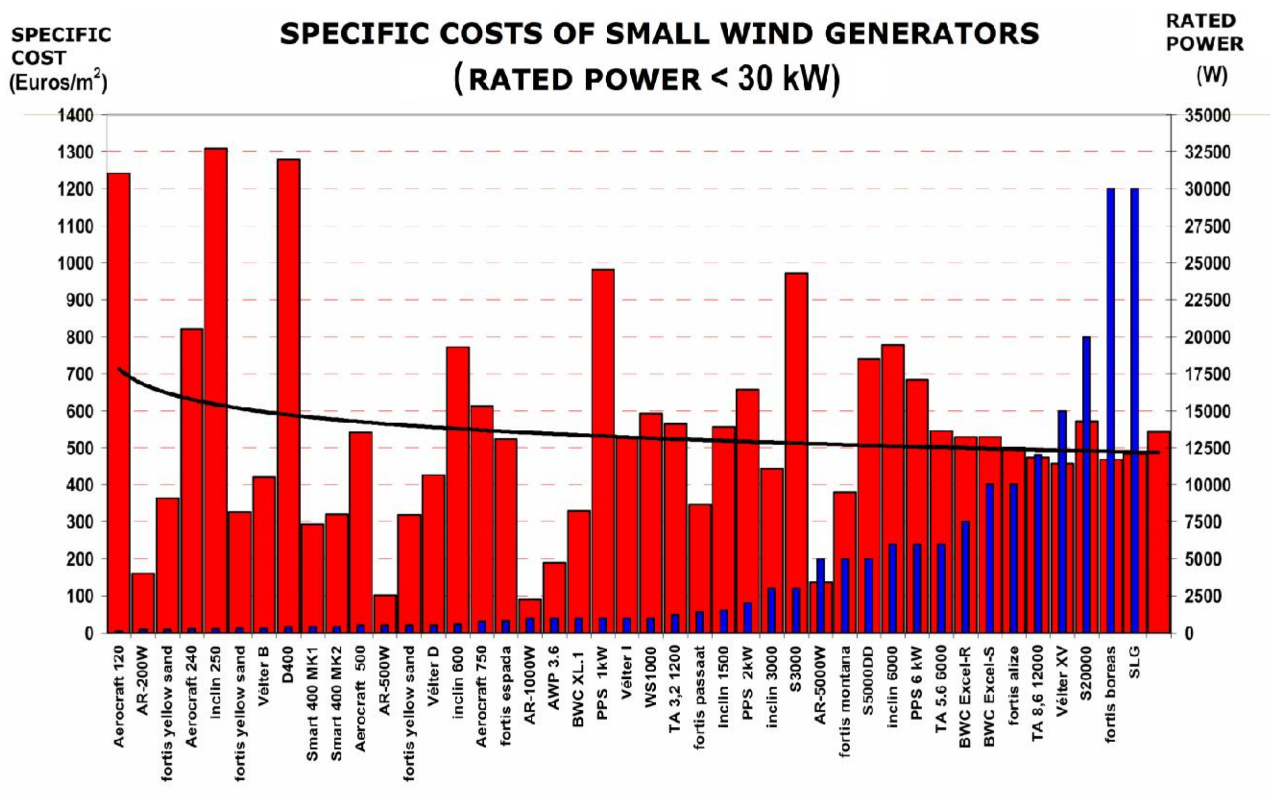


Figure 53. Specific costs of small wind turbines.[86]

The total costs of the installation vary enormously depending on the location, type of installation and total power. A grid-connected installation will be invariably much cheaper for an isolated installation per kW installed as it doesn't need much auxiliary equipment. However its price must be compared with the substitute- in the case of an isolated installation this may be the excessive costs of grid connection or the cost of running a diesel generator many hours a day. Whereas for a grid connected system the equivalent is grid electricity, which is relatively cheap. In many cases the off-grid system although more expensive, will work out more financially viable than a grid connected system of the same size.

[86] *CIEMAT. **Sistemas Eólicos de pequeña potencia: I+d+i.** [Documento electrónico] 2008.*

Another factor that significantly affects the final and partial costs of each component of the installation will be the site of the installation, if it is a mountain or rural or urban area. Figure 54 show a breakdown of the percentages of each component of the installation for these two cases:

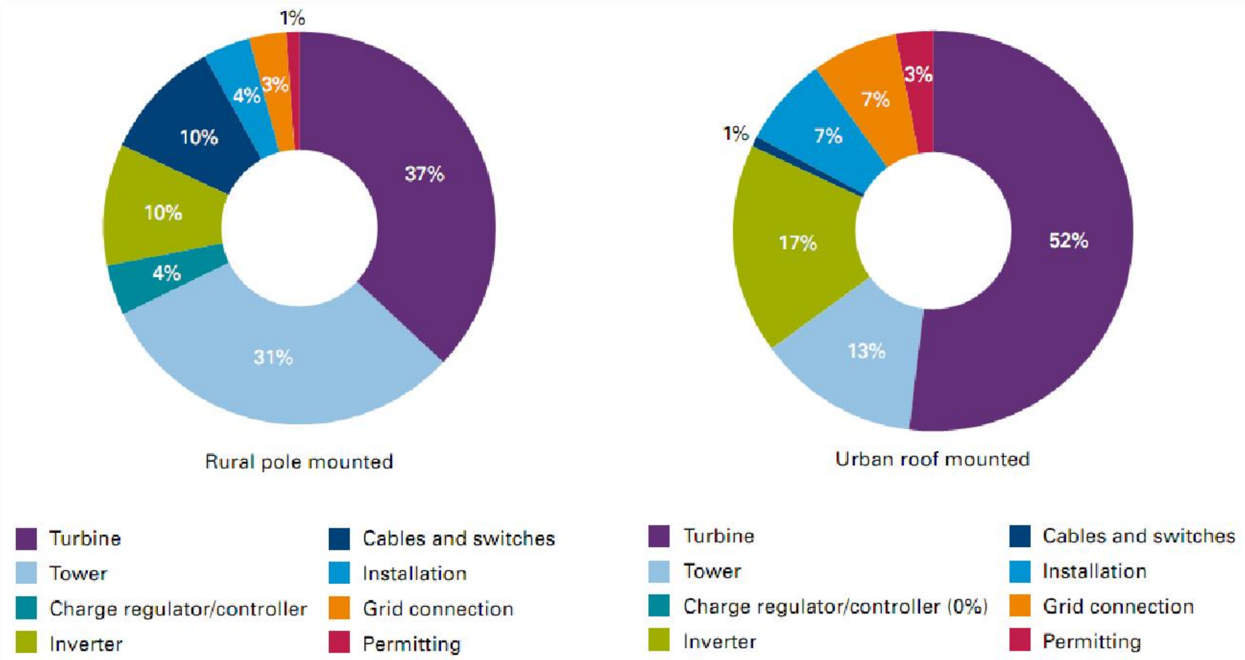


Figure 54: Typical capital cost breakdowns for rural and urban small turbine installations.[87]

2.9 INSTALLATIONS AND APPLICATIONS OF MINIWIND ENERGY SYSTEMS

There are two main categories for Miniwind energy systems:

- Stand-alone off-grid installations.
- Installations connected to the grid.

Within these two categories, applications and specific locations for installations or isolated areas may include:

- Electrification of isolated housings, equipments and public services. Housings in isolated sites, mountain refuges, points of observation, electrical fences, etc...
- Electrical supply to small agricultural or industrial isolated facilities.
- Water pumping by energy supply for the pump or by accumulation of the electricity in batteries, or for systems of irrigation, lighting of greenhouses or farms, milking systems, refrigeration, etc.

[87] *Entec. Carbon trust.Small-scale wind energyPolicy insights and practical guidance*

- Desalination and water treatment in small-scale plants.
- Telecommunications equipment, lighting, maritime signaling, lighthouse, repeaters for radio, television and telephone, alarm devices, etc..
- Drying of flood plains.
- Total sale of the electricity produced to the grid
- Simultaneous sale and consumption of electricity. (Net-metering)[88]

- Production of hydrogen (H_2)
- Water pumping by the direct use of the mechanical energy supplied by the wind turbine.
- Obtaining thermal energy. The mechanical energy of a wind machine could be transformed directly into thermal energy for two mechanisms: water heating by mechanical friction or compression of the cooling fluid of by a heat pump. In both cases, the produced heat can be sent through a heat exchanger to a conventional heating system. Nevertheless, the development of this type of application is normally not economically feasible. It is normally better to generate electricity than to build a wind system only for thermal application.[89]

The possible **locations** for the use of miniwind turbines include:

- Repeaters for television transmission, telecommunications towers, marine signalling ...
- Scattered buildings (independently and/or interconnected to grid): farms, houses, industrial buildings, livestock or agricultural lighthouses, mountain huts, refineries, gas stations, service stations ... In ground or on deck.
- Buildings or semi-urban (independently and/orconnected to grid).
- Apartment buildings or offices, schools, universities, hospitals, nursing homes, hotels, places of worship, malls, government buildings ... floor-mounted or integrated into the design/construction.
- Sports facilities, parks, gardens, promenades ...
- Ports, airports, heliports, prisons, barracks, naval or air bases ...
- Boats, caravans ...[90]

[88] *Net-metering: Where the renewable producer only pays for the difference between electricity consume and that produced- or has a credit with the electricity distribution company if they produce more than they consume.*
[89] *Manuales sobre Energías Renovables. FOCER Fortalecimiento de la Capacidad de Energía Renovables para America Central.*
[90] *CIEMAT.* ***Sistemas Eólicos de pequeña potencia: I+d+i.*** *[Documento electrónico] 2008.*

Applications of the wind turbines of all possible categories, their rated power and their swept area:

Area	Classification	Nominal Power (kW)	Radius (m)*	Connection type**	Energy destination	Actors and Markets	Typical Applications
Study Area of Rural-RES Project	**Microwind**	< 1	<1	**Off-grid**	Charging for small 12V batteries	Individuals	Boats, cars, communication systems (low power radars, radio etc), measuring instruments, meteorological stations, mountain refuges, lighting, electric fences, leisure areas etc
	Miniwind	1-5	1-3		For deep-cycle battery Banks/Net Metering or sale to the grid	Home-owners/Businesses/Administrations	Farms, isolated rural dwellings, pumps, telecommunication systems
		1-10					
		10-50	3-9	**Grid-connected**		Rural and Urban applications/ Businesses/ Administrations	Small wind parks, farms, rural dwellings or communities, water treatment, drainage/irrigation systems
Outside Study Area of Rural-RES Project	**Small wind**	50-100			Net metering/sale to the grid		
	Medium Power	100-300	9-27			Farm owners/ rural communities/ businesses/ Administrations	Medium sized wind parks with uncomplicated infrastructure. Commercial installations or large off-grid installations for communities with back-up generator.
		300-1000				Medium and Large Companies/ Administrations/Communities	
	Large Wind	1.000 - 10000	27-81		Sale to high voltage grid	Large Companies/ Regional or National Government	Land-based wind parks
	Giant Wind	> 10000	>81				Off-shore systems

* Approximate values   ** Most usual applications for power rating

Table 09: Classification of wind turbines to energy produce based on their power.[91]

[91] *Own source*

2.9.1 Isolated installations

The most common application of isolated systems is the electrification of rural housing, for which there are different configurations.[92]

2.9.1.1. Individual systems.

Generally they have a miniwind turbine, one or more batteries to store the generated power and a controller that controls charging and discharging of the batteries. In this system, depending on the final application, it may include an inverter to convert the electricity stored in batteries to alternating current power for the end use.

Generally, the wind turbines of these installations are used for the electrification of certain equipments, isolated housings, and lighting by the load of batteries which supply alternating and direct current regulated by modern electronic control system, but they can also be used to move electrical pumps without having to accumulate the energy previously.

The following image shows the example of an individual isolated system for the electrical supply of an irrigation pump by accumulation in batteries.

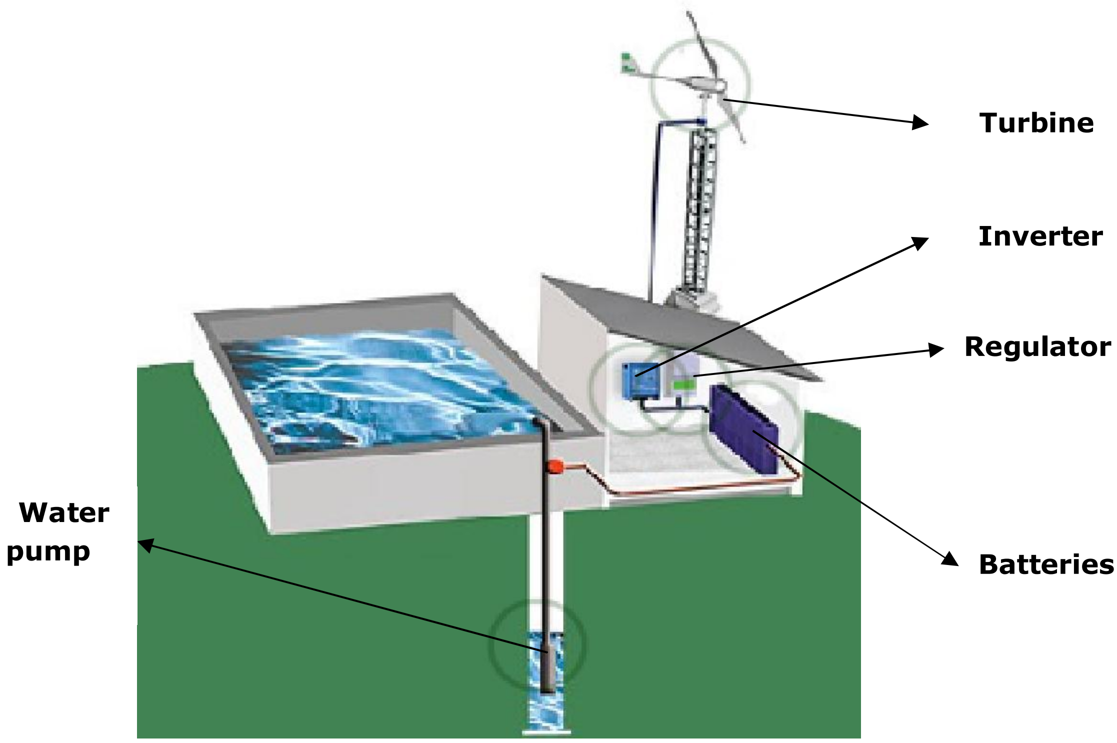


Figure 55:. Isolated installation, pumping water with accumulation of batteries.[93]

[92] reFocus. *Small wind Power. : 1471 pages 40-45. Elsevier Ltd, 2006.*
[93] *Bornay*

As regards the specific application for the water pumping with wind there are two possibilities: the use of an american multiblade mill where what prevails it is the torque to drive the mechanical pump or, an electrical wind turbine that connects directly to a bomb that is designed for a similar frequency to the generator. (we can see an example of this application in the n ° 10 and n ° 12 of the document of good practices elaborated in the project ruralRES)

The american multiblade mill has a mechanical connection through a shaft from the rotor to the pump, making it prone to more frequent maintenance and damage from the elements. In addition, it must be installed on the source of water to be pumped and that site may not be the best one due to the wind production. This system for being very basic can be manufactured at low cost and is most appropriate when the average wind speed is less than 4 m/s.

In contrast, an electric wind turbine is more efficient than traditional multiblades mill and does not have the drawbacks of wear of the connecting hubs. You can connect away from the pump (up to 700 m) in a site with better winds. Its performance is better with wind speeds exceeding 4 m/s and of preference more than 5 m/s.

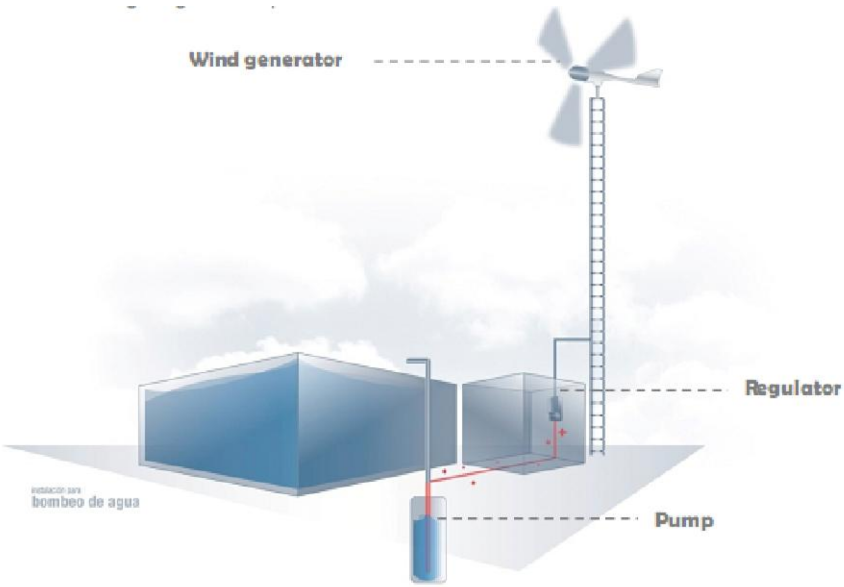


Figure 56:. Isolated installation, pumping water without a battery accumulation.[94]

The installation of a pumping system with an electric wind turbine is justified when the following conditions are fulfilled: a) when the volume of water pumped multiplied by the height of pumping (water head) is between 200 and 1,000 meters, b) for wind speeds above 4 m/s, c) when it is not possible to use diesel generators, and d) when the grid is far more than 2 km. (example of the previous figure).[95]

[94] http://www.enair.es/aplicaciones/bombeo_de_agua
[95] *SÁNCHEZ MIÑO, Santiago J.* ***ENERGÍAS RENOVABLES. Conceptos y aplicaciones.*** *WWF - Fundación Natura: 2003.*

If the housing units to be electrified are relatively close to each other, the most appropriate option can be a centralized wind system due to the concentration of equipments and energy, which offers advantages from a technical viewpoint and economic development.

A centralized wind system satisfies the energetic demand of a community with produced electricity, stored and transformed into a "central wind system" and then is distributed, through electrical lines to each of the housings or other sites. Generally, this type of systems have more than one source of generation, to achieve major reliability of the system. It estimated that if the demand is greater to 10 kWh per day, a wind system is cheaper than the photovoltaic one, though this depends on the availability of the natural resources for both sources.[96]

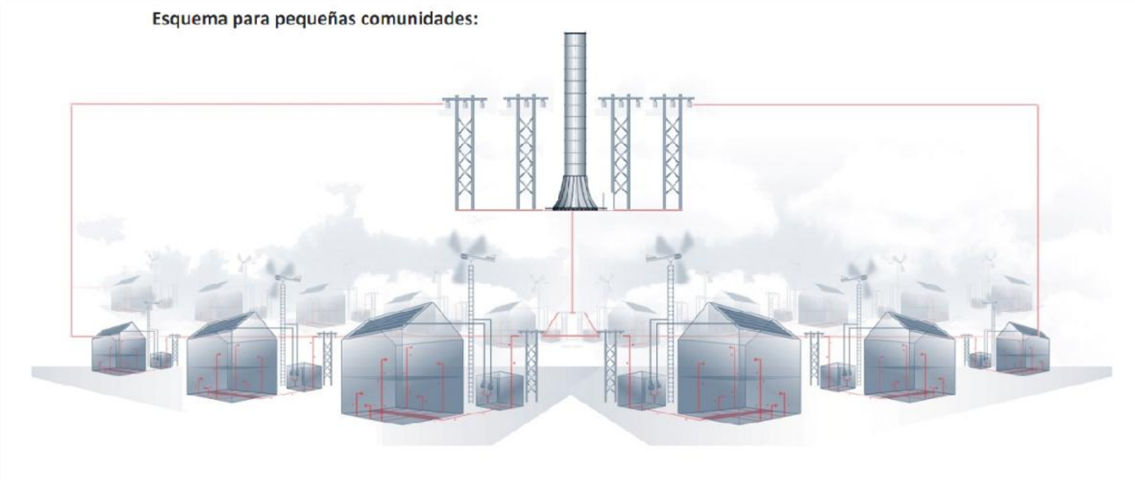


Figure 57: Wiring for small communities.[97]

Figure 58: Roof of the building that incorporates different renewable energy technologies: thermal, photovoltaic and small wind.[98]

Small wind turbines offer an attractive solution for rural electrification, but often the fluctuation of the wind mean that it can not produce electricity constantly. Therefore, it is frequent to use a wind turbine with another source of generation, hybrid systems, such as photovoltaic panels or diesel generators. One of the biggest advantages offered with respect to an individual system is that they give major safety of electricity generation.

There are other hybrid systems:

[96] Manuales sobre Energías Renovables. FOCER Fortalecimiento de la Capacidad de Energía Renovables para America Central.

[97] *Enair. La evolución de la tecnología eólica*

[98] *Gonzalez Vélez, José M.* ***Apostar por las energías renovables****. APPA. Diario El economista. marzo 2009*

- Wind-Photovoltaic.
- Wind-diesel.
- Wind-gas turbine.
- Wind-hydraulic.
- Wind-fuel cell.

The two types of hybrid installations most commonly used are:[99]

2.9.1.2. Wind-diesel installations.

In this type of installation, the diesel generator, interconnected through its control system allows great flexibility in its operating system. The diesel generator operates at full load when the wind is calm or under variable rate supporting the wind turbine production for existing variation of wind speed. When the wind maintains a high speed range, the diesel is stopped and the electricity is supplied only by the wind or maintains its operation in setting conditions for the duration of strong winds

2.9.1.3. Wind-photovoltaic installations.

Both wind and sun are complementary. Together, they improve the reliability of isolated systems. They also make them more profitable than when they operate separately. As we can see in the next figure , these installations are constituted by a small wind turbine that through a rectifier/regulator of load, supplies power to the batteries. In parallel there is a solar panel system, that by its charge controller is connected to the same battery. The dimensions of each piece of equipment (wind turbine and panels) will depend on the weather variables and the characteristics of the load.

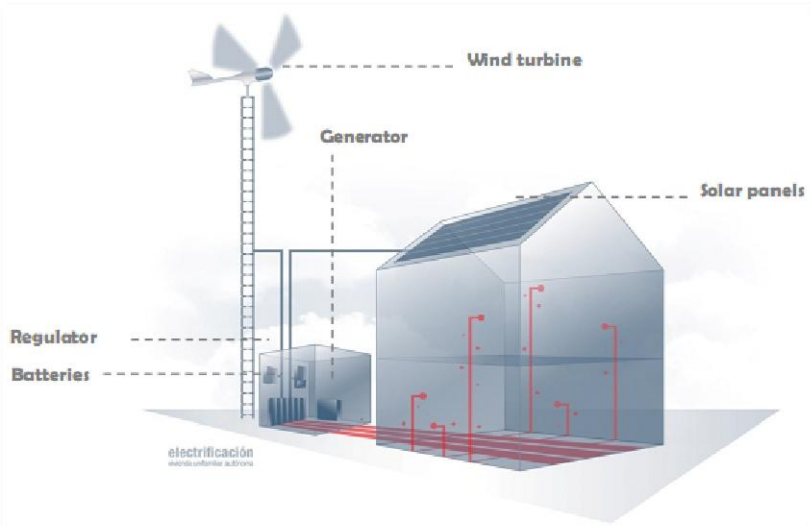


Figure 59: Wiring for electrification of an isolated house with accumulation of batteries.[100]

[99] CIEMAT. *Sistemas Eólicos de pequeña potencia: I+d+i. [Documento electrónico] 2008.*
[100] *Enair. La evolución de la tecnología eólica*

Figure 60 shows an example of installation. It is an isolated installation that integrates the use of wind and photovoltaic power for electricity supply to a mobile phone repeater. The installation is supported by a diesel generator to cover the periods in which the batteries do not have enough load to keep the repeater tower running.

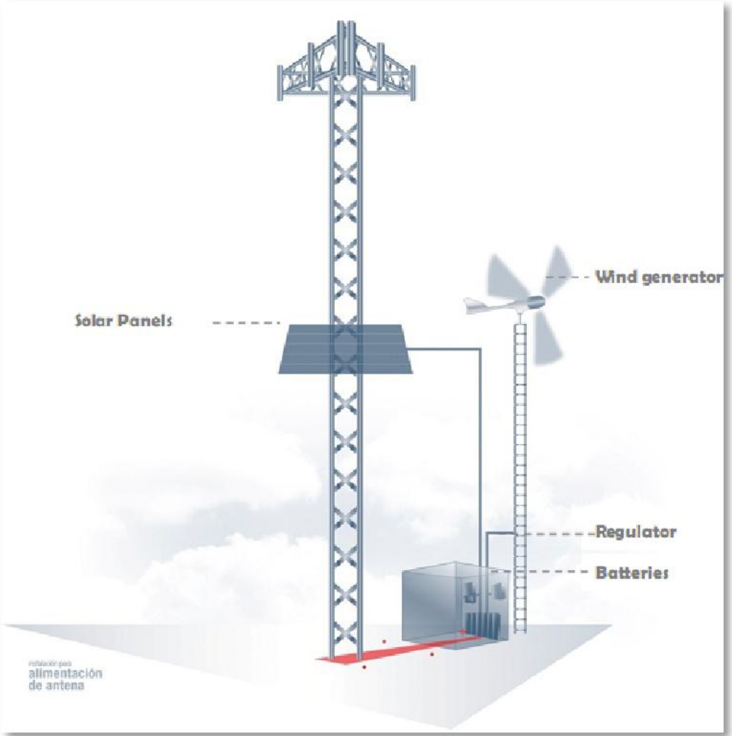


Figure 60: Wiring for electrification of a communications tower with an accumulations of batteries.[101]

2.9.2. Grid-connected installations

If the law of the electricity sector allows there is an opportunity to supply power to the grid with miniwind systems. This applies in cases where grid access is close by. In this case, the energy required by the user would be provided by the wind system and the electricity grid. If the wind turbine produces excess energy, this excess is delivered through the grid and, if there is less energy than the required, it is taken from the grid. This system is known as "Net-metering" this is a special meter that deducts the consumed kWh from those produced, so that the energy generated at the end of each period will be paid to the owner of the wind turbine at the price stipulated by the laws or regulations of that country.

In this type of facilities, the storage of the electricity in batteries is optional, but its incorporation demands extra devices such as rectifiers and inverters as well as other auxiliary equipment.[102]

Within the grid-connected system hybrid systems are becoming important. For example in Spain, Barcelona Energy Agency (AEB) and the Polytechnic University of

[101] *Enair. La evolución de la tecnología eólica*

[102] *reFocus. Small wind Power. : 1471 pages 40-45. Elsevier Ltd, 2006.*

Catalonia (UPC), Regesa and Fecsa Endesa signed in November 2007, a collaboration agreement for the construction of a mixed wind-photovoltaic connected to grid in a building of 175 homes. This one is a pioneering project in the use of renewable energies that is realized as substitution of a solar thermal installation for the production of hot water.

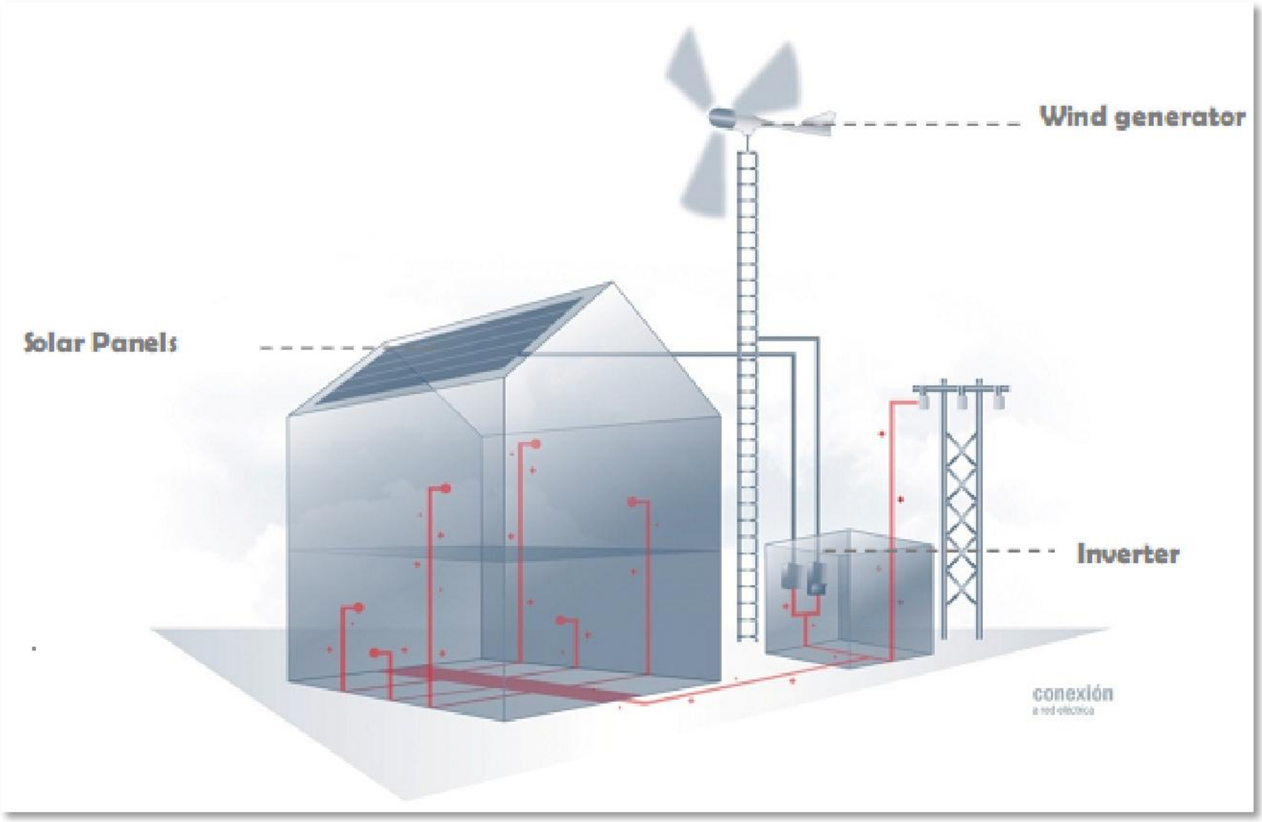


Figure 62: Wiring diagram of grid-connected wind turbine.[103]

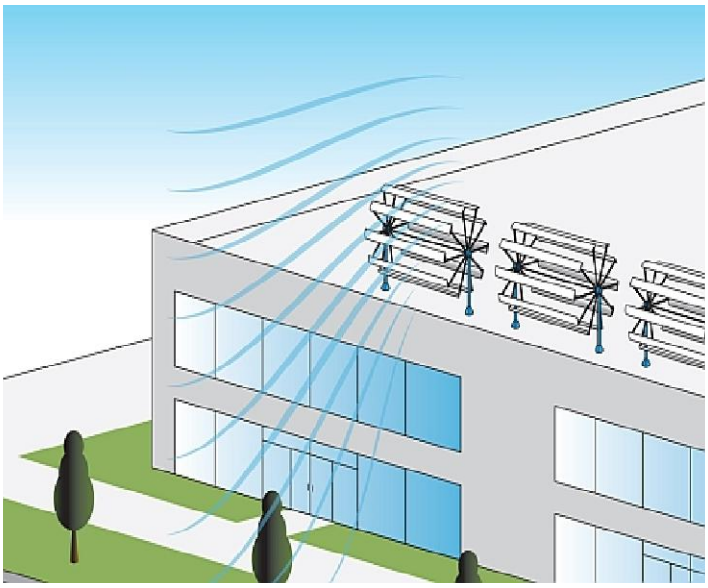
[103] *Enair. La evolución de la tecnología eólica*

2.10 WIND ENERGY IN URBAN AREAS

Currently there is considerable interest in the introduction of miniwind in the urban environment and new types of turbines are being developed for this use. The integration of many miniwind turbines in the urban environment will increase significantly the coverage of energy without using areas destined for other uses such as cultivation or farmland.

Figure 63. Example of wind turbines in urban areas. [104]

One of the main characteristics or urban turbines is to offer the consumer the chance to generate their own electricity. However, the wind resource in towns do not allow a good efficiency for horizontal axis turbines due to turbulence and low wind speeds, which is compounded by the fact that winds have a vertical component particularly near high buildings. [105]



Thus for urban situations, vertical axis turbines may be considered a better option, mainly due to their ability to work with higher levels of turbulence and with vertical wind components, and integrate well with buildings. Furthermore, there rotation is much quieter.[106]

They do however suffer from much lower efficiencies than horizontal axis wind turbines, and thus their correct location is key to maximising production to make the installation worthwhile. There are many simulation models that assist in predicting wind flow in urban environments which can help decision-making.

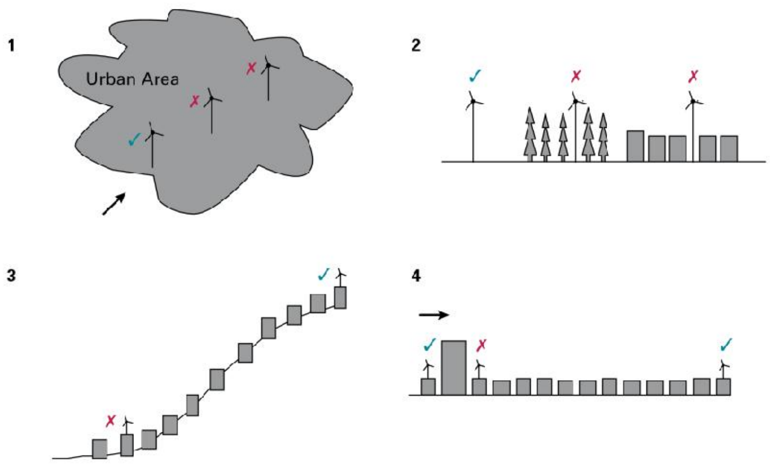
[104] *http://www.quietrevolution.co.uk/projects.htm*

[105] *WINEUR Consortium. URBAN WIND TURBINES Technology review. Catalogue of European Urban Wind Turbine Manufacturers. [Documento electrónico] IEE-European Commission, 2008.*

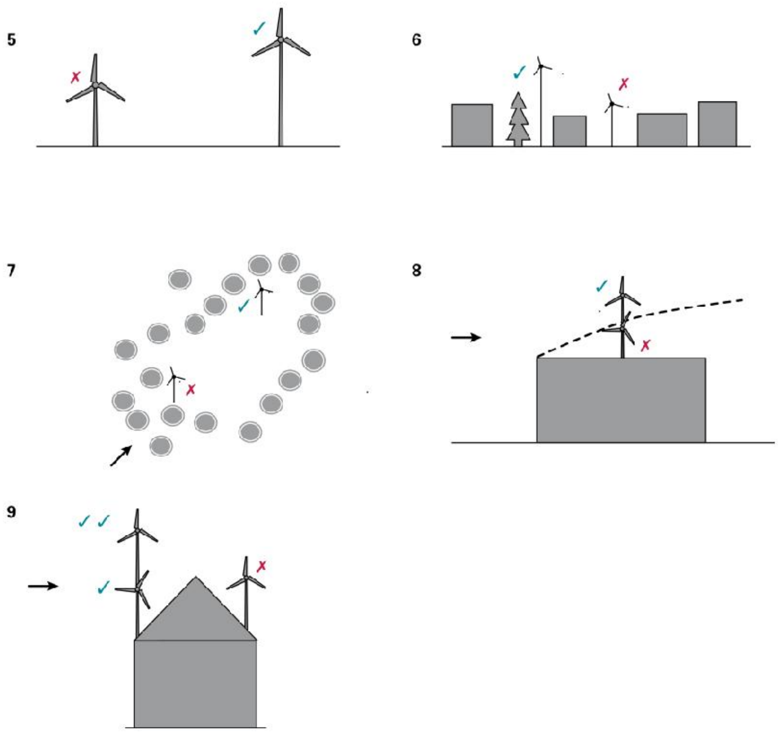
[106] *CARROL, S. Installations of Small Wind Turbines in an Urban Environment. Crest Msc paper, CREST Lboro University, 2005*

In summary the recommendations are as follows:

a) Deciding whether a site is suitable



b) Optimising yields and carbon savings



The arrows indicate wind direction

Source: Met Office

1 Turbines should be sited near the edge of built up or forested areas in preference to central locations. It is best to choose a location on the side of the prevailing wind.

2 Locate the turbine over a rural, non-forested area in preference to built up or forested areas.

3 Site turbines near the top of smooth hills. Sharply changing gradients, such as cliff tops, can cause turbulence and may not be suitable. For steep hills, the turbine should be placed at the highest point or on the side of the prevailing wind if the summit is not an option.

4 For each obstacle that protrudes above the general level of the roughness elements (e.g. a tower block within an area of generally one or two storey housing), try to ensure that the turbine is located.

Either further away than 3 to 10 times the obstacle height (larger factors applying to wider obstacles as seen from the turbine location) and further still if possible, up to 30 times;

Or higher than 1 to 1½ times the obstacle height (larger factors applying when the obstacle is a pitched roof building or a building with an along-sight length viewed from the turbine location which is less than the height) and higher still if possible, up to 1¾ to 2 times.

5 Position the turbine as high as practicably possible or allowed.

6 Position the turbine above the height of nearby trees or buildings.

7 If practical considerations prevent the turbine being mounted above the height of nearby trees or buildings, ensure there is a clear view on the side of the prevailing wind direction (typically south-west in the UK).

8 Turbines mounted on flat roofs should be placed above the turbulence in the wake of the air stream.

9 For turbines mounted on pitched roof buildings that extend above the surrounding obstacles (e.g. other buildings, trees, etc), ensure that:

Either the turbine height above the roof peak is at least half the vertical depth of the roof (base to peak);

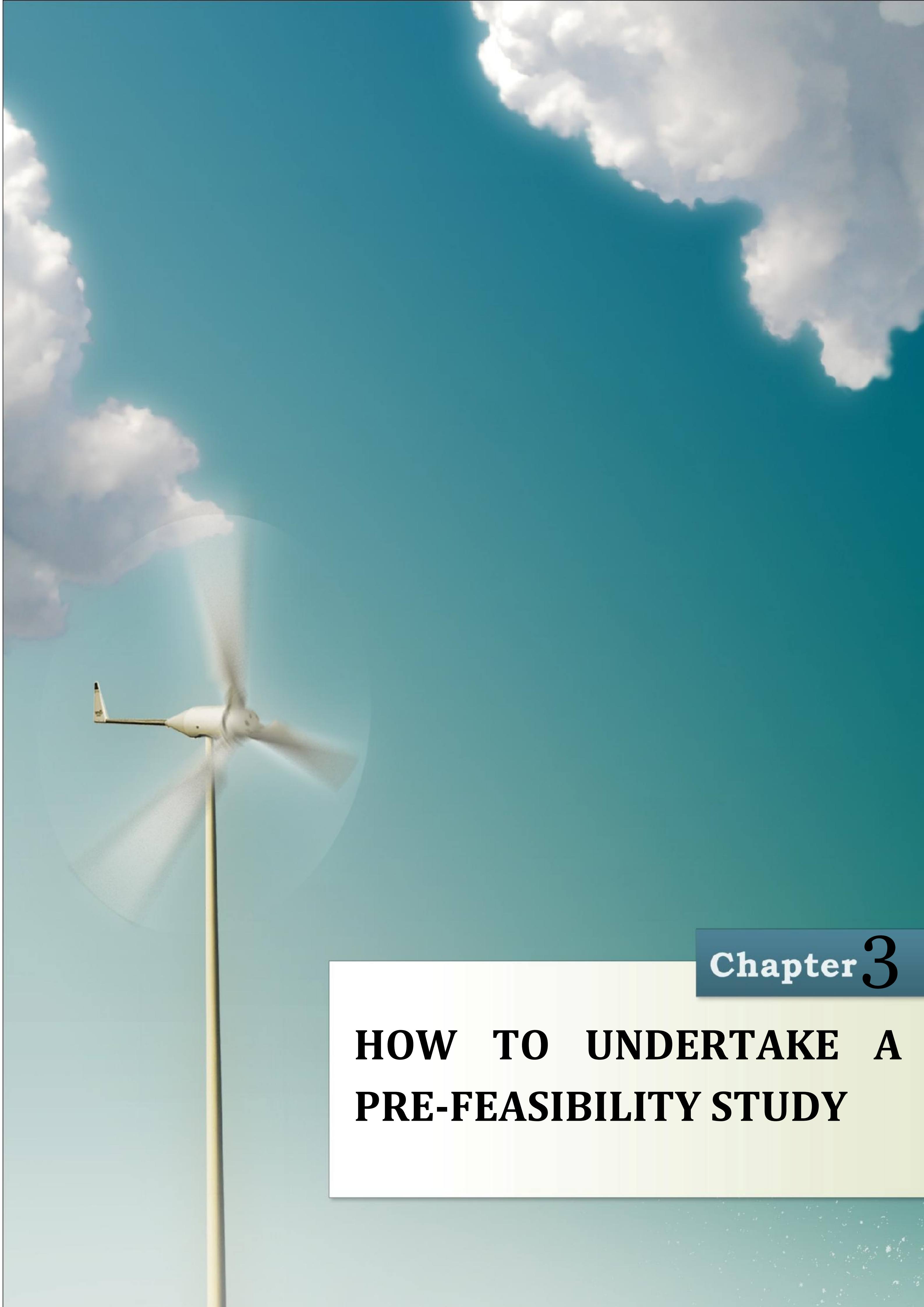
Or the turbine is mounted in front of the peak from the perspective of the prevailing wind direction (and ideally both).

Figure 64: Ideal placement for turbines[107]

[107] *Carbon Trust. Small-scale wind energy. Policy insights and practical guidance.*

2.11 DIFFERENCES BETWEEN SMALL AND LARGE WIND TURBINES

- *The height levels are lower than those of large wind turbines, usually between 10m and 30m. Each site thus needs some form of wind evaluation to take this into account, as sites at these levels are characteristed by lower wind velocities, with susceptibility to turblence or shadow from obstacles.*
- *It can be used for stand-alone off-grid operations. It is more diverse in applications and can be used in combination with other energy sources (solar, diesel, hydro etc)*
- *It can be instigated by a large number of protagonists, being promotors, indivuduals, companies, local authorities etc… due to its low to medium investment requirements.*
- *The technology is not yet mature, and in many cases the manufacture is small-scale. This is reflected in the high cost per kW installed and the longer payback periods.*
- *The reliability and efficiency have more potential for improvement*
- *There is a lack of accreditation and certification of turbines and in general little regulation in many countries. This leaves a large area of legal uncertainty and is a disincentive to investment*
- *They havent been as well tested or proved in practice, and thus there is alot of uncertainty with regard to their perfromance, exacerbated by their susceptibility to local conditions.*
- *The tipspeed of miniwind turbines is high which has an impact on noises and vibrations and in particular security of operation particularly near residential areas.*
- *The ancillary equipment is very different from its larger sister, with low or medium voltage connections.*
- *It requires less space, and can even be situated on rooftops.*



Chapter 3

HOW TO UNDERTAKE A PRE-FEASIBILITY STUDY

3. HOW TO UNDERTAKE A PRE-FEASBILITY STUDY

3.1 INTRODUCTION

The plan to set up a miniwind energy system can arise from the following reasons:

1. To cover necessities for electricity in zones where grid supply is deficient.
2. For investment reasons, to bring financial benefits.
3. For educational or research purposes.

Your prefeasibility and/or feasibility study, will be geared to one of theses 3 system types.

3.2 PROCESS FOR PROJECT IMPLEMENTATION

In summary the phases of Project development for a complex miniwind energy system are as follows (in the case of a simple installation may skip phases 2 and 3):

1. **Prefeasibility phase:** This is a quick, low cost study to evaluate the technical and financial realities of the Project as well as the necessary requirements to undertake a more in-depth study later on. These studies will or will not need a site visit, depending on the project.

2. **Detailed feasibility study:** This is a more detailed study, sometimes costly, following on from the results of the prefeasibility study. The study should include physical characteristics, a detailed financial study, environmental and social impacts, applicable regulations etc.. Site visits will be absolutely necessary with measuring equipment, energy auditing tools, simulation software, as will be consultations with manufacturers and suppliers. The depth of the study will be very closely related to the size of the installation, a small 5kW miniwind installation will require a much less in-depth evaluation than a 50kW one. Financial studies are key for the larger installations, or any investment installation where good financial returns are required. They are usually less vital for isolated installations where the necessity for electrical supply is the main driver.

3. **Engineering and Development:** In the case of larger projects, engineering may be required to meet with necessary regulations and proper execution of the civil works. In some cases, where impacts are larger, some form of local promotion, awareness raising and public consultation may be necessary to ensure smooth implementation of the installation. In general the main elements of a miniwind installation will entail obtaining of permissions, grid connection, consultation with neighbours and the local council.

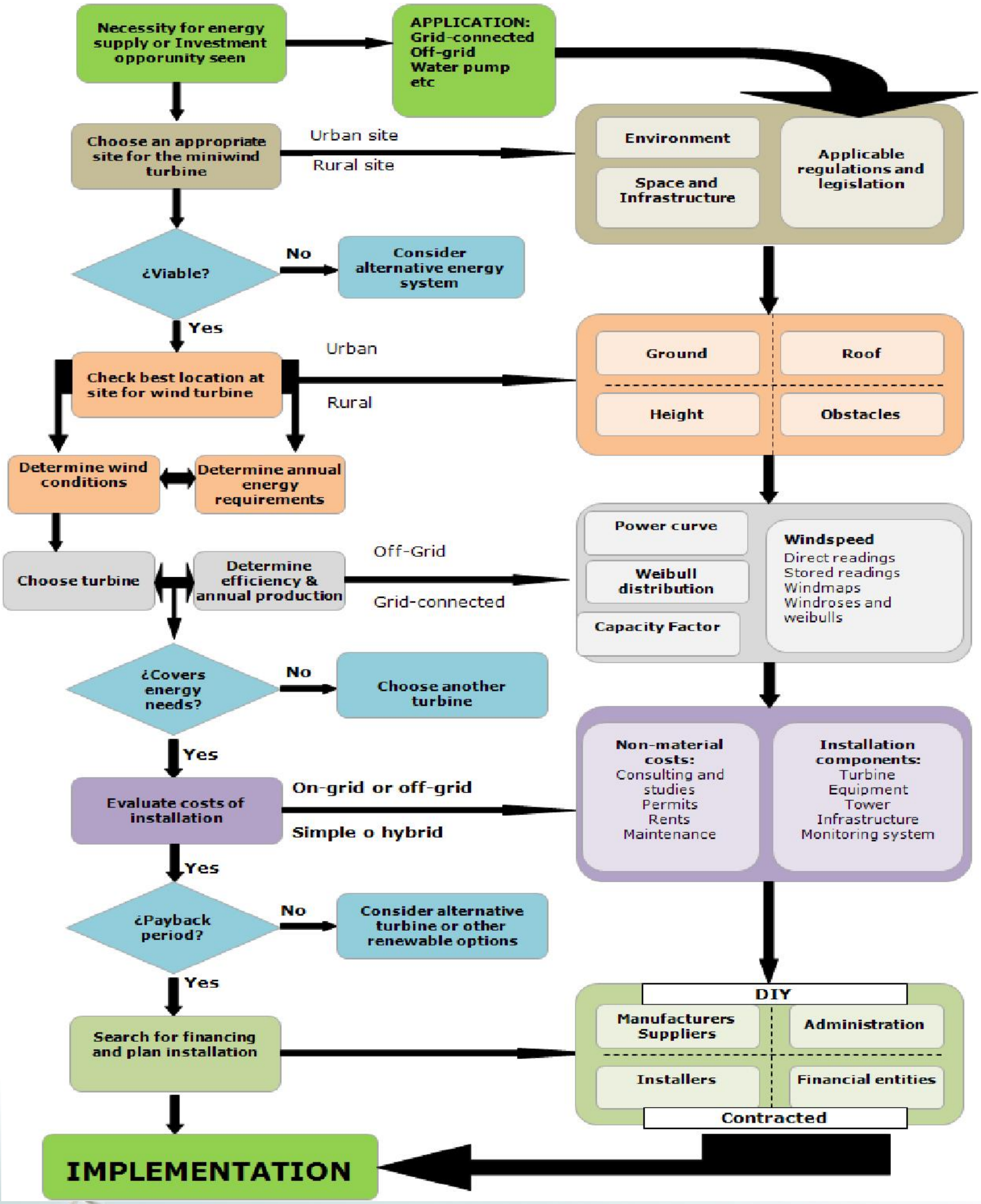
4. **Construction and Start-up:** After having resolved financial issues and the necessary administrative procedures (permits, authorizations, contracts, grants etc) the next step is the physical construction of the installation followed by start-up and trial phase in which the installation parameters can be checked with those estimated in the previous studies. Any system of measurement of real production will assist in determining system performance and is highly recommended.

5. **Maintenance and Monitoring:** All installations, equipment and systems require maintenance and periodic revisions. For miniwind systems, annual servicing is recommended, which excluding problems, should be a quick process.

3.3 PREFEASIBILITY PHASE

In this document we will expound the steps to take in order to undertake a prefeasibility study, based on the work of the RuralRES partners. It does not include how to estimate production or costs from hybrid systems or other complementary parts of an installation such as PV panels and electric generators.

The following table shows the logical process to follow for a miniwind prefeasibility study:



Scheme 1: Pre-feasibility process

3.3.1 Installation design

The first step is to determine and characterise the installation in terms of its type and final application.

There are a multitude of applications as specified in section 2.9. It will be the final use of the miniwind energy that will determine the various components which the installation will take, and also have implications on its costs.

Furthermore one must evaluate the options of combining the miniwind energy with other sources in a hybrid installation, which will give more stability to the performance of the system. In which case one must choose the optimum proportion of energy that will come from the turbine, compared to that of the rest of the energy sources. This will depend on their relative performances and relative costs established in the financial study.

The following table shows the usual components of which a miniwind energy system can be comprised of:

	APLICACIÓN FINAL DEL SEME							
COMPONENTS NECESSARY	**Net-metering**	**Grid sales**	**Off-grid, self-consumption**	**Electric pump**	**Mechancial pump**	**Heat production**	**Hydrogen production**	**Water desalination**
Generator	x	x	x	x	x	x	x	x
Tower	x	x	x	x	x	x	x	x
Rectifier/Charger	-	-	x	x	-	-	-	-
Inverter	x	x	x	Depending on system	Transmission mechanism	Heat exchanger	Electrolysis equipment	Desalination equipment
Batteris	-	-	x	Depending on system	-	Storage	H_2 storage	-
Meter	x	x	-	-	-	-	-	-
Anenometer	recommended	recommended	recommended	recommended	-	-	recommended	recommended
Production monitoring	recommended	recommended	recommended	recommended	-	-	recommended	recommended
Data storage/transmission software	-	Necessary	-	-	-	-	-	recommended
Protection equipment	Small	Small	Medium	Medium	-	Medium		Platform required
Additional components for hybrid systems								
Solar	Solar panels + regulator/charger + radiation measurement systems + solar meters							
Generator	Generator + storage tank							

Table 10: System design components by installation type

3.3.2 Site description

Once the installation and its components have been designed, a site description and evaluation where the miniwind turbine is to be placed must be carried out. This must include the type of terrain, its planning status and environmental and social framework in which it is located.

In general there are two main types of locations for miniwind turbines: urban and rural (excluding aquatic applications). Both have different planning regulations, topography and performance characteristics.

Aside from the energy potential of the site, the general aspects which characterize and define for a prefeasibility study as shown in the table below:

	TYPE OF LOCATION		
ASPECTS TO CONSIDER	**Urban**	**Rural**	**Aquatic**
Regulation related issues			
Landscape	Visibility from other buildings. Building shadow	Necessary permits and restrictions. Landscape restrictions Visual impact	Visual impact and regulation
Noise/vibrations	Acoustic standards. Noise maps. Structural vibrations.	Acoustic standards. Land planning classification. Proximity of buildings.	Medición de ruido desde la costa. Edificaciones próximas Measurement of noise from land.
Protected areas	-	Identify protection levels	Existing uses ie fishing, sports
Birdlife	Study for migratory species and specially protected species. Maximum permitted height levels and tubine sizes and tip speeds.		
Fauna	-	Agricultural requirements and protected species.	-
Planning	Urban regulations on wind.	Urban regulations on wind.	-
Grid connection	Legislation and procedures for grid connection and connection points. Certificate and quality requirements for supply and administrative procedures.	Legislation and procedures for grid connection and connection points. Certificate and quality requirements for supply and administrative procedures.	-
Market Incentives available.	Price per kW for each power rating and type of application.	Price per kW for each power rating and type of application.	Price per kW for each power rating and type of application.
Grants & Subsidies	Direct subsidies and assistance for financing at national, regional and local level. Bureaucracy to obtain grants.	Direct subsidies and assistance for financing at national, regional and local level. Bureaucracy to obtain grants.	Direct subsidies and assistance for financing at national, regional and local level. Bureaucracy to obtain grants.
Social aspects			
Local acceptance	Questionnaire for neighbours and locals. Minimum distance to be required.	Questionnaire for neighbours and locals. Minimum distance to be required.	-
3rd party insurance	Depending on national regulations. Recommended	Depending on national regulations and how isolated site is.	Depending on national regulations and risks.
Property rights	Limitations stipulated	Limitations stipulated	Limitations stipulated
Community rules	Limitations stipulated	Limitations stipulated	-
Neighbourhood agreements	Non-official limitations	Non-official limitations	-
Other nearby wind turbines	Search and study	Search and study	Search and study

Table 11: Points to consider for site description.

Once these aspects have been studied, one must evaluate whether miniwind is the most appropriate technology for this site, bearing in mind its characteristics. Frequently there are barriers, neither technical nor resource-based that can render miniwind inviable, for example, local, regional or national environmental legislation, difficulty in obtaining permits, or impediments to grid-connected sales.

Whereas physical limitations can be discovered by simple observation there are other limitations that require research at the local, or regional authority for planning, and environmental issues or contacts with the energy distribution companies for electrical connection issues.

3.3.3 Optimum location for the miniwind turbine

The correct location and height of the turbine is determined by a series of factors such as distance to potential obstacles and its height, turbulence, proximity or other homes or facilities, the distance to the network connection, speeds and predominant wind directions, etc ...

All these aspects have been addressed earlier, thus if the site description has been successful you should have identified all elements and determining the optimum location shouldn't be problematic.

It is advisable to see an aerial view of the site, in which all elements between 50 and 100m can be seen and potential obstacles indentified that may cause conflict and turbulence and to estimate their height from which one can calculate the minimum distances and heights for the wind turbine.

On the other hand depending on the site, whether it be rural (isolated) or urban (built), the optimum location can vary greatly. Thus while in rural settings they can be located on the ground and roofs, either in towers lattice, guyed or cylindrical, in urban areas they are usually located on roofs of tall buildings and / or isolated, fasteners and special support. Optimum tower heights in both scenarios will also vary, because while in rural areas they must exceed the height the turbulence caused by obstacles, from 10 to 30 m, in urban environments they are already raised by the building and tower heights rarely exceed 10 m.

To achieve a good production most wind turbines need a wind velocity in the order of 5 m/s. The tower height should be chosen so that the rotor is located in undisturbed wind with wind velocity of at least 5 m/s. The choice of tower height is facilitated very much if wind measurements are taken. Without wind measurement data the tower height should be chosen so that the wind velocity 5 m/s is achieved with a good margin

High tower heights incur a higher cost, but one must balance this with a much higher production, as windpseed increases with altitude. A lower tower requires a higher power turbine to produce the same energy as the high tower. As well as considering tower height for ideal energy output, space must also be allowed for obstacles. Thus before the final choice of tower height all these factors must be balanced. Very often, depending on the type of tower, the height increase gives an increase in production that more than outweighs additional cost, reducing return periods or "payback" of the installation.

To summarise these factors that should be considered in the location and height of the wind turbine the following table has been drawn up:

	TYPE OF SITE		
ASPECTS TO CONSIDER	**Urban**	**Rural**	**Water**
Environment			
Relief	Modelling and buildings studies, rooftops and nearby structures	Undulation of surface, hills, mountains, valleys, clifftops etc	Type of coast and wáter (lake, sea etc)
Altitude	Above sea level	Above sea level	-
Natural Obstacles	Trees	Trees,raised areas	cliffs
Climatology	--------	--------	--------
Shadow	Very important. Daily variations in shadows frequency of turbulance.	Relevant if there are buildings or other obstacles close by.	Not relevant
Background noise	Important. dB of wind turbine should be compared to this.	Important. dB of wind turbine should be compared to this.	Not really relevant
Roughness (windsheer) (α)	High roughness factor Type of buildings and rooftops. Determine variation in turbulence and the limits of the zone.	. Roughness factor depends on type and use of ground, particularly vegetation types.	Very low
Ground	Important for anchoring of the tower.	Important for anchoring of the tower.	Depth of water if not a floating platform
Solar Radiation	Determine the possibility of combining with this type of renewable energy	Determine the possibility of combining with this type of renewable energy	n/a
Wind conditions			
Prevailing direction	Wind rose study, compare with location of obstacles.	Wind rose study, compare with location of obstacles.	Relevant if there are cliffs. Sea-breeze (thermal breeze) study useful
Speed	At relevant heights above turbulence	At relevant heights above turbulence	Normally constant
Frequency distribution	From this the anual production for the miniwind system can be calculated		
Gradient	Will affect the height of the tubine		
Turbulence	Use of software and modeling recommended due to real issues in urban areas.	Identify type and height of closeby obstacles. Can be done visually	Not an issue
Infrastructure and Equipment			
Connection point	Determine distance and availability of point. Net-metering or electricity sales required. Check legislation.	Determine distance and availability of point. Net-metering or electricity sales required. Check legislation.	Electrical infrastructure required, which will imply costs and bureaucracy..

	Other nearby installations	Could provide useful data. Could provide connection point and speed up administrative procedures.	Could provide useful data. Could provide connection point and speed up administrative procedures.	Could provide useful data. Could provide connection point and speed up administrative procedures.
	Manmade obstacles	Towers, buildings, rooftops, etc	Towers, buildings, rooftops, etc	-
	Spaces and Locations available	Places available for tower and electrical equipment. Possibilities to fix guy-ropes. Possiiblities for ground, rooftop and wall mountings.	Places available for tower and electrical equipment. Possibilities to fix guy-ropes. Possiiblities for ground, rooftop and wall mountings.	No limitations, as long as legislation permits.
	Other energy installations, existing or proposed	Determine and plan compatibility	Determine and plan compatibility	Determine and plan compatibility
	Existing electrical infrastructure	Capacity. Modifications and amplifications necessary		
	Type of rooftops	This will establish the type of supports, position, height and possible vibrations from the turbine.		Type of platform

Table 12: Points to consider for optimal locational chocice.

3.3.4 Wind study

The main aspects that must be taken in account for wind conditions which will serve as a basis for the following phases to calculate wind turbine production are:

Prevailing Wind: This can be identified through a wind rose diagram. This will determine the location of the tower in relation to obstacles, so that it is always facing the prevailing wind.

Wind distribution: This will identify the number of hours at each wind velocity that the wind will blow and is crucial for estimating annual electricity production.

Wind shear: This will show the rate of increase in wind velocity as height from the ground increases. The rougher the terrain, the more accelerated will be the increase in windspeed as height increases.

Obstacles: Determine where and at what height turbulence is minimized. You need to determine height, form, type, number, minimum distances and heights from which the tower can be erected.

Although the ideal method for wind calculations is to measure the wind directly at different heights in different spots for 12 months, there are some quicker and less costly ways to estimate wind potential, that could be sufficient for a simple prefeasibility study.

3.3.4.1. Visual estimation of wind speed

Using pure observations, there are scales that assist in determining the force available in the wind at the site. The Beaufort scale is the most famous and has been applied at sea mainly, but is now also used on land. It gives an estimate of the strength of the wind based on simple observations on particular the wind's effect on elements in the surroundings.

Beaufort number	Wind speed				Mean wind speed (kt / km/h / mph)	Description	Wave height		Sea conditions	Land conditions
	kt	km/h	mph	m/s			m	ft		
0	0	0	0	0-0.2	0 / 0 / 0	Calm	0	0	Flat.	Calm. Smoke rises vertically.
1	1-3	1-6	1-3	0.3-1.5	02 / 04 / 2	Light air	0.1	0.33	Ripples without crests.	Wind motion visible in smoke.
2	4-6	7-11	4-7	1.6-3.3	05 / 09 / 6	Light breeze	0.2	0.66	Small wavelets. Crests of glassy appearance, not breaking	Wind felt on exposed skin. Leaves rustle.
3	7-10	12-19	8-12	3.4-5.4	9 / 17 / 11	Gentle breeze	0.6	2	Large wavelets. Crests begin to break; scattered whitecaps	Leaves and smaller twigs in constant motion.
4	11-16	20-29	13-18	5.5-7.9	13 / 24 / 15	Moderate breeze	1	3.3	Small waves.	Dust and loose paper raised. Small branches begin to move.
5	17-21	30-39	19-24	8.0-10.7	19 / 35 / 22	Fresh breeze	2	6.6	Moderate (1.2 m) longer waves. Some foam and spray.	Smaller trees sway.
6	22-27	40-50	25-31	10.8-13.8	24 / 44 / 27	Strong breeze	3	9.9	Large waves with foam crests and some spray.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult.
7	28-33	51-62	32-38	13.9-17.1	30 / 56 / 35	Near gale	4	13.1	Sea heaps up and foam begins to streak.	Whole trees in motion. Effort to walk against the wind.
8	34-40	63-75	39-46	17.2-20.7	37 / 68 / 42	Gale	5.5	18	Moderately high waves with breaking crests forming spindrift. Streaks of foam.	Twigs broken from trees. Cars veer on road.
9	41-47	76-87	47-54	20.8-24.4	44 / 81 / 50	Strong gale	7	23	High waves (2.75 m) with dense foam. Wave crests start to roll over. Considerable spray.	Light structure damage.
10	48-55	88-102	55-63	24.5-28.4	52 / 96 / 60	Storm	9	29.5	Very high waves. The sea surface is white and there is considerable tumbling. Visibility is reduced.	Trees uprooted. Considerable structural damage.
11	56-63	103-117	64-72	28.5-32.6	60 / 111 / 69	Violent storm	11.5	37.7	Exceptionally high waves.	Widespread structural damage.
12	>63	>117	>72	>32.7	N/A	Hurricane	14+	46+	Huge waves. Air filled with foam and spray. Sea completely white with driving spray. Visibility very greatly reduced.	Massive and widespread damage to structures.

Figure 65: Source: http://www.gunsails.co.uk/en/Beaufort.htm/

Another similar scale is the Griggs-Putnam wind energy index which refers to the deformity of a pinetree to estimate wind strength:

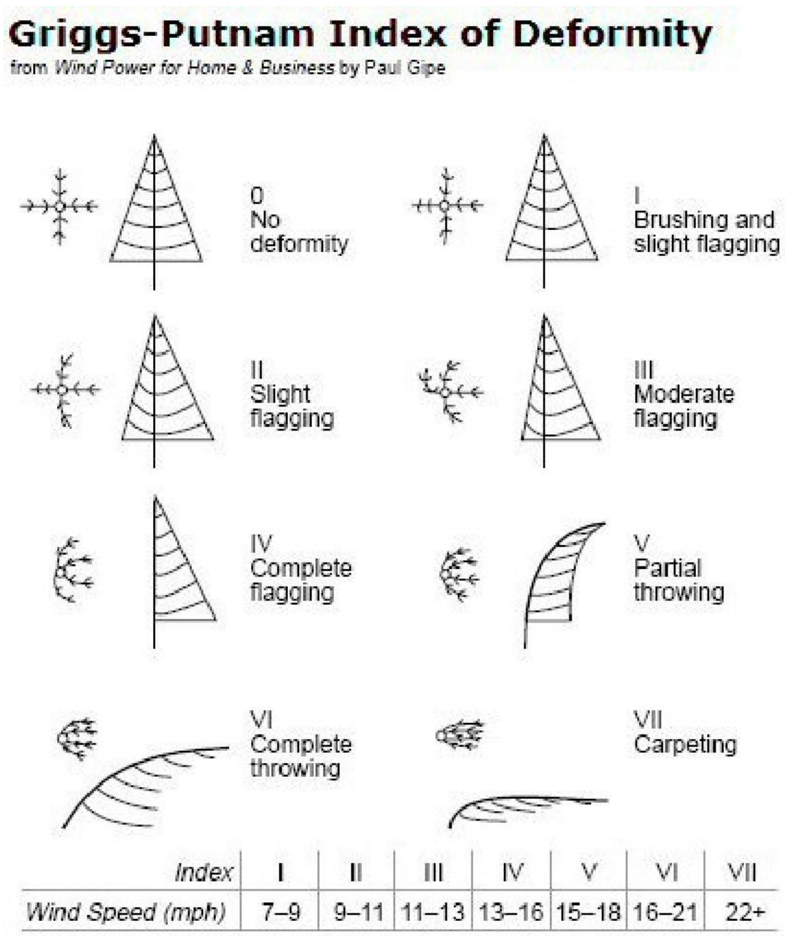


Figure 66: Griggs-Putman Index of deformity

However, these measurements can only be taken on the spot at a a certain point in time and do not give a comprehensive record of the wind conditions on the site and thus could be misleading.

3.3.4.2. Anenometer studies.

The best way to really understand the wind conditions at your site is to undertake a real wind data study, with measurements every 10 minutes, taken through the year. If you are fortunate there may be a weather station nearby that can facilitate the necessary data to get an idea of the wind conditions at your site. If not, then you will have to undertake the wind study yourself, time and costs permitting.

The necessary elements of an anemometer study are:

- A **weather vane** to measure directions at all moments. For determination of the wind direction, potentiometric transmitters are increasingly being used, because the resolution is excellent and they consume little power. It is important to keep in mind that the out-going-signal has to cover a full

360 degrees without gaps. Because they have only a very simple power meters, cheap wind vanes often show a big north-gap. These "low cost"-sensors can also have only a limited life, because the electro-mechanical material used in their construction are not durable enough.

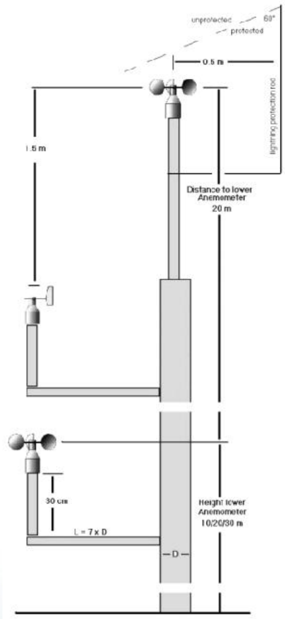
- **Anenometer**. Cup anemometers are the standard way of measuring wind speeds in wind energy measuring systems. Opto-electronic transformers and AC-generators have proved to be the most suitable transducers. One of the reasons is that they are robust. But most opto-electronic transformers supply a much higher pulse-rate (at least 10 Hz per m/s), which is needed for the recording in short measuring-intervals or for the evaluation of turbulence.

It is advisable to choose combined wind sensors and ultrasonic horizontal axis anenometers

- A “**data logger**” which stores the digital information of the anemometer and weather vane.
- If feasible, **data transmission and reception** software.
- A **tower** to locate the measurement equipment
- Other optional equipment for measuring **atmospheric pressure, humidity and temperature,** although these could be sought from the nearest weather station.

For more information please consult the “Wind Measurement for accurate energy predictions” document in the RuralRES Training section of the RuralRES website:

These measuring equipment will need to be raised in a tower or structure of some kind:



1. Height of measuring equipment

The ideal approach would be to measure the wind speed at the hub height of the wind power generation station that is to be installed.

Two arguments against this are that the exact hub height is most probably not yet known, since the final decision will be made on the basis of the measurement results, and secondly, that such as high measurement tower is very expensive and difficult to install.

1. The use of individually calibrated anemometers with a low sensitivity against skew winds
2. The lower anemometer must be fitted high enough to avoid influences by obstacles (bushes, houses etc.)
3. The distance between the two anemometers should be at least 15 to 20 m

On a "simple" location (flat land, no obstacles) a measuring tower with calibrated anemometers in 10 and 30 m is sufficient. In more complex areas, the lower anemometer has to be fitted higher. In order to provide the minimum spacing, the measurement tower therefore has to be higher. Here measuring at 20 and 40 m or even 30 and 50 m is needed.

The weather vane musn´t be positioned in a way that it affects the anemometer, a distance of at least 1,5m below the anemometer is suggested.

An example, what a wrong measurement can cause for energy prognosis:		
Correct Measurement 10 m = 4.4 m/s 30 m = 5.3 m/s	The result is a roughness length of 0.047 m or a wind speed in 78 m height of 6,08 m/s	A WEC with 600 kW power and hub height of 78 m will produce on this site per year: **1210 MWh**
Possible deviations 10 m = 4.2 m/s 30 m = 5.5 m/s caused by • No calibration • Wrong fitting • Skew wind	The result is a roughness length of 0.288 m or a wind speed in 78 m height of 6,63 m/s	By this small measurement mistake the prognosis for the same WEC is now: **1462 MWh**
Measurement error at 10 m = - 0,2 m/s (- 4,5%) Measurement error at 30 m = + 0,2 m/s (+ 3,8%)		Overestimation of the energy prognosis: **= 21 %**

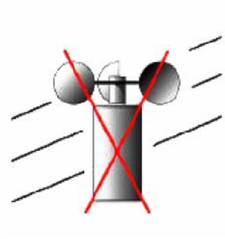
Figurae67: Example of errors that can be made due to bad anemometer readings. [108]

[108] Copyright © 2000.Ammonit Gesellschaft für Meßtechnik mbH. Paul-Lincke-Ufer 41. D - 10999 Berlin

2. Avoidable mistakes

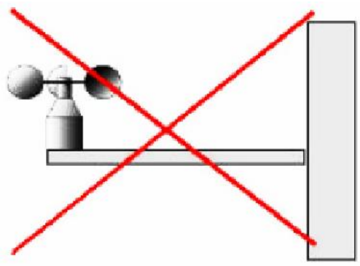
When choosing sensors and installating the measuring tower avoid the following mistakes:

Wrong anemometer: There are a lot of different anemometers! You want to measure the unrestricted horizontal component of the wind stream, because this is what is relevant for energy generation. Wind transmitters with small cups and a sharp-edged body often have trouble with skew winds and turbulence caused by tower and travers. Even calibration cannot help much in these cases.

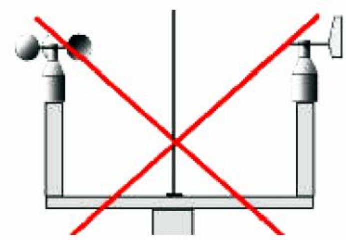


No calibration: Even the accuracy of highly developed anemometers "straight from the firm" do not meet the requirements for accurate energy prognosis. The tolerances specified by the manufacturers can lead to unacceptable deviations in the profit calculations. You only get the necessary reliability of the forecast if each anemometer is calibrated separately in a wind channel

Wrong traverses: Close to the tower and traverses there is always turbulence and shading, which can have a negative effect on the measurements. Wind transmitters installed on traverses should therefore not be fitted directly on the boom. And in relation to the diameter of the tower the boom itself must also have a minimum length. At the same time, the traverse must remain stable, so that it does not oscillate.

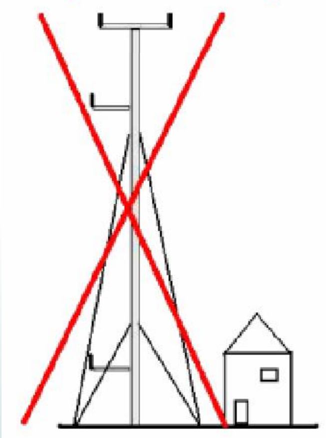


Shaded by wind vane*:* The anemometer should be streamed upon from all directions without obstacles. The important top-anemometer can be fitted in an ideal position, since it is situated over the tower. But this advantage is often ruined by fitting a wind vane right next to it!



Choosing wrong measuring heights The calculation of the height profile is difficult enough, because the logarithmic formula used is just a general approach. If mistakes are made with the basic input data, the uncertainty in the result will grow bigger and bigger.

- Data from anemometers that are shaded by houses, trees or other obstacles is unsuitable.
- Anemometers fitted too near to each other give inadequate data for the calculation of the height



profile, since the difference between the two results is too small.

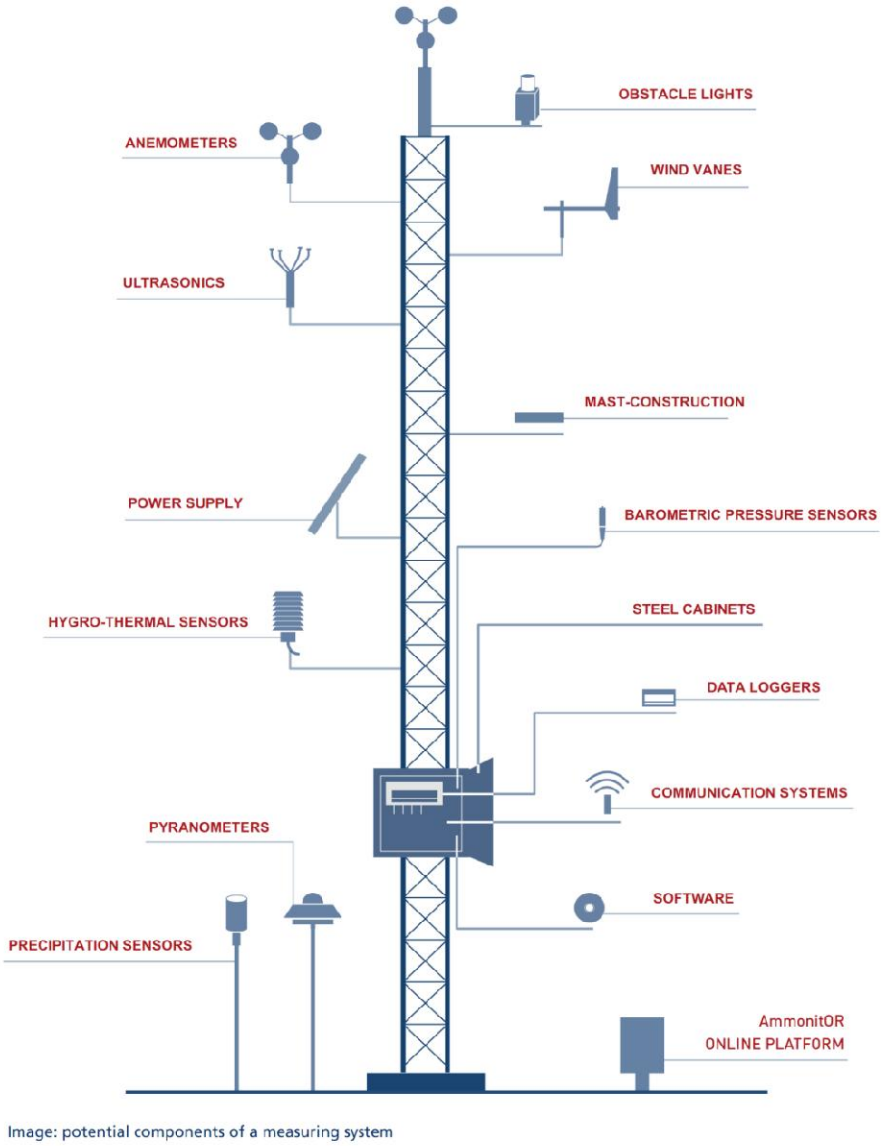


Figure 68: Potential components of a measuring system[109]

3.3.4.3. Wind maps, models and other sources

If the possibility for obtaining real anemometer data in the area is not possible, a desktop research should be undertaken by consulting the different entities that deal with energy and climate like local energy agencies, local administrations and meteorological officers in order to obtain wind data that already exists, especially focused between 10m and 30m most pertinent to miniwind. Most of the windmaps that are available have been designed for large wind parks, often with measurements, or estimates at 80m. However some national and regional databases are available in countries, either directly measured for 10m, or extrapolated according to surface roughness. They are very useful tools but should be applied with caution allowing for a large error margin.

[109] Measuring wind.Know-how for successful wind measurements

The data that should be sought is the following:

- **Average, minimum and maximum windspeed**
- **Weibull frequencies and distributions**
- **Rayleigh distribution**

The Rayleigh distribution is if you know only the average wind speed for a location. Probable fluctuations around this point will be calculated with this function. But the Rayleigh Distribution has a fixed general form, which can only reflect regional features to a certain extent [110]. Its values are shown in the following table[111]:

Velocidad v (mph)	Velocidad media (millas por hora)									
	8	9	10	11	12	13	14	15	16	17
	Número de horas									
8	784	731	666	601	539	484	435	391	353	320
9	716	697	656	605	553	503	457	415	377	344
10	630	644	627	594	554	512	470	431	395	363
11	536	578	585	570	543	510	476	441	408	377
12	441	504	533	536	523	500	473	443	415	386
13	351	429	474	494	494	483	464	441	416	391
14	272	356	413	446	459	458	448	432	412	391
15	204	288	353	396	420	429	427	418	404	387
16	149	227	295	345	378	396	403	400	392	380
17	105	175	242	296	336	361	375	379	377	369
18	73	132	194	250	294	325	345	355	358	355
19	49	97	153	207	253	289	314	330	337	339
20	32	70	119	170	216	254	283	303	315	321
21	20	50	90	136	181	220	252	275	291	302
22	12	34	68	108	150	189	222	248	268	281
23	7	23	50	84	123	160	194	222	244	260
24	4	15	36	65	99	134	168	197	220	239
25	3	10	25	49	79	111	143	173	198	218
26	1	6	18	37	62	91	122	150	176	197
27	0,8	4	12	27	48	74	102	130	155	177
28	0,4	2	8	20	37	60	85	111	136	158
29	0,2	1	5	14	28	47	70	94	118	140
30	0,1	0,8	4	10	21	37	57	79	102	124
31	0	0,5	2	7	16	29	46	66	87	108
32	0	0,3	1	5	11	22	37	55	74	94
33	0	0,1	0,9	3	8	17	29	45	63	81
34	0	0	0,5	2	6	13	23	37	53	70
35	0	0	0,3	1	4	10	18	30	44	60
36	0	0	0,2	0,9	3	7	14	24	36	51
37	0	0	0,1	0,6	2	5	11	19	30	43
38	0	0	0	0,4	1	4	8	15	24	36
39	0	0	0	0,2	0,9	3	6	12	20	30
40	0	0	0	0,1	0,6	2	5	9	16	25

Table 13: Values for Rayleigh distribution[112]

[110] Copyright © 2000.Ammonit Gesellschaft für Meßtechnik mbH. Paul-Lincke-Ufer 41. D - 10999 Berlin
[111] http://www.extractores.com.mx/energia%20atmosferica.htm
[112] http://www.extractores.com.mx/energia%20atmosferica.htm

- **Windrose.** See Section 1.4.4
- **Modelling:** There are some simulation models that with sufficient data can estímate the wind speed and fluctuations based on computer modelling. They are particularly useful with complex building structures.
- **Weather stations:** If weather stations exist close by, this data should be taken advantage of- you should take note of the height of measurement.
- **Other closeby installations:** If other miniwind installations are located closeby try to contact the owner and get them to facilitate information on both the wind data and energy production at that site.

3.3.4.4. Calculation of wind speed by the exponential formula

If the wind speed at a certain height is known, eg 80m a formula can be applied according to surface roughness to estímate the wind velocity at the hub height you wish to measure according to the following equation:

$$\mathbf{V_{(h)} = V_o * (h/h_o)^{\alpha}}$$

v_0 the known wind velocity at height h_0.
v the unknown wind velocity at height h
α the wind shear exponent varying with the terrain

Wind roughness class 0 (open water): α = 0.1
Wind roughness class 1 (smooth, level, grass-covered): α = 0.15
Wind roughness class 2 (country, low bushes, a few trees and farms): α = 0.2
Wind roughness class 3 (smaller villages and low forest): α = 0.3

By means of the above formula the decrease in wind velocity can be illustrated in a graph, a so called wind gradient. As for example shown in Figure 69 how wind velocity 7 m/s at 50 m height decreases closer to the ground depending on the surroundings' wind roughness.

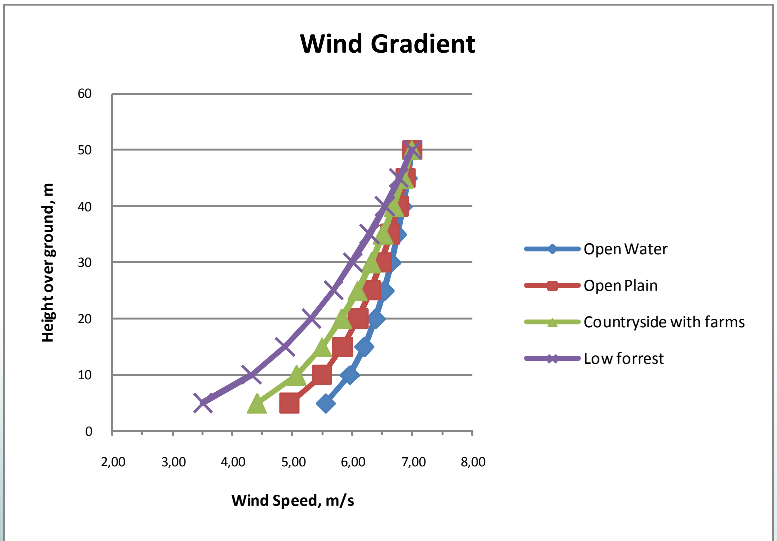


Figure 69. The figure illustrates the relation between the average wind speed, height above ground level and roughness class.

3.3.5. Estimation of energy requirements.

Once the wind potential and the optimum location has been found, the amount of production that the equipment can provide must be estimated, along with the energy demand necessary to establish if the miniwind system can meet the necessary requirements.

Bear in mind that energy efficiency and rational use of energy is the cheapest and best way to save resources, and all energy saving measures should be taken beforehand and will ensure a better performance from the miniwind system.

Battery-supported system

The first step in determining consumption of your installation is to undertake an inventory of all the existing equipment, and those that will be connected, their hours of operation, power rating, periods of maximum and minimum consumption. A precise estimation is key to be able to correctly size the capacity of the miniwind system, and the batteries, if required, for the installation.

A table similar to that shown below is used to calculated consumption and energy needs.

	EQUIPMENT	Nº	CONSUMPTION (W)	TOTAL (W)	HOURS PER DAY	DAILY CONSUMPTION (WH/DAY)
EXAMPLE	Bulbs	5	10	50	3	**150**
...	TV	1	100	100	5	**500**
					TOTAL	**650**

Table 14: Estimated consumption table

Assuming that consumption is the same all year round we can calcúlate the energy demand in kW/year:

650 Wh/day x 365 days/year = 237250 Wh/year =**237.3 kWh/year**

The previous calculations give us a total energy consumption per year in kWh/year that will be required without taking into account system losses through battery losses, cabling, conversion systems AC-DC and viceversa.

This calculation is particularly vital for isolated installations where system losses are more acute and where risk of being left short of electricity is greatest. The table below shows a more involved consumption calculation including losses and the Amp hours necessary for battery energy accumulation.

Equipment	Nº	Current (A)	Voltage (V)	Power AC (W)	Daily use (hours/day)	Weekly use (days/week)	Efficiency	Nominal voltage (V)	Consumption (Ah/day)
Lights	50	0,05	220	**594,00**	4,0	7	0,9	48	**55,00**
Outside lights	30	0,13	220	**858,00**	5,0	7	0,9	**48**	**99,31**
TV	14	0,45	220	**1.386,00**	3,0	7	0,9	**48**	**96,25**
Radio	12	0,03	220	**66,00**	5,0	7	0,9	**48**	**7,64**
Fridge	12	0,38	220	**1.003,20**	8,0	7	0,9	**48**	**185,78**
Computer	2	0,38	220	**167,20**	4,0	7	0,9	**48**	**15,48**
Other	2	13,50	220	**5.940,00**	3,0	2	0,9	**48**	**117,86**
				0,00				**48**	**0**
			Total Power (W)	**10.014,40**				**Total consumption (Ah/day)**	**577,31**

Table 15: Consumption table with system losses

For systems with battery accumulation, once the need is known you can measure the necessary number and type of batteries.

To calculate the number of batteries necessary you need to take into account a series of factors including losses, corrections for temperature, maximum depth of discharge and number of days of supply without charge.

The below extract gives an example of how this can be done:[113]

113 http://www.wirefreedirect.com/battery_sizing.asp

To calculate the battery size required to provide for 5 days of back-up in the event there was no sun or wind, the battery bank would need to be rated as follows: (Total Load x Days of Storage) / (System Voltage x Efficiency after system losses)= (1440 x 5) / (12 x 0.8) or 750Ah at 12V.

Explained:

- *The load is 1440 watt hours per day or 1.44kW. Hence 1440 * 5 (required storage in days) = 7200 watt hours*

  *DIVIDE by System Voltage = 7200 / (12 * 0.8)*

  Amp Hours of storage required = 750Ah at 12V
- *There are many battery sizes available as we have used a 200Ah battery for this example:*
- *Battery storage available: 200Ah @ 12V*
- *NUMBER OF BATTERIES REQUIRED = 750 / 200 = 3.75 220AH batteries.*
- *Naturally, 3.75 batteries would increase to 4 batteries.*

Therefore four (4 x 200Ah) batteries would be required to provide 5 days backup at a discharge rate of 1440 watts per day in a 12V system.1

Or alternatively, a slightly different method is shown below:

1. Determine total watt-hours per day required from your load calculation.
2. Determine the number of days of storage (backup) required.
3. Multiply line 2 by line 1. (storage x watt-hours).
4. Determine depth of discharge (DOD) of the battery. 80% should be considered the maximum for deep cycle batteries. Divide answer in line 3 by DOD.
5. Ensure that your batteries incorporate low temperatures by multiplying the answer in line 4 by the factors shown in the table below using the lowest expected weekly average temperature.

Battery Temp.(F?)	Multiplier	Battery Temp.()	Multiplier
25	1.00	5	1.06
20	1.01	0	1.1
15	1.03	-5	1.14
10	1.04	-10	1.18

6. Find the watt hour capacity of your selected battery. Watt hours = voltage x ampere hour capacity. Example: GEL deep cycle,12 volts x 200 amp-hours = 2400 watt hours
7. Divide line 5 by line 6.The result is the number of batteries required.
8. Round number of batteries to fit system voltage.

For grid-connected systems the energy required will depend more likely on the financial analysis, that is to say how much energy will be necessary to make financial sense, and this is dealt with in later sections.

Water pumping

As for water pumping uses, the process is somewhat different. Firstly you must know what your maximum daily requirements are in litres (Q/d). It is then advisable to divide this by an average of 5 hours of wind per day. This is to take into account the fact that the wind is not always blowing, and to err on the side of caution. Dividing your Q/d by 5*3600 seconds gives the volume of water required per second Q/s.

Mechanical Turbines

For a mechanical wind turbine, where the pump is part of the turbine system, you will need to buy a model that will provide the necessary Q/s for the height you wish to pump (m) and at the average windspeed for your installation site. Therefore if you require 3000 litres per day 4 metres distance, dividing this by 5*3600s gives 6 l/s that your turbine will need to be able to supply at your average windspeed of say 5m/s.

Electric Turbines

For an electric turbine, you will need to follow the same process to achieve your Q/s as above to determine the capacity in litres per second of the pump you require for the given height you wish to pump the water. The power rating (kW) of the pump will then need to be established, this should be given by the manufacturer for its pumping capacity. If you need to estimate the power of pump needed then use the following equation:

$$P = Q*H*9,81/\eta$$

Where:
P = Power for pump required (W)
Q = Pumping capacity, in l/s
H = Height in m
9,81= Acceleration due to gravity
η = efficiency of pump

You will then have the power of the pump required for the job (based on 5 hours of wind per day for cautionary reasons). For example, taking our previous case. If the pump needs to move 6 l/s a height of 4 m, and it has an efficiency of 40%, then the power required (P) will be: 6*4*9,81/0,4 ≈ 600 Watts.

The power of the turbine will then need to be determined. This depends on if you have batteries or if it is a directly connected system. For a directly connected system, it will need to supply 600 Watts of power at the given average windspeed for your site. If you site has an average windspeed of 5m/s then you may need as large as a 3kW turbine (assuming a capacity factor of 20%). If you have an indirect system, then energy can be saved in the form of batteries when there is more supply than demand for power, this supposes a higher cost in batteries but you can have a smaller turbine and smaller pump. The sizing calculations will in this case depend on energy requirements and can be designed as shown in the battery-supported system above.

3.3.6. Estimating turbine production.

Once the site has been established and energy requirements understood, the production of the turbine chosen, or to be chosen, must match the requirements of the system. For this you will need to be able to estimate the production of the various wind turbine models that are available.

The two main efficiencies usually stated for small wind are explained below:

3.3.6.1. Coefficient of Power (Cp).

The power given by a turbine is expressed in the following Wind Turbine Power Equation:

$$P = 0{,}5.\rho.Cp.A.v^3$$

Where:
P = power in watts
ρ = air density (about 1,225 kg/m^3 at sea level)
A = rotor swept area (m^2)
Cp = Coefficient of Power (.59 {Betz limit} is the maximum theoretically possible, .35 for a good design)
v = wind speed in m/s

The Cp is the averaged efficiency of power conversion at a particular location, and varies with both rotor and wind speeds. It cannot exceed the Betz limit of 0,593 a mathematical maximum that any turbine can extract from the wind. It will depend on the turbine, but also on the conditions under which it has been placed. For example some turbines may react well to high average winds of 8m/s with an excellent Cp approaching 0,35- where they may have a very low Cp with average windspeeds of less than 6m/s.

The main Caveat here, is to be suspicious of power output claims by manufactures or installers that give you results that break the laws of physics! Any supposed Cp that appears above 0,35 for small wind turbines must be treated as a misrepresentation or worse. For example, if a manufacturer claims that their turbine that has a swept area (A) of 7m2 will give you 500W of power at a wind speed of 5m/s, then this presumes a Cp of 0,93 (Cp=500/(0,5*1,225*7*125)). Then they are either mistaken or being deliberately misleading.

3.3.6.2. Capacity Factor (CF)

The Capacity Factor, is another method for representing the efficiency of a turbine. It is related to the nominal power of the turbine. The Capacity Factor is expressed as a percentage of a theoretical value, that supposes that the turbine were operating at its full nominal power all year round, 24 hours per day. Thus you multiply its power in kW by the number of hours in a year (8760 or 8766 to be exact) and the result is a theoretical energy production value, usually of several thousand kWh per year. For example, a 2 kW nominal power turbine, will have a theoretical annual production of 2kW*8760h= 17520kWh/year. Obviously this value is unrealistic because the turbine is only functioning in certain wind conditions, and often well below its nominal power. Thus, once the theoretical annual production is calculate, an estimate, or measurement is then performed on the real production that the turbine will give, in the specific site wind conditions.

The real production is then divided by the theoretical figure and a percentage is the result, which is called the Capacity Factor. Therefore if the 2kW turbine actually gives us 3504 kWh/year, the Capacity Factor would be 20% (3504/17520). Large wind farms, due to their optimal locations, and ability to operate at their nominal power rating, give Capacity Factors around 30%, whereas small wind turbines, if incorrectly sited, have Capacity Factors lower than 5%. If correctly sited, a small wind turbine should give a Capacity Factor of between 10-20%.

The main Caveat for this form of measurement, is that it depends heavily on the nominal kW rating that the turbine manufacturer has given, which in many cases is somewhat arbitrary. If their nominal rating is unrealistic, or mistaken, then the Capacity Factor too will be inaccurate. For this reason it is advisable to compare the two results with the measurement using the Coefficient of Power, and verify the Capacity Factor figure.

NB: Both Cp and CF are site-specific and depend on the wind characteristics in each case.

3.3.6.3. Weibull and Power Curve correlation

The only real way of telling how much a certain wind turbine will produce is to measure the data in situ and analyse the results. This is normally not possible, as it involves time and financial investment that, although viable for a large wind park, is not so for a single-turbine installation.

Some manufacturers provide a Power Curve based on real test results. These can be considered accurate, yet many use theoretical mathematical models and these are less reliable. Similarly for wind speed distributions, the ideal is to have an in situ time-series data, but invariably this is not available and we have to rely on a mathematical model that predicts the wind conditions for the site. This is called the Weibull curve. A Weibull curve is a probability distribution model that gives the % of time that the wind is expected to blow at each wind speed velocity interval or “bin”.

The Weibull curve has two main parameters: scale factor C (sometimes A) which gives us the average windspeed value and form factor k which shows how biased to the curve is towards the left and varies between 1 and 3. When k=2 it is known as the Rayleigh distribution, and this is often used for wind distribution calculations.

By correlating the Weibull curve and the Power Curve we can reach conclusions on annual production for a site. This is the most accurate way to estimate annual production. It goes without saying that the more accurate the wind data and the more accurate the Power Curve provided, the more exact the annual production estimates will be. Figure 70 below, shows how we can correlate the two curves to calculate production.

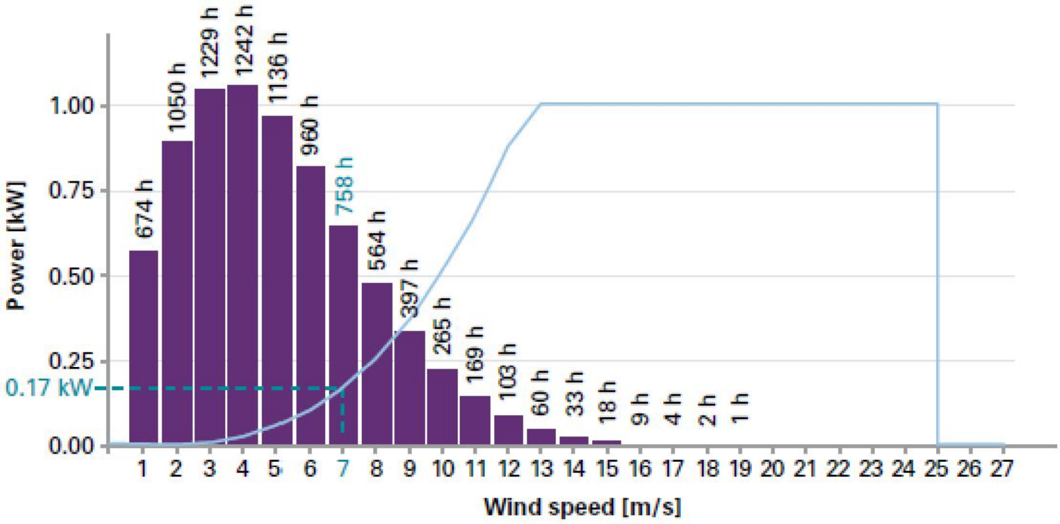


Figure 70: Correlation of power curve and Weibull.[114]

The bars show the number of hours in the year that the wind speed is within each wind speed category. For example, shown in light blue is the number of hours at 7 m/s. From the power curve, it can be seen that the turbine would produce 0.17 kW at this speed. Multiplying the two gives 129 kWh. The sum then of all these multiplications for each wind category gives us the total annual production.

Note: Cut-in speeds are usually between 2 and 3 m/s, nominal power ratings usually between 12 and 15 m/s and cut-out speeds over 25 m/s.

[114] Source: Entec from Small-scale wind energy Policy insights and practical guidance (Carbon Trust 2008)

3.3.6.4. Maximising turbine production

As can be seen in the coefficient of power equation for a turbine ($P = 0,5.\rho.Cp.A.v^3$), the key determinant of power is the average windspeed (v). The relationship is cubed between velocity and power, in that if you increase the windspeed by a factor of 2, you can increase your power and production by 8 (2^3), and so-forth.

There is normally a logarithmic increase in windspeed with height, that is to say, a marked acceleration over a small distance above the ground, followed by a more gradual acceleration subsequently. This is called the Shear effect, and the general rule is that the higher the turbine is mounted, the greater the power that can be generated. Wind shear in urban areas begins higher due to the extra height of the natural surface caused by the buildings. Thus for roof-mounted turbines, height is even more critical, with an increase of hub height from 2 to 9m, we can increase energy production by 3 times.

Wind also tends to speed up over hills, and thus it is not surprising, therefore, to see large turbines in high hill-tops where the highest winds are found. Although hills with steep sides create turbulence at the summit, and therefore shallowly rising hills are optimal. Turbulence both reduces turbine efficiency and its lifespan. Excessive strains and stresses on moving parts can cause critical damage or wear to the mechanical workings of the turbine.

A very detailed study conducted by Met Office (Small-scale wind energy Technical Report, August 2008) in the UK showed the following logical results:

- A rural turbine may achieve a capacity factor of 15-20% in the English countryside. This may be substantially exceeded if mounted near hilltops in hilly terrain, or near the coast. On the other hand, it is likely that small turbines will be mounted near houses which are more likely to be in valleys than on hilltops, so 15-20% may be a realistic typical figure.
- Suburban turbines achieve capacity factors substantially less than this, with less than 10% being common, while urban turbines may achieve capacity factors of only a few percent.
- Rural turbines are thus generally likely to produce a much higher proportion of their nominal output than suburban, which themselves are likely to perform better than urban turbines.
- Comparing different turbine makes, the individual power curves have much less impact on the capacity factor than mounting height and environment.
- Urban and suburban turbines need to be mounted as high as possible above the mean building height.

Often turbine manufacturers will provide production calculation tools which can be used as long as you have successfully measured your wind resource at the site location. In the Training section, Tools and Softwares folder of the RuralRES website you can find tools for estimating production (http://ruralres.diphuelva.es/)

3.3.7. Choice of Turbine

The choice of turbine will depend on the power necessary that has been established in the previous steps, and the type of installation. Types with their respective advantages and disadvantages have been explained in section 2.4 In summary:

- **Horizontal Access Wind Turbines (HAWT):** Efficient, Tested and widely used Cheaper and there is a wide range of products. They do not however stand up too well to turbulence particularly updrafts.

- **Vertical Access Wind Turbines (VAWT):** They have a fairly low efficiency, but have the advantage of not requiring orientation mechanisms, they are less sensitive to turbulence and silent. They are considered a better option for urban areas therefore. However the technology is not very developed and there is a lack of products on the market.

- **Wind pumps:** The best known manufacturers are from the USA. One advantage is that they are relatively easy to build DIY at low cost.

See figure 71 for varying efficiencies of each type of wind turbine:

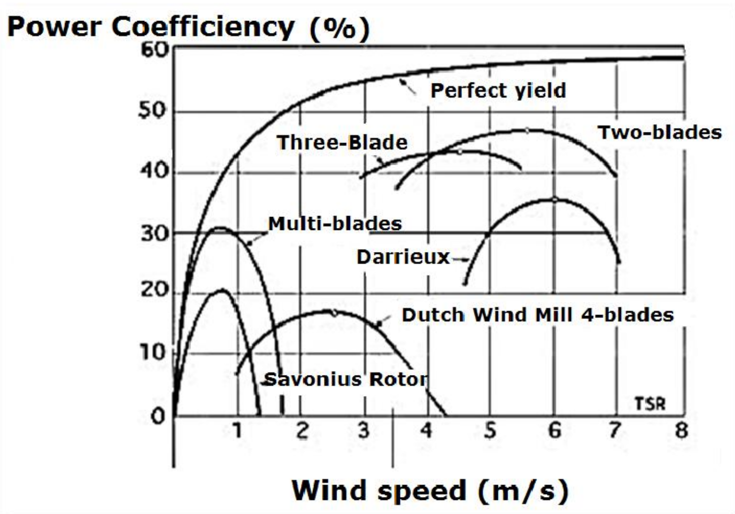


Figure 71: Relative efficiencies of wind turbine types

Choosing a miniwind turbine can be a tricky decision, as unlike the large wind industry, where a few major players dominate the market, there are hundreds of different manufacturers worldwide. The website: www.allsmallwindturbines.com shows the huge range of makes and models that exist on the market. Currently the webpage has over 500 turbines listed by 190 manufacturers.

Another thing to beware of is that there is no real standardisation, thus it is difficult to make comparisons between manufacturers. What usually happens is that an installer or investor works with one company that they know and have confidence in. The only advice would be to follow the maxim, same as with most electronic and mechanical products, in that you get what you pay for. The cheapest turbine is not likely to last many years of operation, whereas a more expensive one will probably give you 15 to 20 years of service.

3.3.8. Financial analysis.

The costs for small wind turbine installations can be generally split into the following:

- Initial Feasibility study (usually minimal)
- The Turbine itself
- Tower Structure
- Inverter
- Batteries (if off-grid)
- Connection to grid (if grid-connected)
- Other electrical equipment
- Licences and Permissions
- Business taxes (if not exempt)

Incomes from small wind turbine:

- Feed-in-tariffs (Grid-connected)
- Energy Sales (Grid-connected)
- Electricity costs saved
- Diesel/Petrol saved (Off-grid)

It is very difficult to generalize in terms of absolute costs for small wind installations. Obviously a 50kW turbine will cost significantly more than a 2 kW turbine. It is also misleading to generalize on costs per kW of nominal power, as this can vary from between 1€ per W for the cheapest import to 4€ per W for specialised turbines.

The costs of the turbines must be therefore analysed case by case to evaluate its value for money. For example, a 10kW system costing 50.000 € installed in a position with an average wind velocity of 8 m/s that produces 20MWh per year, is very different from a 1,5kW costing only 3500 €, but with average wind velocity of 4m/s that produces a lowly 650 kWh per year. In the first case, presuming a period of 10 years operation, gives a cost of 25 €c/kWh, whereas the second case gives one of 54 €c/kWh.

There are three main types of financial analysis carried out for miniwind prefeasibility studies, these are: Payback, Net Present Value and Internal Rate of Return.

3.3.8.1. Payback

This is the simplest of all financial analysis, it simply states the number of years in which it takes the investment to pay for itself. In the case of off-grid miniwind installations or wind pumps, this will be time it takes in terms of the cost of the substitute, albeit diesel for a diesel generator or cost of electricity & grid connection to reach the quantity paid for the original investment. For example, say a miniwind installation cost 15.000 €, and grid connection would have cost 10.000 € plus the cost of electricity day to day. If your electricity costs would have been 1000 € per year, in fiver years you would have paid back your investment (5x 1000 € plus 10.000€ for grid connection). Or alternatively, if your diesel costs for the diesel generator would be 3000€ per year, it would also give you a payback of 5years (3000 € x 5 = 15 000 €).

3.3.8.2. Net Present Value

A Net Present Value study (NPV) takes a sequence of discounted future income streams (positive values) and costs streams (negative values) including the initial investment, to give a theoretical value for the whole investment in todays monetary terms over a given period of time.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Where:

C=net income in time period t
C°=initial investment
r= discount rate.

The project is considered viable if the NPV is equal to or greater than zero. This depends often very much on the time frame (eg 5, 10, 20 years) and the discount rate. The discount rate chosen depends on various factors and varies from project to project. Using a higher discount rate will reduce the NPV whilst using a lower one will increase it. A common method is to use the bank's savings interest rates, in other words, the interest that your investment would have earned in monetary terms if you never went ahead with the miniwind installation, but many people believe that it is appropriate to use higher discount rates to adjust for risk or other factors. These calculations can be easily undertaken in Excel.

3.3.8.3. Internal Rate of Return

Closely linked to NPV, is the internal rate of return (IRR) analysis. The IRR is the discount rate at which NPV=0 for a stream of future cash flows in a given period. That is to say if the IRR is lower than the current rate of borrowing or minimum acceptable rate of return, then it is not viable. If however, it is above the rate of borrowing or a minimum acceptable rate of return, then it is a viable project. So for example, if your miniwind project gives you an IRR of 7%, and borrowing for the investment costs 8%, then it is not a viable project. If, on the other hand, your analysis gives you 10% IRR then it will be viable.

Because the internal rate of return is a rate quantity, it is an indicator of the yield of an investment. This is in contrast with the net present value, which is an indicator of the value or magnitude of an investment. IRR is also easily calculable using an Excel spreadsheet.

Both IRR and NPV are the most appropriate measures particularly for grid-connected systems where the future net income streams from net-metering or feed-in-tariffs. They will show whether the initial cost of the investment will give an adequate return or not.

Not all projects will undergo a rigorous financial analysis. Those used for educational or innovate purposes (eg Scuela Verde, Italy and Hydriada, Greece of the RuralRES Good Practice Guides) are less likely to be financially driven and the entity will just decide whether the costs are reasonable given its budget.

3.3.9. Installation Planning

At this stage, you should have determined the wind conditions, your site, the energy requirements, the suitable turbines and energy systems, and carried out some form of financial evaluation. All these elements being in place there are two choices. The first is to proceed with a full feasibility plan, mainly relevant to larger turbines, particularly grid-connected system, where required. Or you have sufficiently studied the installation to proceed with an investment. At the miniwind scale (less than 50kW) it is invariably individual owners that invest. There are cases of business renting farmland (see Campli, Italy in the RuralRES Good Practices Guide), and undertaking their own installation, but usually it is individuals themselves and the following tasks will be required:

3.3.9.1. Identify Installer and Product to be installed.

All miniwind turbines are not the same, and neither are installers. It is highly recommended that you find an accredited installer if they exist. There are schemes in some countries that accredit installers. If not, try to visit other installations from the same installer to verify their work, and take advice from local energy agencies or local/regional authorities.

As for the turbine itself, it is likely that the installer will work with a certain type that they trust, although you may have already identified the one you want.

If you are doing an off-grid installation, be very careful to ensure that you follow all the necessary safety procedures, and that the turbine comes with adequate guarantees. It is recommended (until common miniwind standards are introduced) to buy from a national producer where possible, as it will be much easier to make claims in case of malfunction within your own country, or at least within the European Union.

If grid-connection is necessary then the installer must have the relevant licence/permit to perform the task. You cannot do this type of installation DIY.

3.3.9.2. Contact Electricity distribution company

Depending on the laws in your country, there may or may not be feed-in-tariffs or net-metering schemes. Agreements must be reached directly with the electricity companies for such arrangements, and any connection to the grid, with or without compensation must be approved. Again local energy agencies and local/regional authorities should be able to give the appropriate contact details, and information on procedures to follow.

It is crucial to know of the procedures and timeframes for grid connection, in some countries the bureaucratic process is so slow and time consuming that it invalidates the financial model and the investment is rendered unviable.

3.3.10. Financing

As such installations are carried out by individuals, financing usually comes from personal savings, or a personal loan. There are no specific bank loans in any of the countries studied for this type of installation. Each individual must reach an agreement with his or her bank. Often a cheap way of gaining credit is through a small remortgage of the property which normally offer much cheaper rates than for non-specific personal loans.

Grants are often available too for this type of installation. For this you will need to contact the relevant authority and apply. However, your business model should not bank on receiving this, as in many countries, the grants come later and sometimes for less quantity than applied for. They can provide a useful boost to the viability of the project, but it is not recommended that you depend on them.

Feed-in-tariffs, are however an integral part of the business model for grid-connected systems. But again, caution must be applied. Recently, in Spain, a law (Royal Decree Law 14/2010) for a retroactive cut in the subsidies for photovoltaic installations was approved. Get in touch with the electricity distribution company therefore to inform yourself correctly of the feed-in-tariff levels and the likelihood of any changes which will have to be factored into your investment.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