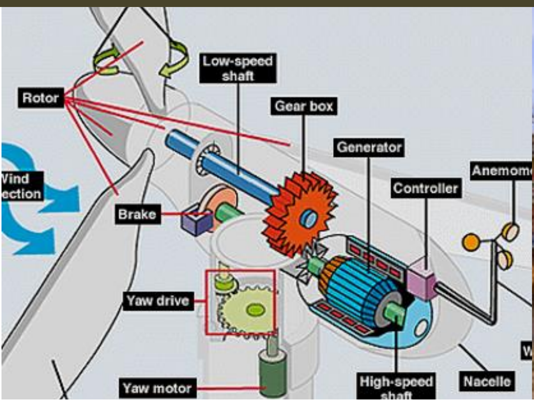
MODULE 4

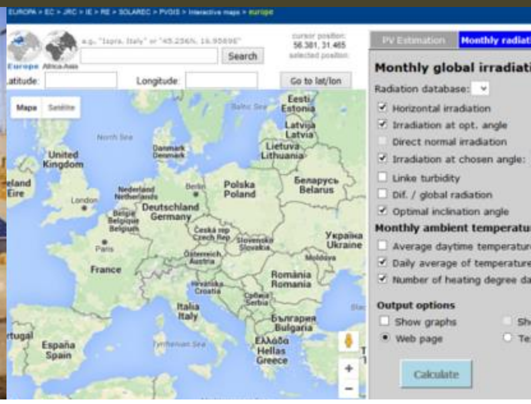
Small wind energy

Open Educational Resources for online course of renewable energy for local development

Coordinator: Leonor Hernández

Authors: Roxana Grigore, Gabriel Puiu, José Segarra and Juan Jorro





IN2RURAL

Co-funded by the Erasmus+ Programme of the European Union

UNIVERSITAT JAUME·I
EGER 1774 ESZTERHÁZY KÁROLY EGYETEM
Universitatea "Vasile Alecsandri" din Bacau
umans
GEOLIN
GENERAL ELECTRIC

Place and year of edition:
Bacău (Romania), 2016

Coordinator:
Leonor Hernández

Authors:
Roxana Grigore
Gabriel Puiu
José Segarra
Juan Jorro

DOI: http://dx.doi.org/10.6035/IN2RURAL.2016.12

The PDF version of this document is available in:
http://in2rural.ub.ro/, http://in2rural.uji.es/ and http://repositori.uji.es/xmlui/handle/10234/154485

TABLE OF CONTENTS

CHAPTER 1. TECHNICAL ASPECTS …………………………………………….. 4

Subchapter 1.1 - Principles concerning the use of wind energy. Conditions for efficient Exploitation ……………..…………………………………………………………... 4

Subchapter 1.2 - Technical alternatives and installation types for wind installations applicable for rural development ……………………………..……………………... 20

Subchapter 1.3 - Calculations and design 36

CHAPTER 2. ECONOMICAL ASPECTS …………………................................... 45

Subchapter 2.1 - Estimation cost of the investment ……………………………………. 45

Subchapter 2.2 - Other costs ……………………..………………………………….. 54

Subchapter 2.3 - Analysis of economic efficiency and profitability ….………………… 63

CHAPTER 3. SOCIAL AND ENVIROMENTAL ASPECTS OF EOLIAN SYSTEMS FOR RURAL DEVELOPMENT ……………………………..……… 67

Subchapter 3.1 - Assesment of enviromental impact. Emmisions and LCA ………..………………………………..……………………………………… 67

Subchapter 3.2 - Social and rural development impact ……………………………...…. 78

Subchapter 3.3 - Vision for future. Ideas and new suggestions ………………………… 83

CHAPTER 4. FULLY DEVELOPED CASE STUDY OF APPLICATION OF WIND ENERGY FOR RURAL DEVELOPMENT…….......……...………………. 89

Subchapter 4.1 - Introduction and technical aspects of the case study …………………. 89

Subchapter 4.2 - Economical aspects of the case study ………………………………… 103

Subchapter 4.3 - Environmental, social and rural development impact of the case study . 108

CHAPTER 5. PROPOSED CASE STUDIES ………………………………………. 115

Subchapter 5.1 - Case Study 1 …………………………………………………………. 115

Subchapter 5.2 - Case Study 2 …………………………………………………………. 119

Subchapter 5.3 - Case Study 3 …………………………………………………………. 122

Subchapter 5.4 - Case Study 4 …………………………………………………………. 125

Subchapter 5.5 - Case Study 5 …………………………………………………………. 129

Subchapter 5.6 - Case Study 6 …………………………………………………………. 132

Subchapter 5.7 - Case Study 7 …………………………………………………………. 136

Subchapter 5.8 - Case Study 8 …………………………………………………………. 140

Subchapter 5.9 - Case Study 9 …………………………………………………………. 144

Subchapter 5.10 - Case Study 10 ……………………………………………………… 147

MODULE 4: WIND ENERGY

CHAPTER 1. Technical aspects

Subchapter 1.1. Principles concerning the use of wind energy. Conditions for efficient exploitation

Roxana Margareta Grigore

"Vasile Alecsandri" University of Bacau

Summary: To start this module it is necessary an introductive part about the use of wind energy to produce electricity. There are presented historical data of wind energy use, the evolution in time of wind turbines, basic constructive configurations of turbines with the principal elements components. There are presented the conditions for efficient exploitation and it is pointed out the importance of the development of electricity production using wind energy.

INDEX

1. Principles concerning the use of wind energy……………………………………………….2
   1.1. Historical data of wind energy use…………………...……………………………..2
   1.2. The evolution of wind turbine…………………………...……………………...…..4
   1.3. Basic constructive configurations of wind turbines………...……………………....5
   1.4. Constructive components of horizontal axis wind turbine…………………..…...8
2. Conditions for efficient exploitation…………………………………………………..…12
   2.1. The wind map……………………………...………..……………………….13

1. Principles concerning the use of wind energy

1.1. Historical data of wind energy use

As already introduced in Module 1 of the course, wind can be defined as the movement of air masses from the Earth's atmosphere, generated by differences of pressure between two areas of the globe (baric gradient). These differences are determined by the uneven heating due to solar radiation and to Earth's rotation. When the air is heated, the warmer air rises faster because a volume of hot air is lighter than an equal volume of cold air. Hot air particles have a higher pressure than colder particles, therefore, it takes fewer particles to maintain the same air pressure. When warm air rises, cold air flows into the spaces that hot air leaves behind it, and the air that rushes to fill the gap is called wind. The wind presses on any object that lies in its path, and in the process, energy transfers occur to the object which was in the path of wind. This is how wind turbines produce energy.

Wind is a clean energy source, free and inexhaustible. That is why, as explained in the introductory module of the course, wind power has been used by humans for thousands of years. For example, wind power was used for navigation in sailing vessels movement. All the great nations of Antiquity and the Middle Ages had fleets of ships sailed using this energy.

Those who are said to have invented the windmill are Chinese. At the same time, Babylonian emperor Hammurabi planned to use windmills for irrigation in 17th century BC. Windmills existed in ancient Persia. The first historical reference tied preserved windmills is presented by Hero of Alexandria (c. 10-70 AD) in his book Pneumatics. A reconstruction of these windmills is presented in Figure 1.

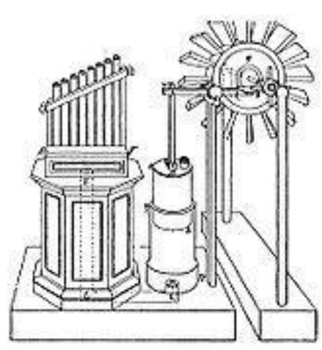


Figure 1. Hero of Alexandria windmill [1]

The first known practical windmills were built in Sistan, an Eastern province of Iran, from the 7th century [1]. These windmills were vertical axis windmills, and substantially based on the aerodynamic drag of rectangular sails.

By the 14th century, Dutch windmills were used to drain areas of the river Rhine. In Denmark by 1900 there were about 2500 such mills which were used for mechanical loads such as water pumps and presses and producing an estimated combined peak power of about 30 MW [9].

The first wind turbine to generate electricity was a machine which charged a battery and was set in 1887 by James Blyth in Scotland, UK [2]. It was a vertical axis wind turbine having a diameter of 17 m away. The blades were concave surfaces operating at resistance, Figure 2.

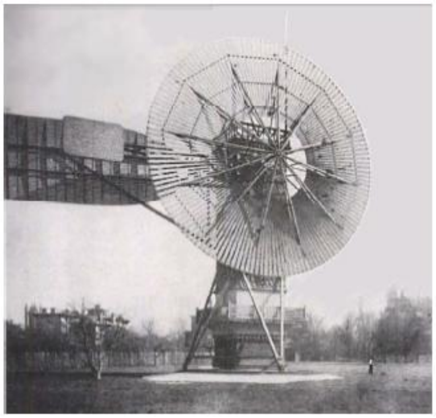


Figure 2. The wind turbine constructed by James Blyth

The first wind turbine in the US which has been produced in order to generate energy electricity was installed in 1888 in Cleveland, Ohio by Charles F. Brush, and in 1908 there were 72 generators set in motion by force winds that produced electricity from 5kW to 25kW. The largest devices were 24 m tall, with 4 blades and rotor diameter by 23 m. During World War I, American manufacturers had made 100.000 windmills per year, mostly used for pumping water. By the 1930s wind turbines were especially common in the US where distribution systems had not been installed.

A precursor of all modern horizontal axis generators existed in Yalta, USSR 1931. This was a 100 kW generator on a 30 m tower and it was connected to the local distribution network of 6,3 kV. Its annual capacity factor was 32%, with value much different from other windmills values so far. The first utility turbine was used in Orkney Islands - UK firm and built by John Brown in 1954. It had a diameter of 18 m, three blades and a power output of 100 kW. In 1931, the French aeronautical engineer Georges Jean Marie Darrieus built and patented the Darrieus wind turbine. The wind turbine is of the type with a vertical axis, is also used today and is based on the exploitation of lift wind. An important installation is on the Gaspé Peninsula, Quebec, Canada.

This project has never been a commercial power plant, but the wind turbine operated for 1983 to 1992. It was the biggest Darrieus turbine: 110 meters high, and 4 MW power plant.

Figure 3. Darrieus wind turbine

1.2. The evolution of wind turbines

The emergency of new concepts in the field of materials and modern technologies have resulted in a spectacular development of wind turbine size, from heights of 15 m in the 80 to heights of 140 m in 2014. Also, the rotors diameters have evolved depending on the installed power, up from 15 m to a power of 50 kW to 126 m for an installed capacity of 8.000 kW. In 2012, in France was built a large wind turbine in the world, Haliade 150 wind turbine, with a power of 6 MW. In 2013, in Fife, Scotland was built a Samsung Heavy Industries' S7.0-171turbine with a power of 7MW turbine. In 2014, Vestas announced that it has produced the largest wind turbine on the planet generating electricity, with the installation of its V164-8.0MW prototype at the Danish National Test Center for Large Wind Turbines in Østerild, Denmark [10].

Evolution of installed capacity and size of wind generators is a reflection of the efficiency of commercial approach, as demonstrated by the design below (Figure 4):

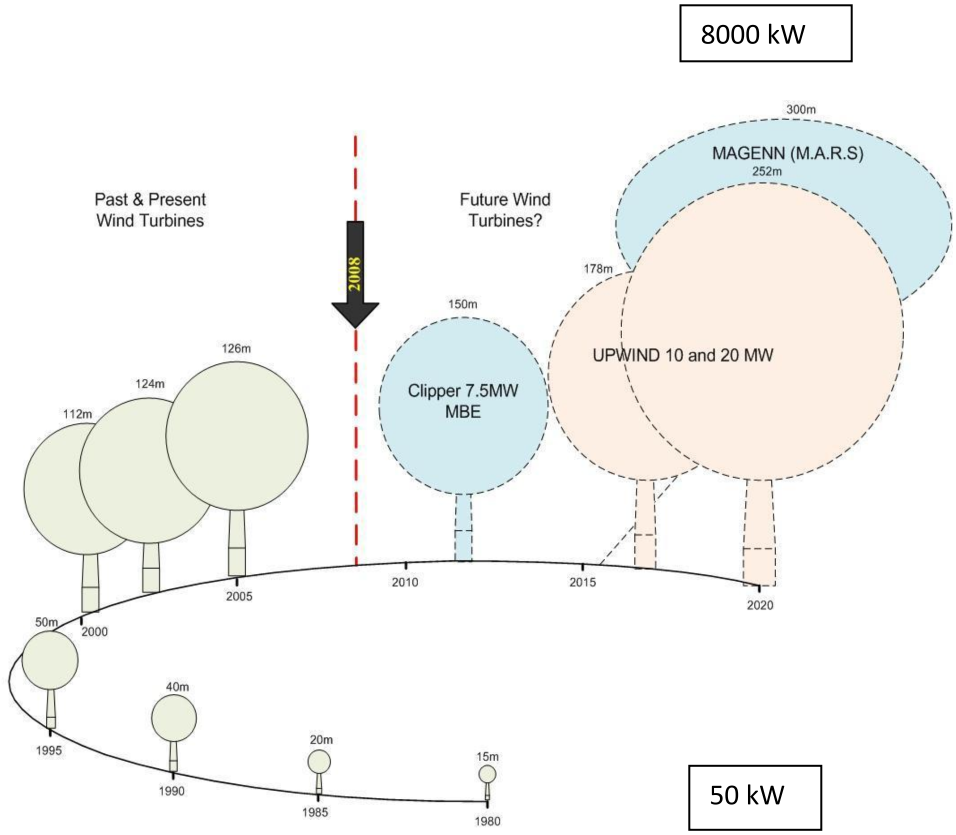


Figure 4. Evolution of winds turbine [3]

1.3. Basic constructive configurations of wind turbines

The electricity derived from wind energy by means of wind turbines depends, on the one hand, by the kinetic energy of the wind that hits the rotor blades of the turbine, and on the other hand, by the design. In this regard, there are two basic general configurations of wind turbines:

- vertical axis, with the axis of rotation perpendicular to the direction of the wind (VAWT = Vertical Axis Wind Turbine);
- horizontal axis, at which axis of rotation is parallel to the wind direction (HAWT = Horizontal Axis Wind Turbine).

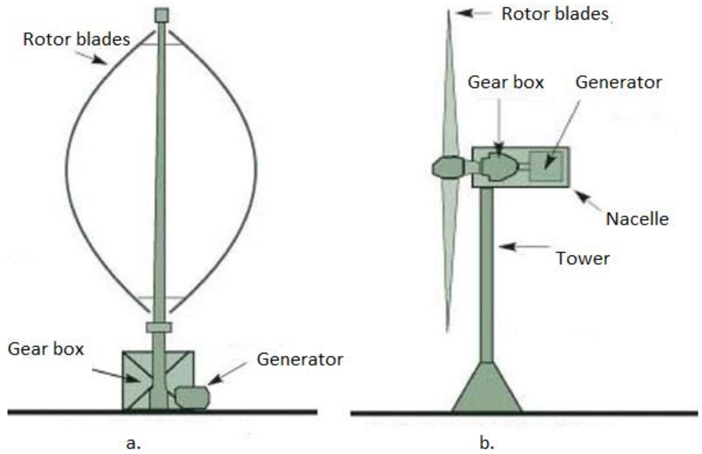


Figure 5. Basic configurations of wind turbine: a. with vertical axis, b. with horizontal axis

Regardless of the constructive configuration that has turbine, its function is to generate the necessary torque to drive electric generator in the conversion of wind energy into electricity.

Wind turbines with vertical axis

The turbines with this type of configuration have supporting pillars with low waist, height of these pillars having values between 0,1 – 0,5 of the height of the rotor and also helps the location of device energy conversion - speed multiplier, generator, etc. -at the base of the turbine wind. This mode of equipment placement facilitates the maintenance of turbine, which gives an advantage to such a turbine. Also another advantage of vertical axis turbines is that during the operation does not require a dispositive of rotor orientation. The disadvantage of this type of turbine is the low yield caused by reduced intensity of wind at ground level. In addition, it requires drive mechanism for starting, the pillar being subjected to mechanical stress important. This is the reason why manufacturers have geared mainly to towards horizontal axis turbines.

Wind turbines with horizontal axis

Based on the principle of the mills, rotor shaft is positioned horizontally. This type of turbine is currently the most widely used and available in several variants. Horizontal axis turbines in their aerodynamic efficiency are superior to the vertical axis and are less subject to mechanical stresses. Manufacturers of such equipment show greater interest in this model because they have a lower cost. An important advantage of this type of turbine: it is characterized by a power coefficient Cp with values close to the limit of Betz, who according to his theory even for the most powerful turbine is maximum 0.593.

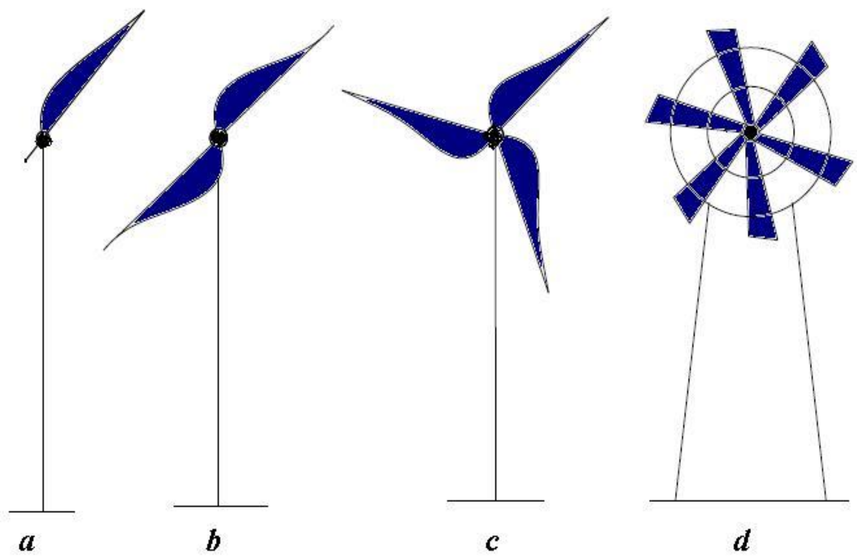


Figure 6. Types of the horizontal axis turbine according to the number of blades: a. with one blade, b. with two blades, c. three-bladed, d. multi-bladed

In the literature, **a classification of horizontal wind turbines** has been carried out on the basis of various criteria:

- Depending on the number of bladed, the horizontal axis generators can be grouped into two broad categories, namely:

  - Quick turbines, which can have 1-3 blades

  - Slow turbines, which have multiple blades, their number can be from 3-18

- after the placement of the blade:

  - placed blade against the wind - "upwind" (first encounters wind blades and nacelle then), Figure 7a

  -located downwind paddle - "downwind" (wind meets first nacelle and blades and then Figure 7b

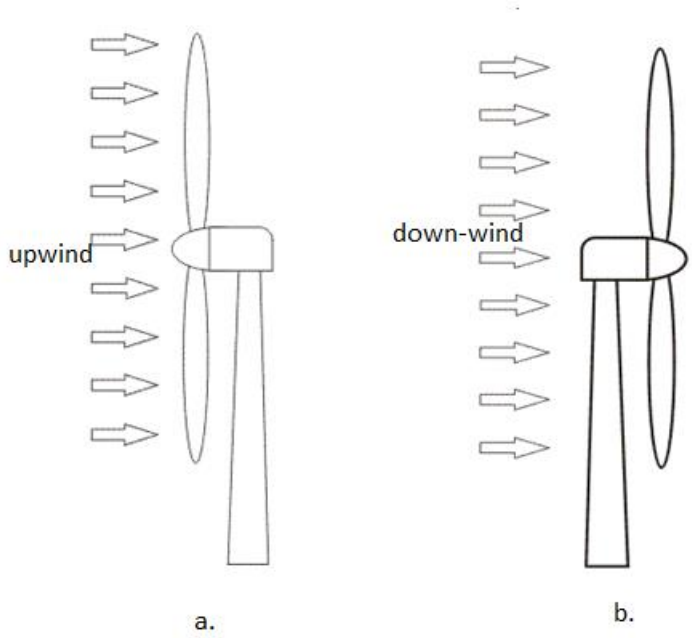


Figure 7. The location of the turbine blades relative to the direction of the wind: a. upwind turbine, b. downwind turbine

- depending on the equipment used in the conversion process:

  - with speed multiplier (gearbox), equipment that connects the hub of the wind turbine and electric generator

  - without speed multiplier, the hub of the turbine shaft is coupled directly to the generator

- depending on location:

  -terrestrial location -onshore

  -marine location – offshore

1.4. Constructive components of horizontal axis wind turbine

The most used turbines are those with horizontal axis. In what follows it will be made a presentation of the main components of such turbines.

The main components of wind energy conversion system (Figure 8):

- electric generator
- turbine rotor (hub) and rotor blades
- rotor shaft (main shaft) and generator shaft (high speed shaft)
- gearbox (which can dispense in case of use synchronous generators)
- brake
- nacelle, where are placed all the components of the turbine
- cooling system of the generator and gearbox
- yaw system
- measurement and control systems (wind vane and anemometer)
- supporting tower

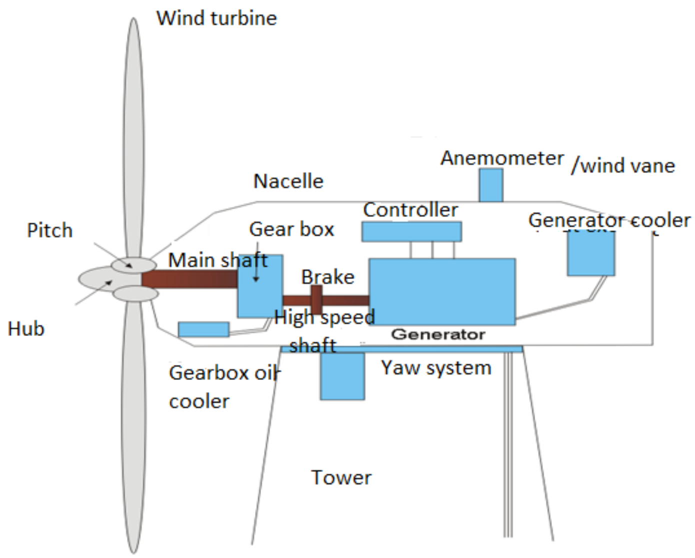


Figure 8. Scheme with components of horizontal wind turbine

The hub - is the mounting bracket of the turbine blades and it is fitted with their guidance system that allows control of the rotation speed of the wind turbine - "outlet wind", control which may be:

- Active - pitch control, also called hydraulic control, and it uses hydraulic motors to ensure the angle of incidence of the blades by moving around their own axis so as to allow full use of the wind instantaneously and also to limit its the power when the speed exceeds the nominal value;

- Passive - stall control, also called aerodynamic control, where the blades wind turbine relative hub are fixed and are so designed so that at limit speeds of wind these can be released gradually and even stop them, if the wind speed reaches critical values. The method is used in most wind turbines because has the advantage that the control system does not require moving parts in the rotor.
- Mixed - active stall or actively control by aerodynamic release, it uses the both advantages of active and passive control in wind energy conversion process. High power turbines have mixed control.

The turbine blades - are the energy absorbers and are designed to transmit kinetic energy of wind to the rotor. These technologies are realized based on the principle used in the industry aerodynamic from composite materials mixed with fiberglass and the interest of obtaining the best possible torque in the turbine operation has led to the continuous changing of the profile thereof. Were taken into account also the benefits due to the number of blades used, the system most used being with three blades which provides:

- Limiting vibrations, noise and reduce fatigue rotor;
- Increasing power factor by approximately 13% compared to the one blade turbine and 3% compared to two blades turbine;
- A low investment cost taking into account the rotational speed of the wind sensor.

Diameter of turbine blades is determined according to the desired power as follows:

P < 10 kW can have a diameter up to 7 m;

P < 1 MW diameter may be from 12-45 m;

P > 1 MW can have a diameter of 46-124 m.

The nacelle - the housing where are mounted the turbine components which are:

- **the main shaft** - is being called the turbine rotor shaft and shaft slow speed due to reduced values of the order of 20-40 rot / min, which through the gearbox the rotational movement is transmitted to the drive shaft;
- **the gearbox** - converts mechanical power of wind turbine characterized by high values of torque but low speed in power with low levels of torque but high speed, implemented to turbine generator through secondary shaft. The gearbox can be like:

- One or several steps transforming a mechanical motion (gear train) which allow a conversion ratio of 1:50 i.e. from 20 to 30 rot / min the shaft slowly to about 1500 rot / min for the drive shaft (the generator). In this type of multiplier axes of rotation of the toothed gear wheels are fixed relative to the housing;
- The planetary system which can achieve high ratios in a small space and the wheel axles are not fixed relative to the housing.

It is pointed out that there are direct drive generator version (without the use of a gearbox), the generator used in this case is the synchronous generator.

- **cooling - system,** provided for the gearbox (that performs mechanical transmission of efforts between the main and secondary) and for generator, consists of heat exchangers with water or oil if the it is for the gearbox;
- **generator shaft** (secondary shaft) - aims to train electric generator and it is equipped with a safety device (mechanical disc brake) for limiting rotation speed when the wind speed reaches critical.
- **controller or electronic control system** - monitors the overall operation of the turbine and provides:
  - Commissioning of the wind
  - Adjusting the angle of incidence of the rotor blades
  - Brake rotor at wind speeds above the nominal values
  - Nacelle orientation relative to the wind
- **electric generator** - with power up to 5 MW turbines in the power producing electricity and can be DC or AC. Generally used type of generator is the AC which has the advantage of low price and better yield.

The devices for measuring wind speed and direction - made up of two components mounted on the top of the platform, namely:

- Vane or wind valve which serves to assess wind direction;
- Anemometer for measuring wind speed.

On the basis of transmitted information from the devices to the control system are performed automatically numeric guidance commands to the nacelle so that the turbine operation will be with a better efficiency.

The yaw system – assures the orientation of the nacelle to the wind direction and blocking it by means of a rack (toothed disk), it being possible by operation of an electric motor;

The tower - is generally made from a metal tower serving to support nacelle and the wind turbine and in which are passed connecting cables for the electricity supply. The height of the tower is of major importance because the more it grows so wind intensity is greater and better turbine efficiency but is taken into account and getting a good compromise between cost of production and exposure to wind.

2. Conditions for efficient exploitation

Wind energy is the most rapidly expanding source of energy in the world today [5]. The main advantages of wind power are:

- Lack of pollutant emissions and greenhouse gases
- Does not require any combustion process to obtain this form of energy
- Does not involve the generation of waste

The cost per unit of energy (€/MWh) produced with this technology has declined substantially in recent years, making it competitive with traditional generators in most of the electricity markets worldwide.

The cost for the decommissioning of a wind system at the end of normal use is also reduced, it can be fully recyclable. The results obtained in the last 30 years in the use of wind to produce clean energy led to the development of industries with major implications for energy systems and sustainable development plans. There are many issues to be considered when choosing a location for a wind turbine, for example: space availability, access for construction machinery, environmental considerations, but the most important factor is the availability of enough wind as intensity and duration. To perform a large wind turbine project, a wind farm, one must first carry out a study on wind turbine placement, called wind study and which is conducted for a year. In the absence of concrete data, the study duration can be extended for two years. It will include information on the average and maximum values of wind speed and turbulence level. Based on the data obtained, we can determine the type of turbine that can be installed in the area. The study is very important in terms of cost investment, and its goal is to ensure an adequate level of safety in the operation of the wind turbine over its planned lifetime, because a turbine designed to withstand wind speeds up to 70 m/s (being excluded the turbine operation in such conditions) can be 40% more expensive than one that is designed for maximum values of 42 m/s.

In this sense, the International Electrotechnical Commission (IEC) has defined several classes of wind in the Standard IEC 61400/2005, table 1. Under this standard, a wind study should determine the following parameters:

The value of this parameter is measured at intervals of 3 seconds is determined and then the mean velocity over a period of 10 minutes;

• V50 - maximum wind speed recorded in the last 50 years;

• I15 - turbulence value (standard deviation of wind speed in relation to the reference value of 15 m / s at the nacelle).

Table 1. Classification of wind turbine according STANDARD IEC 61400/2005

Class of wind turbine		**I**	**II**	**III**	**S**
V50 - maximum wind speed recorded in the last 50 years, [m/s]		50	42,5	37,5	Values specified by the designer
I15 – turbulence value	class A	0,16			
	class B	0,14			
	class C	0,12			

In this table, the parameter values apply at hub height, and A designates the category for higher turbulence characteristics, B designates the category for medium turbulence characteristics, C designates the category for low turbulence characteristics and S is the special class.

2.1. The wind map

The principal characteristic wind sizes are:

- the wind intensity and the wind speed variation in time
- the variation in wind speed with altitude
- the wind direction

The wind intensity in meteorology is measured by a scale of speeds. The ranges are identified by the effects on the environment (smoke, leaves, etc.).

The variation in wind speed with altitude refers to the profile of the wind speed in the boundary layer land.

Terrestrial boundary layer is the layer of air that manifest the influence of the Earth surface on the wind speeds field. This influence is one of the frictions, the layer of soil having zero velocity. The wind velocity profile in the boundary layer depends on the topography and roughness of the terrestrial land.

The wind direction is determined by the part of the horizon from which the wind blow, the obtained information indicating the repetition of the wind in a certain time (usually average meteorological year) after cardinal directions, plotted in the form of so-called wind rose, shown in Figure 9.

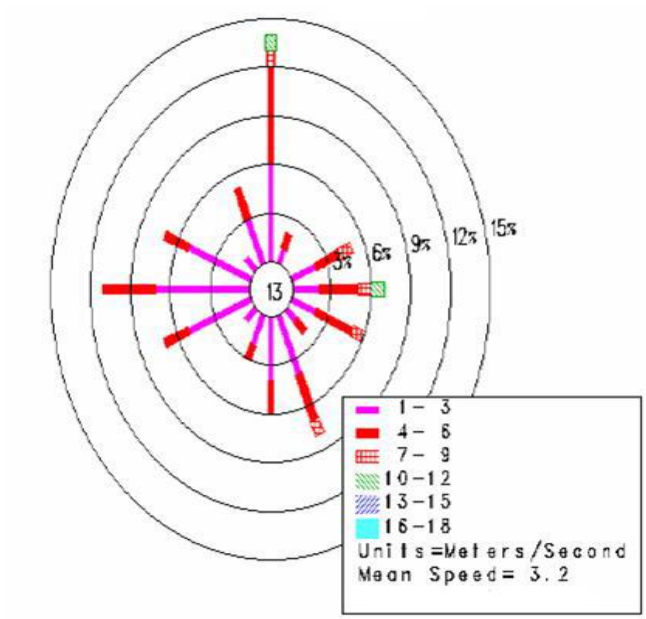
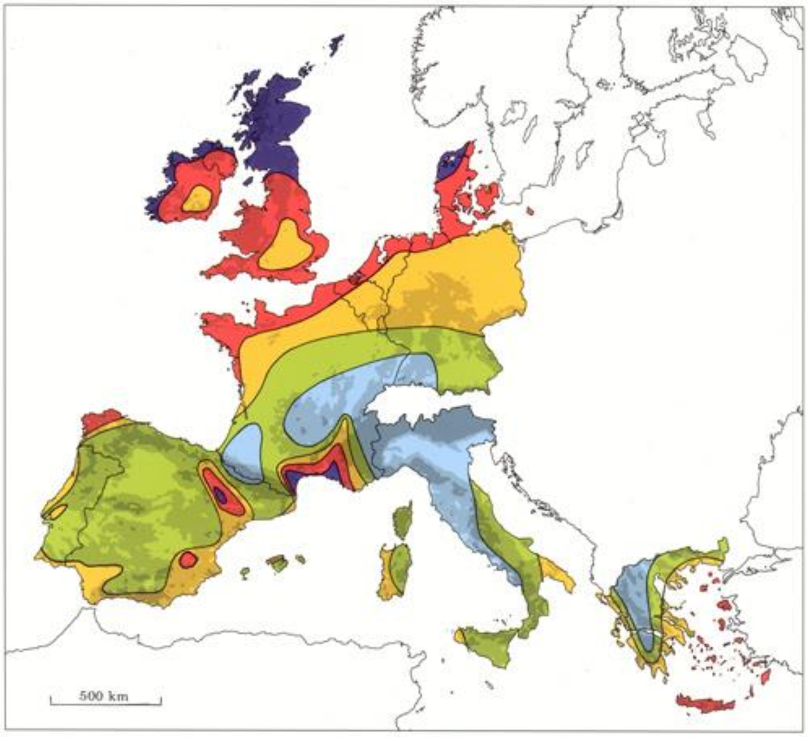


Figure 9. The wind rose

At Europe level there is an example of a wind atlas, shown in Figure 10. The map shows different wind speed regions. The wind speeds at a 50 m height above ground level within the regions identified may be estimated for different topographic conditions using the table below the figure [12]. On the site http://www.wind-energy-the-facts.org are shown in Appendix A a lot of wind maps for a number of European states.



Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 10. European Wind Atlas, Source: Risø DTU National Laboratory, Denmark

This kind of map should be used for information, because every individual sites has a different wind potential and varies greatly from case to case occurring turbulence due to terrain, buildings, forests, vegetation around, even if they are in the distance.

As is shown in Module 1, subchapter 1.1, the most noteworthy would the international atlas of developed by IRENA (available at: http://irena.masdar.ac.ae/).

References

[1] https://en.wikipedia.org/wiki/Wind_turbine

[2] www.hawkge.com

[3] EWEA 2009 report "The Economics of Wind Energy"

[4]http://ie.ucv.ro/elee/ro/realisations/EnergiesRenouvelables/FiliereEolienne/Generalites/Generalites/GeneralitesEolien2.htm

[5] Handbook of Energy Efficiency and Renewable Energy, edited by Frank Kreith, D.Yogi Goswami, CRC Press, Taylor &Francis Group, 2007

[6] Notes of the course ‘’ Energetic ‘’, teacher Renato Ricci, Università Politecnica Delle Marche, Ancona, Academic Year 2012 – 2013;

[7] http://785.ro/wp-content/uploads/energie-eoliana-studiu-de-vant-teren.pdf

[8] Notes of the course “Renewable Energy”, teacher Roxana Margareta Grigore, “Vasile Alecsandri” University of Bacau, Romania, academic year 2015-2016

[9]https://books.google.ro/books?id=4aJAAAAAQBAJ&pg=PA110&lpg=PA110&dq=By+the+14th+century,+Dutch+windmills+were+used+to+drain+areas+of+the+river+Rhine.+In+Denmark+by+1900+there+were+about+2,500+such+mills+which+were+used&source=bl&ots=VWwkFX9T4p&sig=zk_JBF3AeYtt7lFCND5JT6Dns80&hl=ro&sa=X&ved=0ahUKEwj3p7ik9ZrMAhVCsxQKHfaOCVgQ6AEIITAB#v=onepage&q=By%20the%2014th%20century%2C%20Dutch%20windmills%20were%20used%20to%20drain%20areas%20of%20the%20river%20Rhine.%20In%20Denmark%20by%201900%20there%20were%20about%202%2C500%20such%20mills%20which%20were%20used&f=false

[10] http://www.renewableenergyworld.com/articles/2014/02/meet-the-new-worlds-biggest-wind-turbine.ht

[11]http://www.unitbv.ro/Portals/31/Sustineri%20de%20doctorat/Rezumate2016/TudorCamil.pdf

[12] http://webbut.unitbv.ro/teze/rezumate/2010/rom/NegreaIonela.pdf

[13] http://www.wind-energy-the-facts.org/appendix-a.html

MODULE 4: WIND ENERGY

CHAPTER 1. Technical aspects

Subchapter 1.2. Technical alternatives and installation types for wind installations applicable for rural development

Roxana Margareta Grigore

"Vasile Alecsandri" University of Bacau

Summary: The aim of this subchapter is to present types of wind turbines which are applicable for rural areas. A small size wind turbine, carried out in a simple construction and high reliability can be used in a highly efficient mode in isolated areas without electricity or when it is desired electricity saving. There are presented the components of the small horizontal axis wind turbine, the most used wind turbine in rural areas. Finally, in this subchapter, are shown small wind electric systems used in rural environment for different applications.

INDEX

1. Types of wind turbines applicable for rural areas……………………………………2
   1.1. Small vertical axis turbines (VAWT – "vertical-axis wind turbine")……………….3
   1.2. Small horizontal axis turbines (HAWT – "horizontal-axis wind turbine")…....……5
2. The components of the small horizontal axis wind turbine……………………………8
3. Small wind electric systems used in rural areas……………………………………..11
   3.1. Household installations ……………………………………………………....11
   3.2. Water-pumping installations…………………………………………………..…12
   3.3. Installation of wind turbine in small ships……………………………….…..13
   3.4. Wind hybrid power systems……………………………………...…………….…..14

1. Types of wind turbines applicable for rural areas

The field of wind energy conversion systems is vast. Most national programs are devoted to large-scale applications of wind turbines for supplied electricity to a public network. However, at the same time, there are decentralized applications of wind energy conversion (each household should have its own turbine, possibly combined with solar and / or a biogas system), especially in rural areas. Thus, in rural environment are two possible types of wind installations, mainly:

1. The development of wind farms, which can be connected to the network and which can provide electricity for a community made up of several families

2. A small wind turbine that would provide energy needs for a home. This can be combined with other energy producing systems.

In the first case, the investment is very high and difficult to support by rural community, even when using European funds. The policy to promote renewable energy sources varies from country to country, taking into consideration that there are different national action plans in the field of energy production from renewable sources. Therefore, we will focus on the second case.

Moreover, a wind turbine of small size, carried out in a simple construction and high reliability can be used in a highly efficient mode in isolated areas without electricity, or when electricity saving is desired.

Heating water is another application of small wind turbines. The most flexible electricity production is based on the use of heaters and temperature sensors (this kind of electricity production is independent of the relation between energy production and use [11]).

In this subchapter, there are presented a lot of types of wind turbines that are projected for being used in rural areas. It is important to note that we will discuss about small turbines, not about the wind turbines used in wind farms connected to the national grid electricity [8].

The small wind turbines are constructed today in various embodiments. They can have a horizontal axis with the rotor upstream or downstream of the wind direction, with two, three or more blades, or they can have a vertical axis. These turbines can be with electronic or mechanical safety systems against over-wind.

In this subchapter there are going to be given examples of several types of small vertical axis turbines, putting afterwards emphasis on small horizontal axis turbines.

Co-funded by the Erasmus+ Programme of the European Union

1.1. Small vertical axis turbines (VAWT – ”vertical-axis wind turbine”)

a. The Marilyn Wind Turbine presented in Figure 1 is a vertical axle, helix type, omnidirectional foil. The turbine from the picture has a nominal power of 1200 W, at a wind speed of 11m/s. The turbine's main rotor is a (2m diameter x 2m high) fiberglass construction which incorporates three helix mono-block surfaces [1]. The rotor movement begins at a wind speed of approximately 1.4 m/s, and at high wind speeds of more than 20 m/s. Its geometrical construction provides a hydraulic self-braking mechanism.

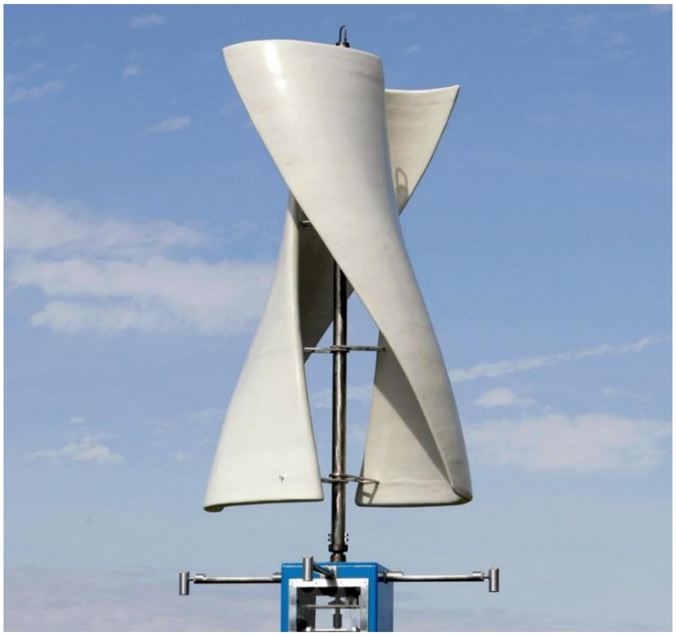


Figure 1. Marylin model wind turbine

b. The Darrieus wind turbine, mentioned in subchapter 1.1, uses lift forces generated by the wind hitting airfoils to create rotation. Its great disadvantage is that it is not self-starting. Therefore a small powered motor is required to start off the rotation, and then when it has enough speed, the wind passing across the airfoils starts to generate torque and the rotor is driven around by the wind.

c. The Lentz turbine. This turbine has blades type "cup", which ensures high efficiency at low wind speeds, reliability and low noise.

Figure 2. Lenz model wind turbine.

Source: http://www.palebludot.com/2008/01/08/ed-lenzs-wind-turbine-powered-home/

d. Savonius wind turbine. The power from the Savonius turbine design is based on the difference in air pressure across the blades as one set of blades retreat from the wind and the other set of blades advance into the wind. This is in turn related to the difference in the drag coefficients associated with the convex side of the blade and the concave side of the blades. Generally, compared to other forms of wind turbine designs, the Savonius rotors have fairly low efficiencies [5]. This type of turbine can be used to generate electricity in strong windy conditions and also for pumping water, and grinding grain for which are desired slow rotation and high torque.

Figure 3. Savonius wind turbine.

Source: http://www.reuk.co.uk/Savonius-Wind-Turbines.htm

There are combinations of these types of turbines. In Figure 4 is shown a Darrieus-Savonius turbine. This type of wind turbine combines two types of blades, the S-shaped Savonius and the curved Darrieus aerofoil. Whereas the Savonius-blades are drag-driven, the Darrieus-blades will experience a lifting force when the wind is blowing across the turbine. Since a pure Darrieus Wind Turbine is (mostly) not able to start without an initial net rotational force, the Savonius-Vanes are added to make the turbine self-starting.

Figure 4. Darrieus- Savonoius wind turbine. Source: http://www.alternative-energy-tutorials.com/energy-articles/vertical-axis-wind-turbine-design.html

Another interesting model is the combined wind turbine Darrieus-Maglev. This kind of turbine uses the advantages of Darrieus turbine with those of magnetic levitation turbine.

1.2. Small horizontal axis turbines (HAWT – ”horizontal-axis wind turbine”)

The majority of the marketed turbines are with horizontal axis. The rotation axis of the turbine coincides with the wind direction and is parallel to the soil surface. The classifications of small wind turbines with horizontal axis are the same with the general classifications presented in subchapter 1.1 (apart from offshore turbines which are not specific for rural areas).

A key feature of turbines with horizontal axis is the number of blades. As it was shown in subchapter 1.1, these turbines can be with two, three or more blades.

Figure 5. Wind turbine with 2 blades. Source: https://www.youtube.com/watch?v=5ttQQSH8jV4

In Figure 6 it is shown a popular wind turbine used for rural area, REDriven 3 kW, with three blades. The cut-in speed is 2 m/s and the cut-out speed is 18 m/s. The rated power output is 3 kW and it is realized at a rated wind speed of 10 m/s, [10].

Figure 6. REDriven 3 KW wind turbine with three blades, Source: http://www.roanokecountyva.gov/DocumentCenter/Home/View/2018

Figure 7. Wind turbines with many blades (six and eleven blades). Source: http://www.hydrogenappliances.com/Commander.html

As the turbine has more blades, the surface area which is swept by the rotor, increases. As a turbine has more blades, the turbine rotation speed is smaller and the developed torque will be higher and vice versa. Because of this, the turbines with fewer blades are used to generate electricity, while those with more blades are used for pumping water or for different equipment that require low speed rotation and high torque at startup [7]. Nowadays, the most used wind turbines have three blades. This is due to the power coefficient. The power coefficient describes the efficiency of producing electricity from wind. This coefficient is not constant; it varies depending on the type of machine and the wind speed. Figure 8 shows that the wind turbine with three blades has the highest power coefficient followed by the turbine with two blades.

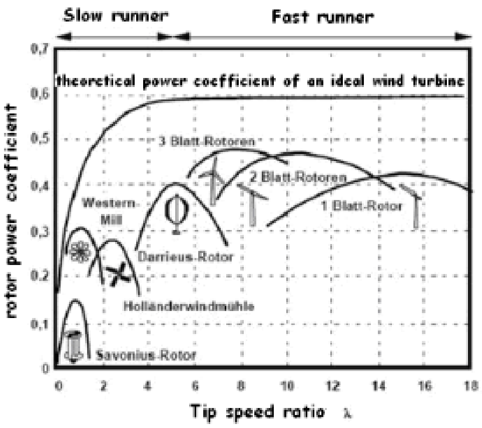


Figure 8. The variation of power coefficient with tip speed ratio and wind turbine type. Source: http://amet.ro/documents/Studiu_Energii_Regenerabile_Timis.pdf

Tip speed ratio, λ, is the ratio between the tangential speed of the tip of a blade, *U*, and the actual speed of the wind, *v:*

$$\lambda = \frac{U}{v} = \frac{\omega * R}{v} \quad (1)$$

Where ω is the rotor rotational speed in radians/second and *R* is the rotor radius in meters.

2. The components of the small horizontal axis wind turbine

In principle, the small horizontal axis wind turbine has the same components as those shown in subchapter 1.1, section 1.4. The construction is simpler, like it is shown in Figure 9.

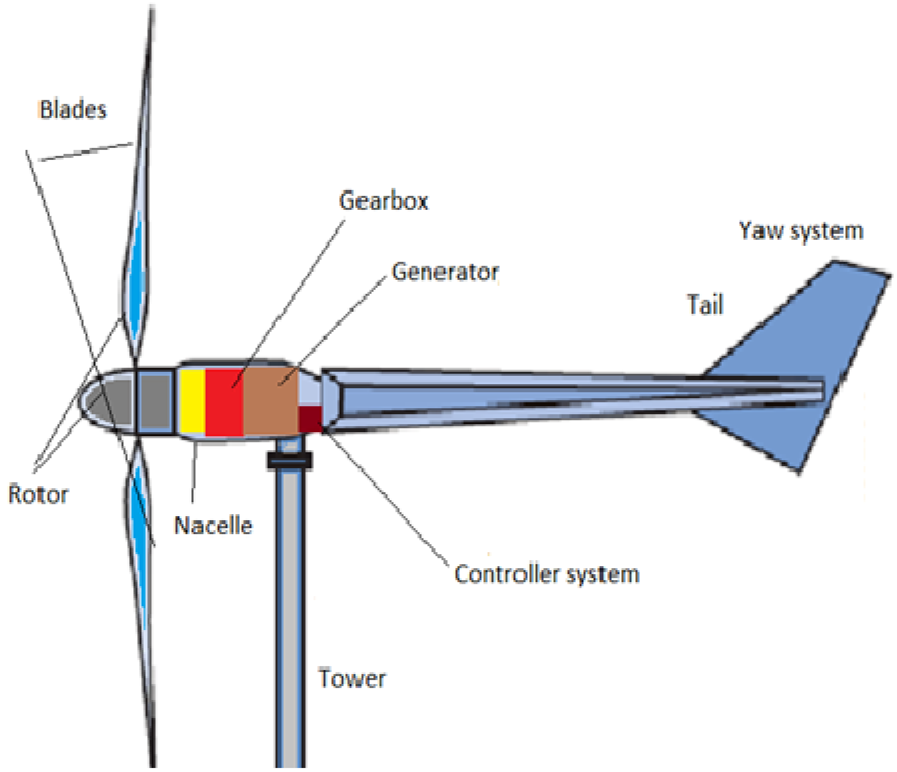


Figure 9. Components of small horizontal axis wind turbine

Table 1. The description of components [8]

No.	Component	Description
1	***Rotor***	The rotor is formed from the main-shaft and its blades. The blades have

		an aerodynamic shape and are made from composite materials mixed with fiberglass. In a complete rotation, the surface covered by blades determines the generated power. The main shaft is positioned horizontally.
2	***Generator***	The generator is the component which transforms mechanical energy of rotational movement of the propeller turbine into electricity.
3	***Gearbox***	The gearbox is used in small wind turbines with outputs greater than 10 kW. It serves in adjusting the rotation speed of the rotor.
4	***Nacelle***	The nacelle is the housing where are mounted the generator and the gearbox.
5	***Yaw system***	The yaw system assures the orientation of the nacelle to the wind direction. A lot of the small wind turbines have a simple system with tail.
6	***Controller system***	The controller or the electronic control system monitors the overall operation of the turbine. His complexity depends on the type and capacity of wind turbine.
7	***Tower***	The tower supports the guidance system, the nacelle and the rotor of the wind turbine. It is generally made from a metal and its purpose is to support the nacelle. There are two basic types of tower: free standing and guyed. The height of the tower is of a major importance because the higher it is, the greater the wind intensity becomes and so, the turbine will have a better efficiency. But, it has to be taken into account to reach a compromise between the cost of production and the exposure to wind. Generally, the tower height is smaller than the radius of propeller blades.

The design of the wind energy system for areas where it is possible that the national energy system has no coverage, highlights the need of ***storage batteries*** to sustain a minimum consumption for the periods in which the weather conditions are unfavorable for using the wind generator. They have the same role like in the case of use the solar power. So, the function of the batteries is to balance the outgoing electrical requirements with the incoming power supply. They offer a reliable source of electricity which can be used when wind power is not available.

Batteries are able to provide short term power output many times higher than the charging source output.

Batteries for photovoltaic systems, wind hybrids are of a special construction regarding the free maintenance and the fact that it supports a large number of charge-discharge cycles.

In Module 2, section 1.2, there are shown types of batteries used in PV systems. They are similar to those used for wind systems.

The most common types of storage batteries in photovoltaic systems, wind systems and hybrid systems are lead-acid batteries. Recently, there have been developed *Li-Ion* batteries and nickel - cadmium (*Ni-Cd*) batteries for high capacity.

Lead-acid batteries continue to be the main option for energy storage, having the advantage of price and availability. Besides this, they can release a huge amount of energy in a very short span of time, being able to withstand very high currents. Lead-acid batteries used in photovoltaic systems, wind systems and hybrid systems are encapsulated and sealed. There are valve-regulated lead-acid batteries (*VRLA*).

Gel batteries use sulphuric acid that has been turned into a gel form. Sealed at the factory, they do not leak or spill, so they are easily transported and require no maintenance.

With *AGM* (Absorbed Glass Mat) lead-acid batteries, sulphuric liquid acid electrolyte is absorbed into mats fibers glass so they would not leak, even if cracked. Many *AGM* batteries are designed for stand-by 'float' applications, not for deep discharging.

Tubular plate batteries, also called *OPzS* (liquid electrolyte) or *OPzV* (gel) batteries, are made especially for off-grid applications and have excellent deep discharge characteristics. The positive plates in tubular cells are made of rods protected in a 'tubular' sleeve – not a flat plate – which gives them an exceptionally long life cycle.

The correct sizing capacity for a storage battery depends on the load rating chart and the consumer intervals. The lifespan of a pack of batteries is dependent on the depth of discharge and temperature. Depending on the capacity and the type of storage batteries, inverters are selected.

As shown in Module 2, ***power inverters*** transform stored energy from the batteries or from generated energy DC current from the wind turbine at 12, 24 or 48V into alternating current at the necessary voltage and frequency. There are two types of inverters: grid-tie inverters and stand-alone inverters. They were presented in Module 2, chapter 1.2.

In Figure 10 it is shown an example of an inverter used for power plants with renewable energy: PV systems, wind turbines and hydro power: Powador 2002-INT inverter 1600 W.

Figure 10. Inverter 1600 W, Source: http://elec.ro/136-powador-2002-int-invertor-kaco.html

3. Small wind electric systems used in rural areas

This section is devoted to introduce some of the applications derived from small wind power installations [9].

3.1. Household installations

Figure 11 presents a domestic system of production and use of direct and alternating current using a small wind turbine.

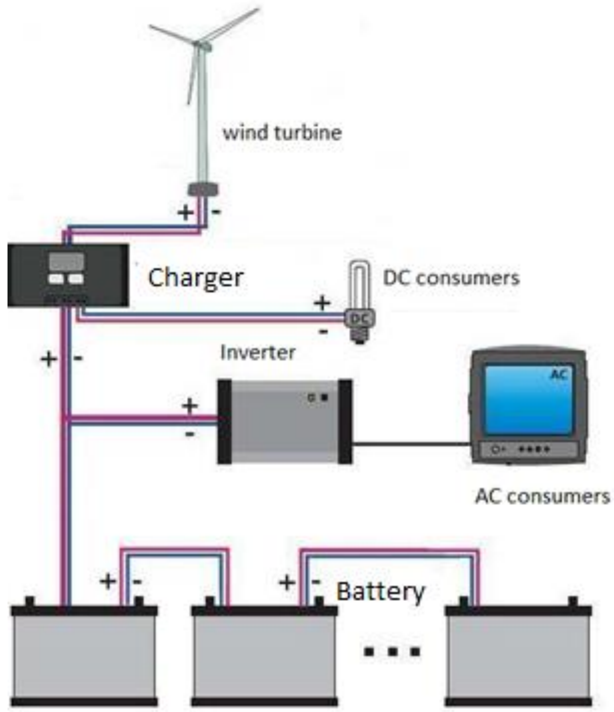


Figure 11. Simple system of using wind energy for a residential house. Source: www.lpelectric.ro

With this system it is possible to supply with energy both DC and AC loads.

3.2. Water-pumping installations

In areas where water is in limited quantities, but there is ground water in depth and wind blows regularly, a wind turbine can be successfully used to pump the water to the surface for further use of it. The scheme of such a system is shown in Figure 12.

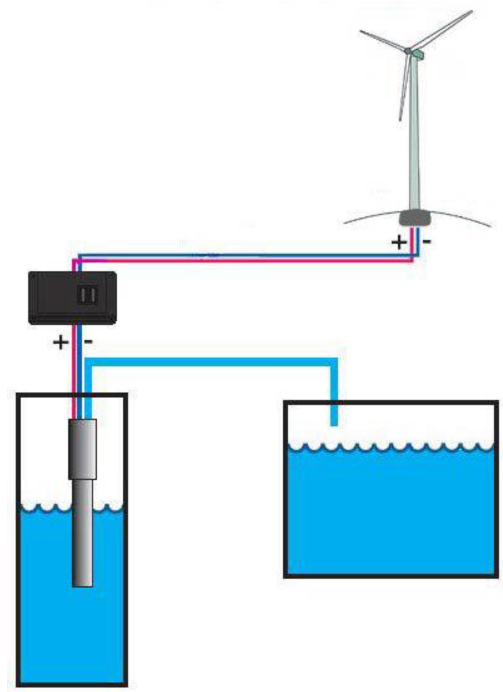


Figure 12. Water-pumping windmills. Source: www.lpelectric.ro

This system is used in agriculture for irrigation in dry areas, pumping water from rivers, etc. Basically, the operation of such a system of water pumping windmill is almost free, except for eventual maintenance costs. The costs of the initial investment (which can solve a number of serious problems caused by water shortages in some regions) must be analyzed in the context of economic and social importance [9].

3.3. Installation of wind turbine in small ships

In Figure 13 is shown small demonstration ship with a wind turbine attached to the deck. The picture is from the following site: http://www.propit.se/news.shtml, in which it is presented the project "Development and demonstration of new technologies to harness wind power on ships", developed since 2013 by Chalmers University of Technology and PROPit AB and supported by the Swedish Energy Agency, Region Västra Götaland, Stena Teknik, Wallenius, Lloyd's Register.

Figure 13. Wind turbine on small ship. Source: http://www.propit.se/images/images/PROPit_4B2.jpg

3.4. Wind hybrid power systems

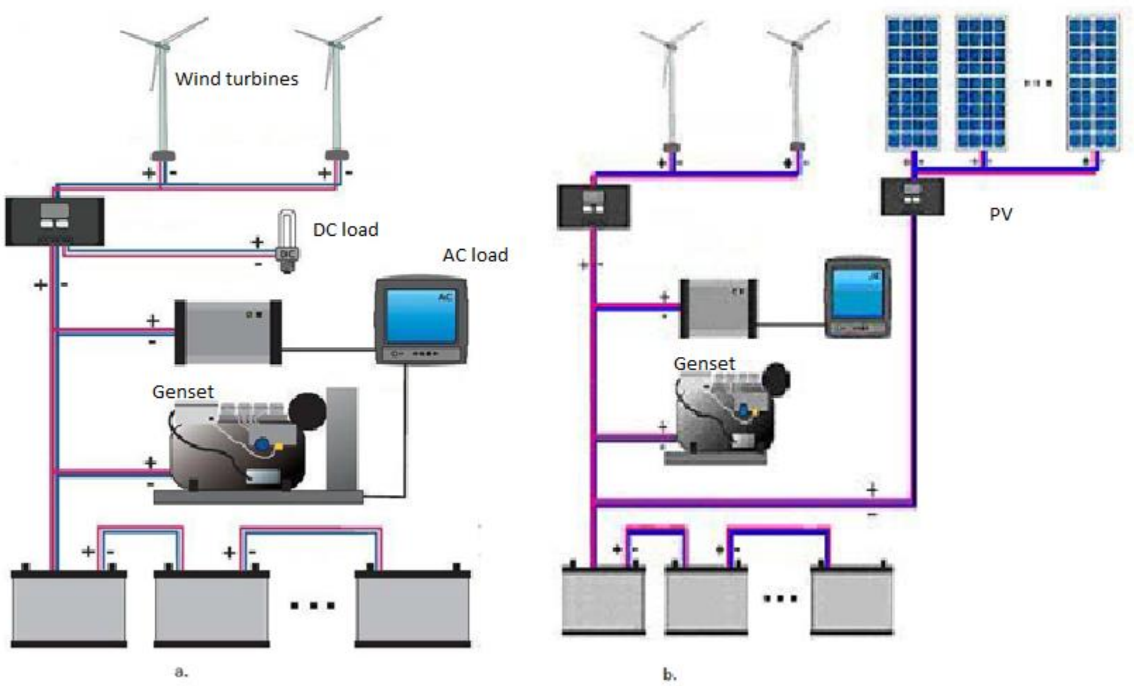


Figure 14. Wind hybrid power systems: a. Wind-Diesel system, b. Wind-Diesel- Solar systems

Hybrid systems can often provide the most efficient and cost effective option for rural electrification. Systems photovoltaics (PV), which convert sunlight directly into electricity are often used to supplement wind power because PV tends to function best in the seasons when the wind is calm. Diesel generators or batteries can be used for backup power and to maintain wind energy production during seasons with low wind.

In Figure 15 is shown a wind hybrid power system used to generate electricity for a house situated in rural area, in village Totoesti, county Iasi, Romania. It can be seen that they used a small vertical axis turbine and photovoltaic panels.

Figure 15. Wind hybrid power system in village Totoesti, county Iasi, Romania

References

[1] http://www.karenoneel.com/gortechrenewables.com/breakthrough.technology.html

[2]http://photos.mlive.com/4472/gallery/kvcc_wind_turbine_class/index.html?fromentry=5030943&fromblog=4132#/0

[3] http://www.finex-energy.ro/energia-eoliana/turbine-eoliene-cu-ax-vertical

[4]https://www.google.ro/search?q=Darrieus+wind+turbine+small&biw=1843&bih=905&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwiMgaaR6qbMAhWJ2SwKHZ1ZBU0QsAQIQg&dpr=1#imgrc=T9rnnKIaF_IcrM%3A

[5] http://www.alternative-energy-tutorials.com/energy-articles/vertical-axis-wind-turbine-design.html

[6] http://www.wwindea.org/small-wind-world-market-back-on-track-again/

[7] Victor Emil Lucian, Turbine eoliene. Manual de documentare, proiectare, dimensionare si montajul turbinelor eoliene, Editura Universitara, Bucuresti, 2015

[8] Ionela Negrea, Studiul adaptabilitatii turbinelor eoliene de mica putere la conditiile climatice din Romania, teza de doctorat, Brasov, 2010

[9] http://www.termo.utcluj.ro/regenerabile/6_5.pdf

[10] http://www.roanokecountyva.gov/DocumentCenter/Home/View/2018

[11] http://www.propit.se/news.shtml

MODULE 4: WIND ENERGY

CHAPTER 1. Technical aspects

Subchapter 1.3 - Calculations and design.

Roxana Margareta Grigore

“Vasile Alecsandri” University of Bacau

Summary: The aim of this subchapter is to present the necessary steps for sizing a wind turbine installation for a dwelling from the rural area. It is very important to calculate correctly the energy needs and to choose the proper wind turbine. It is presented the dimensioning of each installation component, based on the adequate equation. Finally, in this subchapter, are shown some considerations about the influence of wind speed over the power produced by the wind turbine.

INDEX

1. The sizing of wind installation components…………………………………………..2
2. Some considerations about wind speed……………………………………………….2
3. Calculations of the energy needs ……………………………………….……….3
4. Calculation of the needed daily amount of electricity that is necessary to be produced by the generator..………………………………………..5
5. Choosing the wind turbine……………….....…………………………………...….5
6. Calculation of the batteries…………………………………………………………7
7. Calculation of the inverter…………………………………………………………..8

1. The sizing of wind installation components

The calculation of size for components of electricity generation plant are required to be made for knowing what kind of equipment we choose.

The first step is to determine the daily consumption of energy required by the beneficiary of the wind turbine. This can be done by knowing the rated powers of each individual consumer and the daily operation.

The second step is to determine wind energy potential for the area in which the wind turbine will be located. In general, the following are of a great importance: the wind intensity, the variation of wind speed in time, the variation of wind speed with altitude, the wind direction and the time period in which the wind blows. On site, it is used an anemometer with a periodically data recording system to record the wind speed in a given period of time. Measurements should be made on an annual basis and then it should be calculated the frequency of wind at different speeds with Weibull probability for every season.

The main parameters to be taken into account in sizing calculations are:

- The total power consumption of all consumers from the considered place (house) for which we need to assure the electricity
- The power of the largest consumer
- The number of the days in which the wind blows
- The simultaneity coefficient of the consumers

2. Some considerations about wind speed

The power generated by a wind turbine depends by the wind speed, according to next equation, (1):

$$P_t(W) = \frac{1}{2}\, C_p\, \rho\, A\, v^3 \qquad (1)$$

where C_p - the power coefficient,

ρ - the air density $(1{,}225\ \frac{Kg}{m^3})$ at a temperature of 15°C, at the sea level and with an atmospheric pressure of 101.325 Pa,

A - the area swept by the rotor in squares meters

v - is the wind speed in m/s.

Figure 1 shows a typical wind turbine power output (power curve). The wind speed is a decisive parameter that influences the choice of wind turbine, taking into account the influence of wind speed to turbine power curve (Figure 1). In choosing of the wind turbine must be taken into account the rated wind speed (12 m/s – Figure 1) and by the cut wind speed (3 m/s – Figure 1).

Rated output power- this is the wind speed at which the turbine starts to generate the rated power

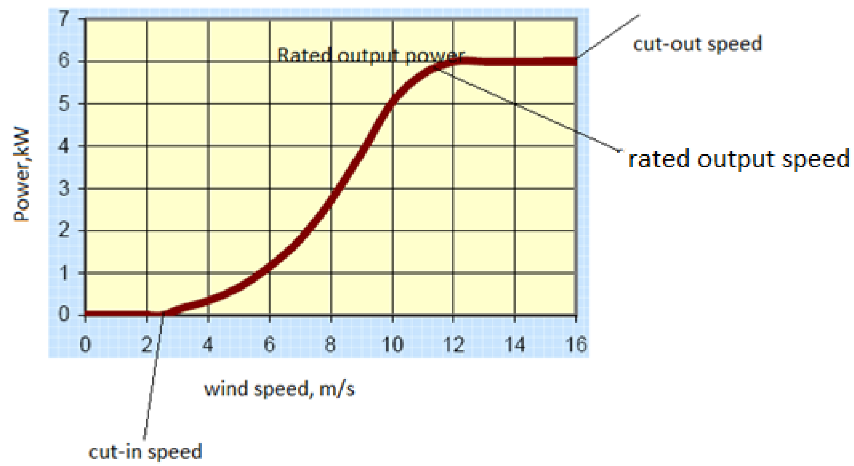


Figure 1.Typical wind turbine power output, source [3]

Cut-in wind speed - this is the minimum wind speed at which the turbine blades overcome friction and begin to rotate.

Cut-out speed - This is the speed at which the turbine blades are brought to rest to avoid damage from high winds. Not all turbines have a well-defined cut-out speed.

These important parameters are found in specialized data bases, like it was shown in Module 4, subchapter 1.1. For example, in Romania there is a data base available surcharge from National Meteorological Administration, site: http://www.meteoromania.ro/anm/?page_id=640.

3. Calculations of the energy needs

The calculation is made in the same way as it is made for PV panels. In the Module 2, subchapter 1.3, it is shown this way of calculation. It is important to know the daily consumption of energy required. To do so, it will therefore be necessary to list the energy consumed by the equipment and the daily number of operating hours.

For example, it is possible to have a list of consumers like in Table 1. The data are taken from the producers.

Table 1. Power consumption of different domestic equipment

Lighting	**Power**		**hours/day**		**number**		**kWh/day**	**kWh/month**
Energy -efficient bulbs	11 W	x	2.0 h	x	12	=	0.26 KWh	7.92 KWh
Fluorescent bulbs	13 W	x	3.0 h	x	3	=	0.12 KWh	3.51 KWh
Appliances	**Power**		**hours/day**		**number**		**kWh/day**	**kWh/month**
Mixer	300 W	x	0.2 h	x	1	=	0.06 KWh	1.80 KWh
Dryer	1000 W	x	0.1 h	x	1	=	0.10 KWh	3.00 KWh
Washing machine	700 W	x	0.5 h	x	1	=	0.35 KWh	10.50 KWh
Microwave	900 W	x	0.3 h	x	1	=	0.27 KWh	8.10 KWh
Electric stove	2100 W	x	0.0 h	x	0	=	0.00 KWh	0.00 KWh
Fridge	200 W	x	6.0 h	x	1	=	1.20 KWh	36.00 KWh
Vacuum cleaner	700 W	x	0.5 h	x	1	=	0.35 KWh	10.50 KWh
Iron	1100 W	x	0.2h	x	1	=	0.22 KWh	6.60 KWh
Communications	**Power**		**hours/day**		**number**		**kWh/day**	**kWh/month**
TV color 25"	150 W	x	4.0 h	x	2	=	1.2 KWh	36.0 KWh
AC stereo/home cinema	500 W	x	0.0 h	x	0	=	0.0 KWh	0.0 KWh
CD Player	35 W	x	0.0 h	x	0	=	0.0 KWh	0.0 KWh

Desktop Computer	300 W	x	5.0 h	x	1	=	1.5 KWh	45.0 KWh
Ink jet printer	35 W	x	0.1 h	x	1	=	0.0 KWh	0.1 KWh
Laptop Computer	100 W	x	0.0 h	x	0	=	0.0 KWh	0.0 KWh
Satellite Antenna	30 W	x	5.0 h	x	1	=	0.2 KWh	4.5 KWh
Video Recorder	40 W	x	0.0 h	x	0	=	0.0 KWh	0.0 KWh
Video games	20 W	x	0.0 h	x	0	=	0.0 KWh	0.0 KWh

The daily energy required in kWh/day is obtained by multiplying the rated power by the operating hours of the equipment and division with 1000, according to equation (2):

$$Ed\left(\frac{Wh}{day}\right) = \sum_{i=1}^{n} P_{n,i}(W) \times t_i(h), \quad (2)$$

Where: *i* = number of consumers.

Usually, for a dwelling, the monthly energy required is between 250 kWh/month and 300 kWh/month, [3].

Average electrical power consumption is calculated with equation (3):

$$Pc(W) = \frac{Ed\left(\frac{Wh}{day}\right)}{24} \quad (3)$$

4. Calculation of the needed daily amount of electricity that is necessary to be produced by the generator

The inverter is necessary to convert DC in AC. The inverter efficiency is η_i = 80% ... 90%, [3]. In this regard, the energy that is necessary to be produced by the wind turbine generator is calculated by the expression (3):

$$Eg\left(\frac{Wh}{day}\right) = \frac{Ed\left(\frac{Wh}{day}\right)}{\eta_i} \quad (4)$$

5. Choosing the wind turbine

After it was realized the wind study and the wind data base was generated, it is chosen the wind turbine, according with the required energy by the consumers. The wind turbine P_t is chosen with the rated power higher than the necessary power P_c.

Wind turbines are designed for specific wind resource and environmental criteria, summarized by four International Electrotechnical Commission (IEC) classes (I-IV), as shown in subchapter 1.1, table 1. In general, turbines designed for high energy capture in low wind regimes will have larger rotors. On the other hand, turbines designed for high wind regions tend to have larger nameplate generator ratings and smaller rotors, [6].

There are a lot of producers of wind turbines. There are hundreds of models, with different particularities. Besides the wind conditions, there are very important in wind turbine choosing, the reliability, the availability and its price. The most used small wind turbines in rural areas, for a household, are with horizontal axis and they have three blades. For example, a lot of models of small wind turbines are described on site http://www.roanokecountyva.gov/DocumentCenter/Home/View/2018 .

The technical data for the REDriven 3 KW wind turbine, from Figure 5 subchapter 1.2, Module 4 are next:

- Rotor Diameter: 3.6 m;
- Swept Area: 10.2 m^2
- Rated Power Output: 3 kW
- Rated Wind Speed: 10 m/s
- Cut-In speed: 2 m/s
- Cut-Out Speed: 18 m/s
- Maximum Wind Speed: 40 m/s

The power produced depending from wind speed is shown in Figure 2:

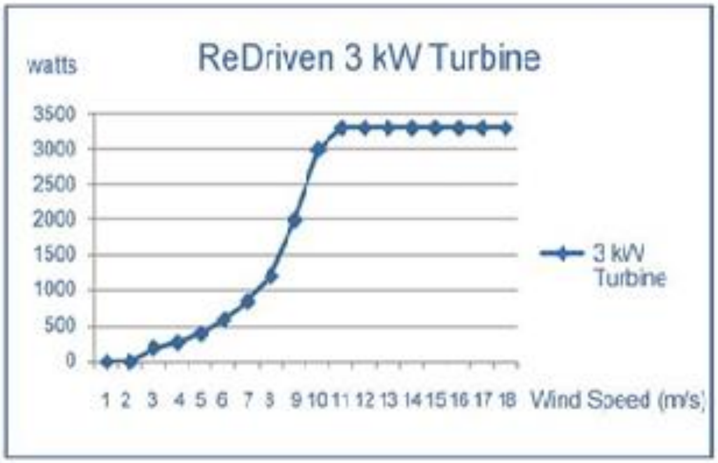


Figure 2. The variation of produced power according with wind speed

6. Calculation of the batteries

The required energy to be stored in the batteries is determined by the relation (5):

$$Eb = V_{bat} \times \sum_{j=1}^{m} I_j \times t_j \qquad (5)$$

Where: V_{bat} *is* voltage, I_j is electric current in time period t_j. It is recommended to use 12V batteries for energy requirement of less than 150 kWh/ month, 24 V or 48 V batteries for an energy requirement between 150 kWh / month and 700 kWh / month and 48 V batteries for an energy requirement of more than 700 kWh / month. High voltage batteries are selected when the connecting is made with long cables in order to reduce losses, [3].

The amount of current supplied by the generator is determined by the relation (6):

$$Cg(Ah) = \frac{Eg}{V_{bat}} \times (1 + \lambda_s) \qquad (6)$$

Where: λ_s = 20% ... 25% represents the system losses (in batteries, controller and cables).

For the sizing of batteries, there are taken into account the number of days in which the wind speed is below the value at which the wind turbine develops its rated power, *D* (for safety in operation, it is recommended that the batteries operate at 80% capacity).

The batteries capacity C_B, in Ah, is determined by the relation (7):

$$C_B(Ah) = \frac{Cg \times D}{0{,}8}, \qquad (7)$$

The number of batteries:

$$n_b = \frac{C_B}{C_{bat}}, \quad (8)$$

Where: C_{bat} (Ah) is the capacity for one battery.

The required capacity for a battery is determinated with next relation, (9):

$$C_{bat}(Ah) = \frac{E_g \times D}{V_{bat} \times DOD_{max}}, \quad (9)$$

Where: DOD_{max} is the maximum depth of batteries discharge and D is the number of days when the wind generator does not produce energy.

7. Calculation of the inverter

The inverter power is calculated with the next formula, (10):

$$P_i(W) = 1{,}35 \times P_c \quad (10)$$

The power of the chosen wind turbine, P_t *(W)*, must be greater than the average electrical power consumption, P_c *(W)*.

In the case of insufficient energy production, more wind systems or hybrid systems (composed of photovoltaic panels and wind turbine or diesel generator electric) could be good solutions for covering the energy demand of a dwelling [3].

References

[1] Victor Emil Lucian, Turbine eoliene. Manual de documentare, proiectare, dimensionare si montajul turbinelor eoliene, Editura Universitara, Bucuresti, 2015

[2] Camil Tudor, Research regarding the implementation, adaptation and functioning of the wind turbines for small consumers, PhD thesis, Brasov, 2015

[3] Mihai Tiberiu Lates, Wind Systems. Theory and practice, Editura Universitatii Transilvania, Brasov, 2012

[4] http://www.wind-power-program.com

[5] http://www.roanokecountyva.gov/DocumentCenter/Home/View/2018

[6] http://www.windustry.org/community_wind_toolbox_15_turbine_selection_and_purchase

MODULE 4: WIND ENERGY

CHAPTER 2. Economic aspects

Subchapter 2.1 - Estimation cost of the investment

Petru Gabriel Puiu

„Vasile Alecsandri” University of Bacau, Romania

Summary: In making the decision to install a wind turbine, the cost is a critical factor. It is therefore important to establish from the start the price for each watt produced, keeping in mind the entire period of operation.

After completing this chapter, students will be able to appreciate the price components of a wind system with an installed capacity of up to 100 kW.

INDEX

1. Overview………………………………………………………………… 2
2. Costs……………………………………………………………………….. 3
   2.1. Indirect costs……………………………………………………………. 3
      2.1.1. Speed and constancy of wind……………………………………..... 3
      2.1.2. Selection of placement of the wind powered plant………..……...... 3
      2.1.3. The project’s risks………………………………………………….. 4
      2.1.4. Exploitation and maintenance costs……………………..…………. 4
   2.2. Direct costs………………………………………………………………… 4
3. Average prices and graphical representation………………………………. 5
   References………………………………………………………………….. 9

1. Overview

Even if the costs of wind energy production have dropped quite a lot in the last three decades, the initial investment, cost/W, is a lot higher than in the case of conventional power plants. That is due to the fact that the greatest part of the investment (approx. 80%) must be made from the beginning. However, if we take into consideration the fact that the feedstock to produce power is free comparing to other types of generators that need wood, coal, petrol, etc., in the long run (20-25 years), wind power plants produce the cheapest MWh. [1]

This is demonstrated by the growing number of wind turbines. Figure 1 highlights worldwide installed capacity in wind power until 2015.

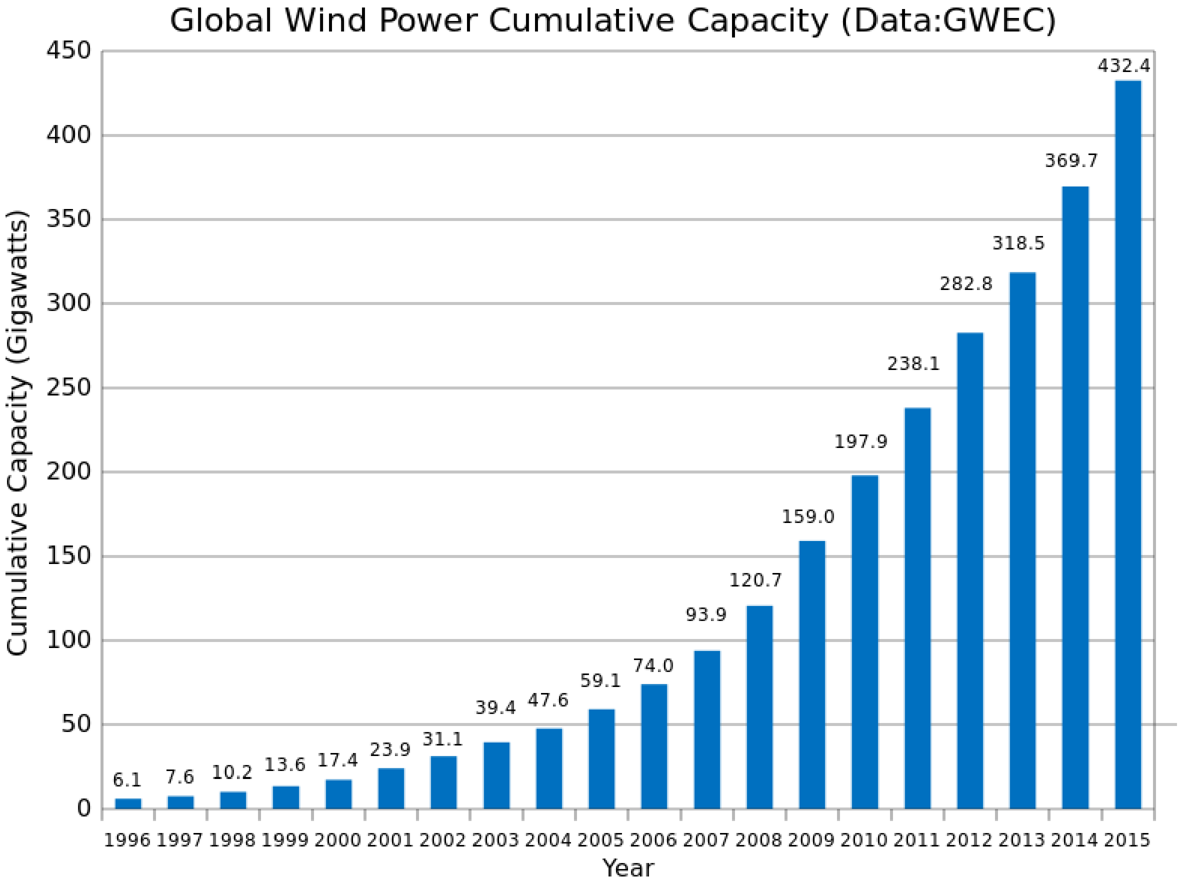


Figure 1. Total cumulative installed capacity from wind power, Source: Wikipedia

Although there is a wide variety of wind turbine types from the constructive point of view (horizontal or vertical axis), of dimensions (from hundreds of watts to megawatts), in the following pages we will discuss horizontal axed turbines with a capacity of production lower than 100 kW, being therefore accessible to rural communities. These can operate in a system with accumulators or by combining accumulators and the power network.

In any case, before planning the investment it is necessary to make the analysis of at least 2 indicators that must be known before the disposition of a wind-powered plant: the wind speed (over 4m/sec) and the annual number of hours in which this speed is reached (an optimal period must overcome 3000-4000 hours).

2. Costs

The installation of a wind-powered plant involves indirect costs required by the feasibility, the project, the maintenance and the direct costs that involve the necessary equipment for the installation, functioning and the exploitation of the installation. Taking into consideration these aspects, the price of wind power produced by turbines with a power any less than 100 kW may reach even 3000 euro/kW for the whole installation.

2.1. Indirect costs

The indirect costs involve the following aspects

2.1.1. Speed and constancy of wind

Wind speed translates into the power produced, so, in movement, mass has a certain energy that varies according to the product of mass and the square of the speed ($p=1/2\ mv^2$, where: P is power (Nm/s or W), m is the mass flow capacity (kg/s), v is the wind speed (m/s)). Reported on time, this represents power [2].

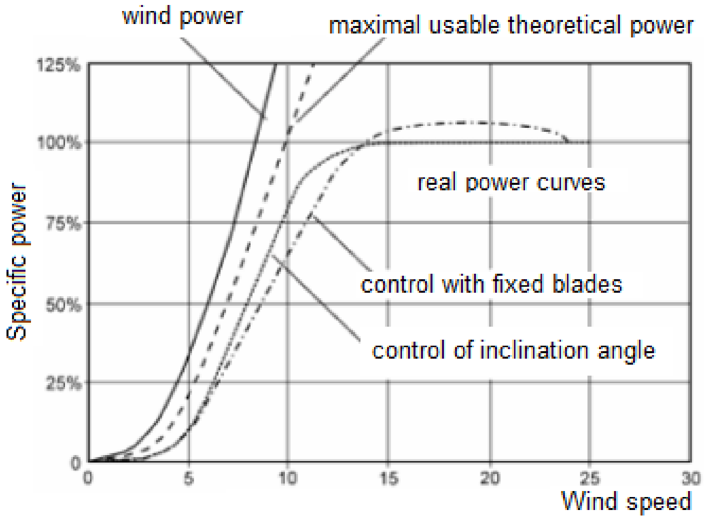


Figure 2. The characteristic of turbine. Output power depending on wind speed. Source: www.sier.ro

Wind is a free inexhaustible "fuel". The turbines are easy and fast to install and they are reliable with an availability of 98%. All these being mentioned, the wind is not always available and that is why the functional availability is much lower. [2]

It is necessary that, before doing the investment, a study referring to the wind speed and its availability should be made, knowing that this parameter influences the produced power to a great extent (wind that has a low speed reduces the produced power, or on the contrary, if the wind speed is higher than 25m/s, the turbines block themselves to prevent the damage of the system, or they are equipped with a system for the setting of the attack angle, Figure 2

2.1.2. Selection of the location for the wind powered plant

Choosing the location of a wind-powered plant must be done by taking into consideration a series of aspects, such as the availability of the space, assuring the access for materials and construction mechanisms, diverse environment and proximity aspects and, last but not least, the availability of sufficient wind.

2.1.3. The project's risks

The major risk is represented by the change on the long term of the wind climate in the placing area. As mentioned earlier, the power produced is proportional with the square of the wind speed. A relatively small drop in wind speed leads to a considerable drop in the power generation and consequently, a longer investment recovery period. This result is assumed as a loss in the project. To avoid such a situation, it is recommended that the project should take into account a moderate value of the wind, lower than the one resulting from the study of wind maps or measurements.

The minimizing of the risks involves extra attention given to details that involve placement. Areas with natural screens such as hills and other obstacles should be avoided.

2.1.4. Exploitation and maintenance costs

The maintenance costs for the functioning of the installation go up to approximately 2€ for 100kW, including maintenance services.

2.2. Direct costs

Directs costs involve the following aspects:

The wind turbine (the assemble of the equipment that produces direct power)

a. The system of blades
b. The electrical generator
c. The pole+ basis+ the system of fixing/anchorage
d. Controller
e. Battery
f. Inverter
g. Resistant to devoiding
h. Charge (consumer)

What is important to see is the fact that the system of anchorage composed of the pole, anchoring and the construction works of the foundation can have a significant cost (up to a third of the turbine's costs).

Example:
For an installed power of 10 kW**,** a propeller of 6 m diameter and a fixed pole with a 320 mm diameter and a height of 12-18 m, we would need, according to the project, a foundation of concrete of approximately 2 x 2 x 1,5 m= 6m^3 concrete + 80 kg reinforcing bars, so:

Table 1. The cost calculus

No.	Materials	Price calculus	Total
1	6 cm beton	6 x 77€/mc = 462€	462€
2	80 kg reinforced concrete	80 x 0,55€/Kg = 44€	44€
3	mechanized excavation in the ground 6 m^3	6 x 12€/mc = 72€	72€
4	2 people labor (smiths + carpenter)	2 x 16 ore = 32 ore x 3€= 96€	96€
5	transport + indirect expense (15%)+ quotas in the state + profit (5%) + VAT (19%)	140 + 100 + 532 + 34+ 128	934€

6	Pillar		3.872 - 19.591
Total Foundation + Pillar			**5408 - 21199**

The cost distribution in the final investment is illustrated in the Figure 3.

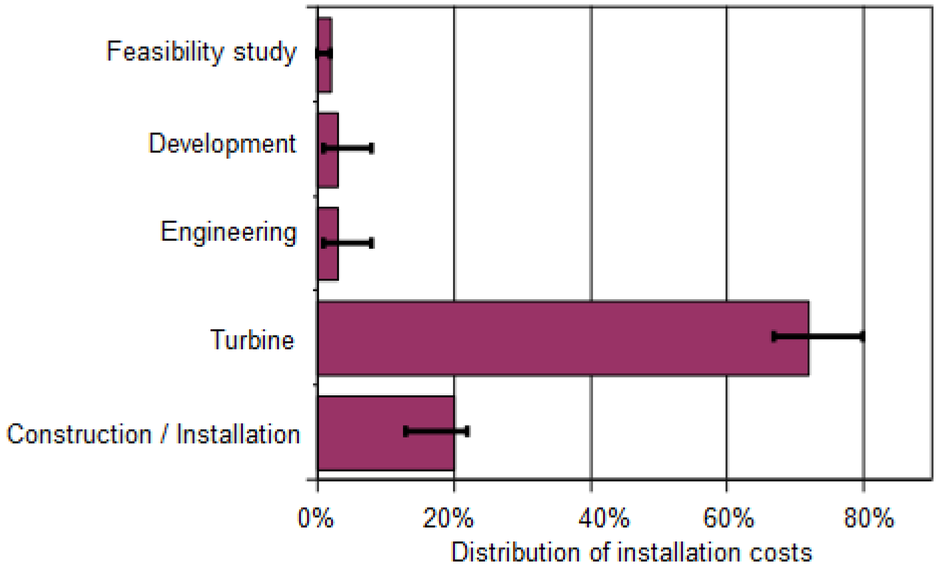


Figure 3.The cost distribution in final investment. Source: http://www.ro-bul-ret.eu

3. Average prices and graphical representation

The average prices for horizontal axis wind turbines are presented in Table 2 and those for pillars in Table 3.

Table 2. The average prices for horizontal axis wind turbine

	Prices horizontal axis wind turbine																	
	300W	**500W**	**1 kW**		**2,5 kW**		**3 kW**		**5 kW**		**10 kW**		**20 kW**		**30 kW**		**50 kW**	
	Off-grid	Off-grid	Off-grid	On-grid	Off-grid	On-grid	Off-grid	On-grid	Off-grid	On-grid	Off-grid	On-grid	Off-grid	On-grid	Off-grid	On-grid	Off-grid	On-grid
Wind turbine	630	680	1.903	1.903	-	-	5.184	5.184	8.268	8.268	14.340	14.340	25.840	25.840	37.030	37.030	84.954	84.954
Controler Off-grid	25	272	636	-	-	-	1.584	-	1.656	-	2.274		4.370		6.072		14.360	
Controler On-grid	-	-	-	396	-	-		1.368	-	1.656		2.274		4.370		6.072		14.360
Inverter Off grid	-	372	540		-	-	1.032		1.968	-	4.056		8.188		11.903		19.320	
Inverter On grid	-	-	-	1.682	-	-	-	2.904	-	3.576		5.990		13.708		20.562		32.430
Fix pillar	638	638	-	-	-	-	-	-	-	-	-	-	-	-	-			
Battery charger	-	-	-	-	-	-	-	-	2.010	-	2.910							
Total KIT	**1.524**	**1.962**	**3.079**	**3.981**	**7.150**	**8.688**	**7.800**	**9.456**	**13.902**	**13.500**	**23.580**	**22.604**	**38.398**	**43.918**	**55.005**	**63.664**	**118.634**	**131.744**

Table 3. The average prices for pillar

Height	PILLAR PRICE (EURO)					
	2.5 - 3.5 kW	5 kW	10 kW	20 kW	30 kW	50 kW
7m	1.560	-	-	-	-	-
9.2m	2.180	-	-	-	-	-
12m	2.775	3.267	3.872	5.973	6.358	-
12m, hydraulic lifting - descending	-	6.292	6.732	9.383	9.713	-
15m	3.650	-	-	-	-	--
18m	4.710	7.568	7.832	10.582	11.792	14.872
18m, hydraulic lifting - descending	-	9.812	10.802	14.916	15.785	23.573
21m	5.725	-	-	-	-	-
24m	6.575	10.901	13.695	16.335	16.335	25.058
24m, hydraulic lifting - descending	-	-	-	23.958	24.970	39.523
30m	-	-	19.591	-	24.662	32.978
30m, hydraulic lifting - descending	-	-	-	-	32.175	-

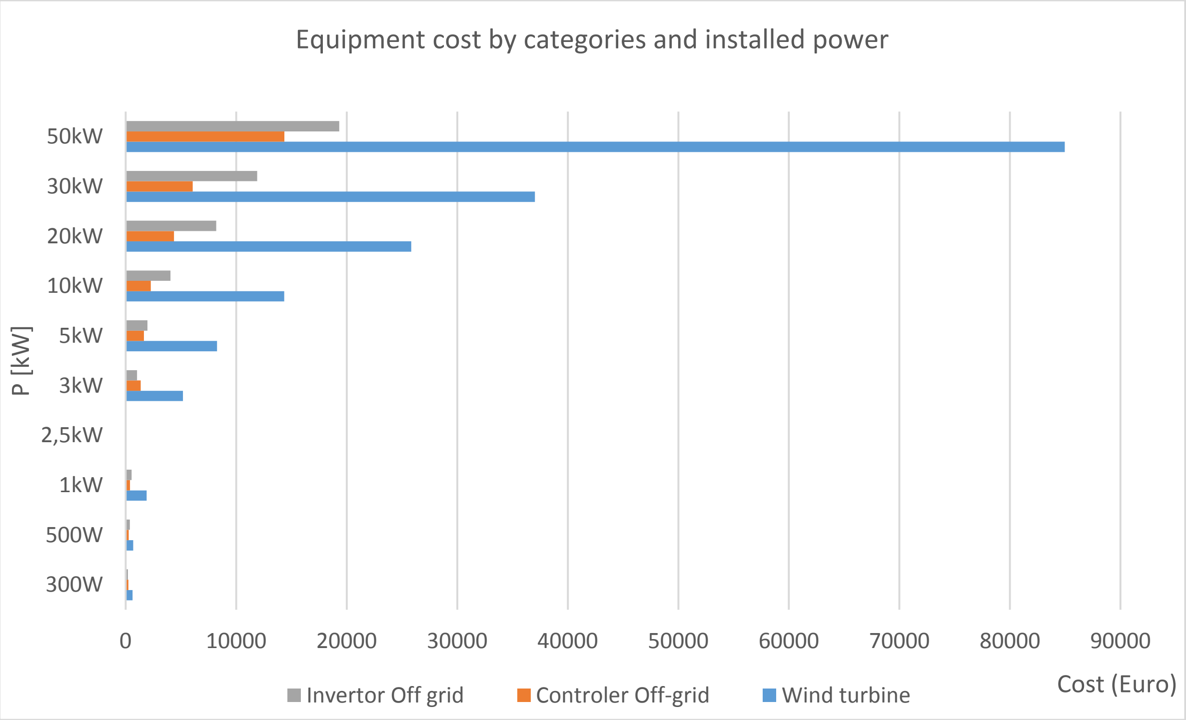


Figure 4. Equipment cost by categories and installed power

It can be observed that most of the costs of an installation are connected to the wind turbine. Its price rises almost exponentially with the power installed (Figure 4). The second in the price hierarchy is the controller. Its price is lower for the off-grid systems and rises for the on-grid system, as it can be observed in the Figure 5.

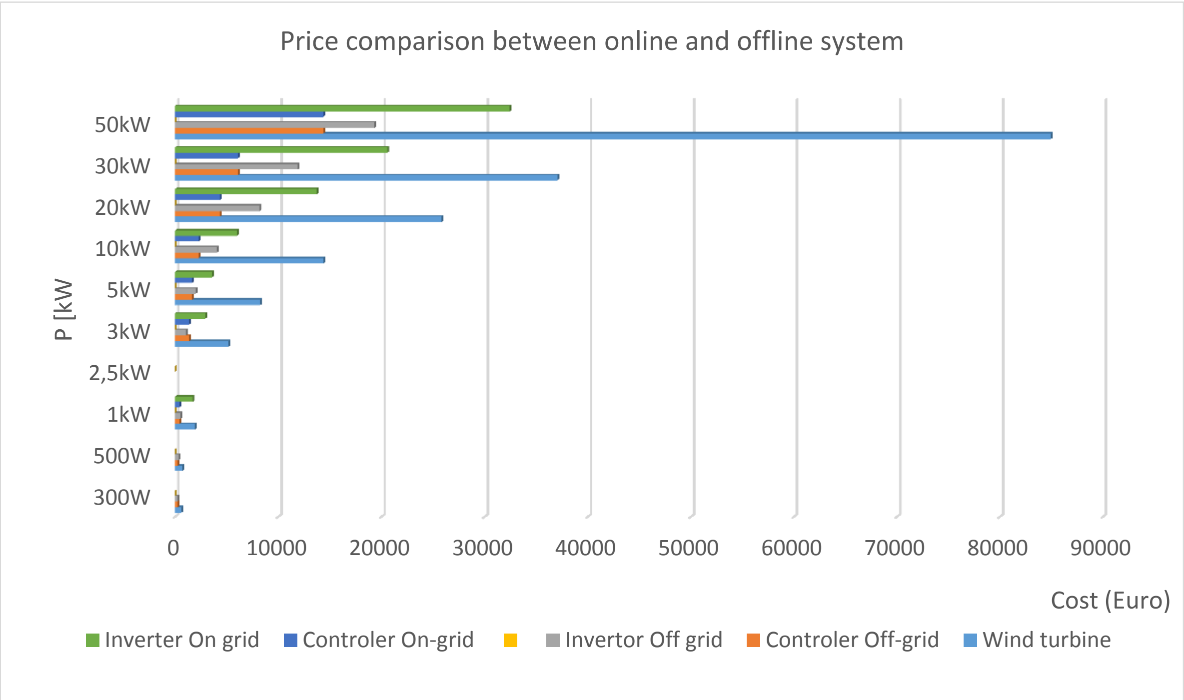


Figure 5. Equipment cost by type of system (on line or off line)

In Figure 6, the difference between the cost of the on-line system and that of the off-line system can be observed. The difference in price increases with the rise in the power installed.

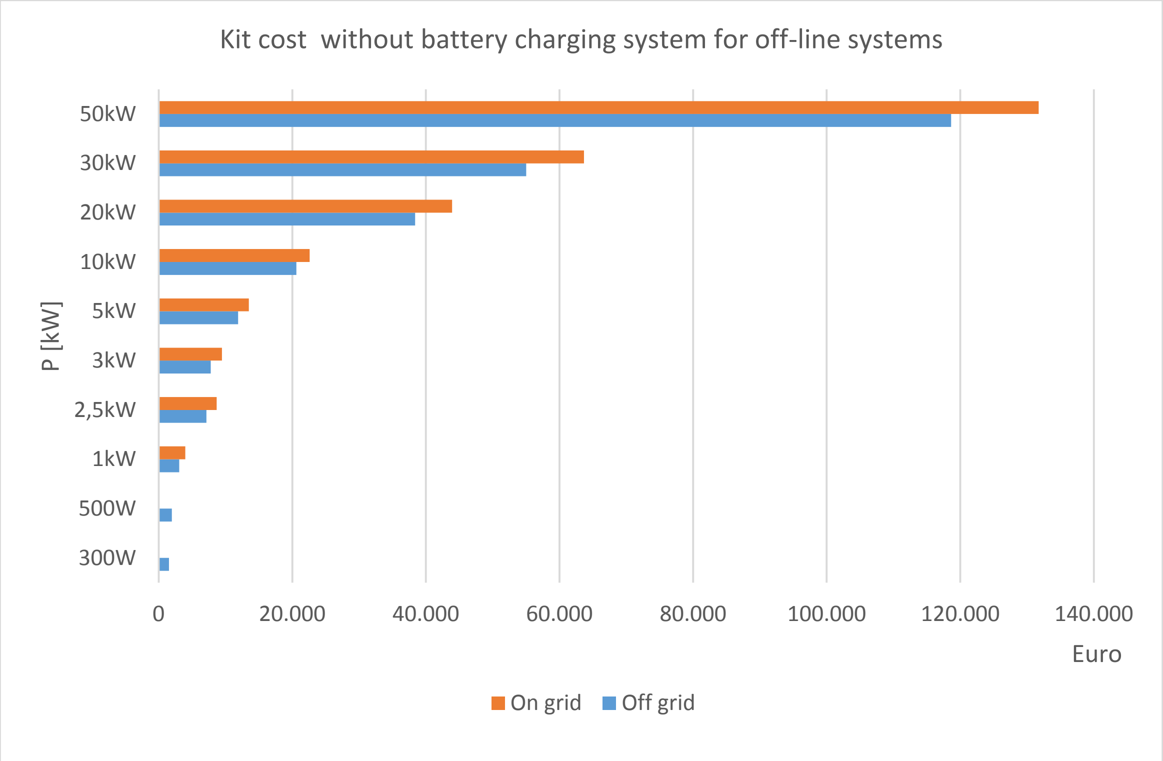


Figure 6. Kit price by type of installation (on line or off line)

References

[1] www.cheso.ro/turbine-eoliene, 2016
[2] Calitatea şi Utilizarea Energiei Electrice, www.sier.ro, 2016

MODULE 4: WIND ENERGY

CHAPTER 2. Economic aspects

Subchapter 2.2. Other costs (employment, management, maintenance, etc.)

Petru Gabriel Puiu

„Vasile Alecsandri" University of Bacau, Romania

Summary: This subchapter refers to the fixed and variable operating and maintenance costs for wind energy.

INDEX

1. Maintenance costs ……………………………………………………..…….. 2
   1.1. Wind turbine component failure ……………………………………..... 2
      1.1.1. Defects in the blades…..............…………………….…………… 2
      1.1.2. Defects in the drive system……………………………………… 2
      1.1.3. Defects in rolling bearings. ……………………………………..… 2
      1.1.4. Defects in the gearbox…………………………………..……..… 3
      1.1.5. Defects of the electric generator………………………..………. 3
   1.2. Maintenance techniques……………………..………………………… 4
      1.2.1. Corrective maintenance………………….……………………… 5
      1.2.2. Preventive maintenance………………….……………………… 5
      1.2.3. Predictive maintenance……………………………………….… 6
2. Operation costs……………………………………………………………….. 7
   References……………………………………………………………………….. 9

"The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein."

Besides the installation costs of a wind turbine, we should take into account the operating and maintenance (O&M) costs.Complex analyses are done especially for wind parks.
The mechanisms of damage to various parts of wind turbines are the same regardless of the installed power, so these analyses can be considered for a wind turbine up to 100 kW.

1. Maintenance costs

1.1. Wind turbine component failure

The monitored elements in a wind turbine are:

- tower, blades, nacelle
- mechanical components (bearings, shafts, couplings, gears etc.)
- electrical generator
- power transformer

Defects can occur in:

1.1.1. Defects in the blades

They occur due to changes in the blade surface roughness. Changes in the blade roughness are caused by pollution, ice deposition, structural defects in construction. Changes in the blade roughness produce an imbalance of rotating masses which results in the appearance of centrifugal forces that are forward nacelle and tower.

The aerodynamic asymmetries are caused by different aerodynamic behaviors of the blades. The aerodynamic asymmetries determine a different angle of attack of the blades.

These differences generate strong axial and torsional nacelle oscillations with a frequency equal to the rotation rotor frequency.

1.1.2. Defects in the drive system

The defects in the system of wind turbine drive are the typical defects that occur in the shaft (cracks or imbalances mass).The causes of faults in the drive system:

- understated design loads;
- torque overloads;
- inappropriate materials;
- issues of production, transport and assembly;
- flawed centering;
- faulty assembly of bearings or their elements.

1.1.3. Defects in rolling bearings

A classification of these is presented in Table 1.

Table 1. Classification of defects in rolling bearings

Category	Defect	Causes	Consequences
Friction destruction	Wear	Destruction of surfaces under the influence of load and increased wear due to poor lubrication	Increased distance between ball and raceways
	Weariness	Loads	Cracks and raceway destruction
Overload	Deformation	Extreme loads, continuous wear	Runway deformation
	Crack	Continuous wear	Cracking elements
Overheating	Cracks	Frequent overheating and cooling	Cracks parts
	Operating at high temperature	Increased speed, deformities, problems with lubrication	
Corrosion	Surface corrosion	High humidity, environmental influences (salty air)	Wear, lubrication oil pollution
Conduction currents	Bearing surface destruction	High current due to natural electrical discharges or electrical problems	Problems with bearing surfaces

1.1.4. Defects in the gearbox

The causes and the consequences of damages in wind turbine gearbox, are presented in Table 2.

Table 2. Classification of defects occurring in the wind turbine gearbox

Category	Defect	Causes	Consequences
Breach	Cracks at the teeth base	Extreme loads, blockages	The teeth destruction surface modified
	Cracks on the teeth face		Cracks and raceway destruction
Front teeth	Cracks, holes, wear, erosion	Wrong geometry overload, vibrations	Surface deformation or pinching
Overheating	Cracks	Frequent overheating and cooling	Cracks and excessive wear
	Operating at high temperature	Increased speed, shape deformations, lubrication problems	
Corrosion	Surface corrosion	High humidity, environmental influences (eg salty air)	Excessive wear
Induction current	Surfaces destruction	High current due to natural electrical discharges or electrical problems	Problems with surfaces

1.1.5. Defects of the electric generator

The stator insulation system damage is a gradual process. The fall stator insulation usually occurs after a period of years or decades, not hours or days. This parameter is critical not only because the increase in the stator insulation degradation determines increased losses, but also because the resulting heat can damage the wire insulation and, in major cases, stator iron melts.

Core damage can be expensive. There is a repair cost and a loss of profit while the generator is not running.

Defects in the stator iron can have multiple causes.

- in the factory, these defects come from a poor insulation of lamination, accidents in assembly or winding burnt beyond the limit (edge) of channels or shortness of the chocks on the sheet irons.
- in operation, they may be brought about by foreign bodies coming into the machine and damaging the notches surface or causing excessive heat or wear due to the deterioration of insulation.

1.2. Maintenance techniques

In its development, maintenance activity has undergone several phases, evolving simultaneously with the increasing complexity of electrical equipment and user requirements. There are two main approaches in terms of maintenance strategies:

- maintenance designed for equipment recovery after damage occurrence
  - corrective maintenance
- maintenance designed for failure prevent
  - preventive maintenance
  - predictive maintenance

Figure 1 represents system failure graphs depending on the frequency with which they performed maintenance work [1].

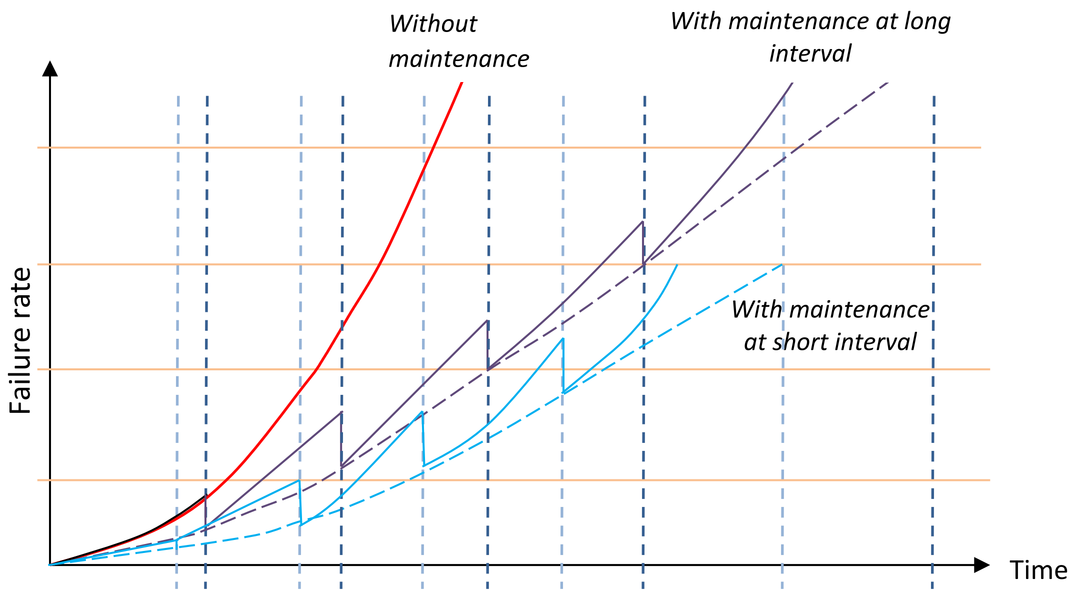


Figure 1. Failure rate with or without maintenance works

1.2.1. Corrective maintenance

Corrective Maintenance is a concept that is based on intervention on equipment after it has crashed (eg repair, partial or total substitution of defective equipment).

In the corrective maintenance work it focuses on scheduled tasks at regular intervals to ensure optimum functioning of the machines / systems. The effective maintenance program is judged according to the life cycle cost and not according to how fast it is reinstated.

Corrective maintenance advantages:

- the value of the stock of spare parts can be quite low,
- unnecessary monitoring equipment,
- intervention requires no programming,
- the maximum use of the installation parts,
- maintenance is cheap.

Corrective maintenance disadvantages:

- there is no a schedule of working hours of staff in charge of maintenance;
- there is no resource (money, time) allocated;
- maintenance team gives the impression of inefficiency;
- there is no budget for the damaged components;
- the waiting time until the delivery of spare parts can be long;
- sometimes, interrupted operation of the plant.

Exclusive focus on the production costs is now a changing concept. Most companies look for ways to reduce maintenance costs. By focusing only on the idea of intervention on the equipment when it is damaged, you can neither control, nor foresee the appearance of defects and cannot find ways to reduce maintenance costs.

1.2.2. Preventive maintenance

Preventive maintenance is a concept that is based on preventive action executed at predetermined intervals recommended by the construction company equipment or resulting from operational experience and aimed at preventing failure of installation components or at reducing the probability of faults.

Preventive maintenance is also known in scientific literature as the time-based maintenance or scheduled maintenance.

The maintenance activities are managed over time. Figure 2 shows the rate of defect occurrence according to operation time.

Thus, new equipment has a good chance to be damaged in the first week of commissioning due to installation issues. After this period the probability of a defect is relatively low for a long period of time. After this period, called life cycle, the probability of failure increases rapidly with time. Preventive maintenance management must consider this statistic in the planning of repairs [2].

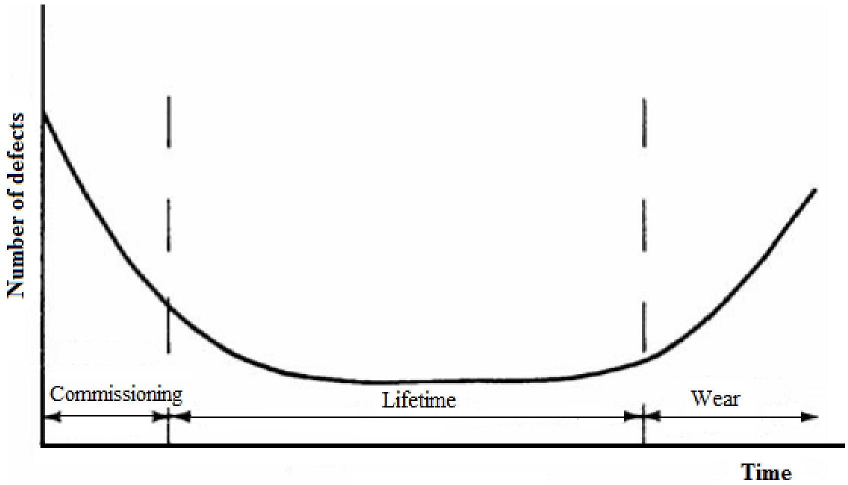


Figure 2. The statistical representation of damage to a machine / equipment / system.

Preventive maintenance advantages:

- it is a repetitive activity;
- it is easily programmed and executed;
- it requires little control team work and equipment;
- efficiency of maintenance is high;
- theoretical training for the maintenance team is easy to organize;
- budget planning is clear, easy to do;
- transport and distribution of electricity and maintenance activities are carried out according to the rules of labor protection.

Preventive maintenance disadvantages:

- repetitive work can become tiring, boring,
- there is a tendency to skip some checks,
- some replaced elements may work, others are replaced too late,
- the budget for spare parts is important,
- stock parts is high.

1.2.3. Predictive maintenance

Predictive maintenance is a concept that is based on the use of measuring devices able to monitor device status, in order to determine its technical condition.

The concept of predictive maintenance is also referred to in the technical literature as the condition based maintenance.

Through predictive maintenance actions are carried out by means of diagnostics and monitoring equipment in order to detect incipient faults, to reduce their probability of evolving over time and to avoid equipment damage.

Co-funded by the Erasmus+ Programme of the European Union

Applying the predictive maintenance strategy requires a proper equipment with systems capable of continuously transmitting "online" or, at certain times, "off-line" information by means of modern recording devices and diagnostics (thermal imager, chromatography, etc.).

This data represents an important basis in the organization of maintenance. It can avoid unscheduled interruptions of the production process by identifying problems before they become serious. The biggest problems can be minimized by detecting them in their early stages.

In many cases, predictive maintenance programs have not produced the expected results, this being generated not so by technical limits as the elaboration and implementation of maintenance techniques in the workplace.

2. Operating costs

Based on experiences in Germany, Spain, the UK and Denmark, O&M costs are generally estimated to be around 1,2 to 1,5 eurocents (c€) per kWh of wind power produced, over the total lifetime of a turbine. Spanish data indicates that less than 60 per cent of this amount goes strictly to the O&M of the turbine and installations, with the rest equally distributed between labour costs and spare parts. The remaining 40 per cent is split equally between insurance, land rental and overheads.

Figure 3 shows how total O&M costs for the period between 1997 and 2001 were split into six different categories, based on German data from DEWI. Expenses pertaining to buying power from the grid and land rental (as in Spain) are included in the O&M costs calculated for Germany. For the first two years of its lifetime, a turbine is usually covered by the manufacturer's warranty, so in the German study O&M costs made up a small percentage (2-3 per cent) of total investment costs for these two years, corresponding to approximately 0,3-0,4 c€ /kWh. After six years, the total O&M costs increased, constituting slightly less than 5 per cent of total investment costs, which is equivalent to around 0,6-0,7 c€/kWh. [3]

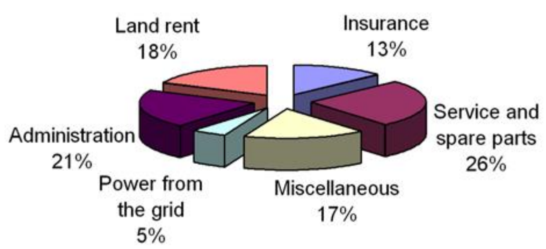


Figure 3. Different Categories of O&M costs for German Turbines, as an Average over the Time Period 1997-2001.

The operating costs decrease with the increase in the installed power turbine, as shown in Figure 4. This graph is the result of a study by the European Wind Energy Association.

Figure 4. The costs for O&M regarding different types of wind turbines,
Source: [4]

Figure 5 shows the total O&M costs resulting from a Danish study, and how these are distributed between the different O&M depending on the age of the turbine.

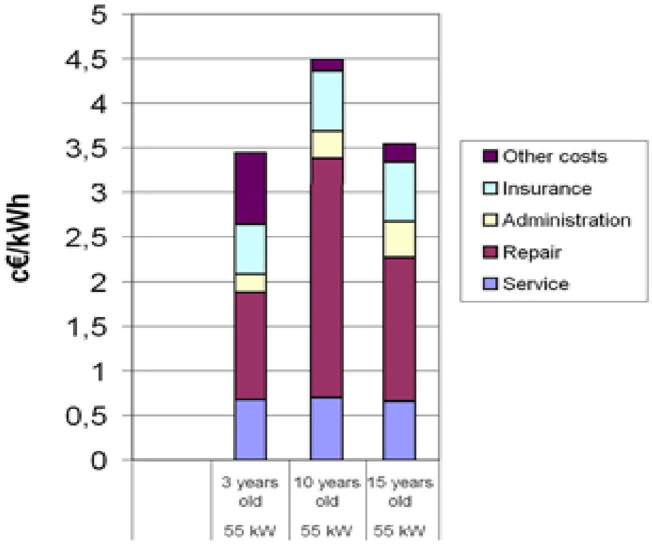


Figure 5. O&M Costs depending on the age of the turbine,
Source: [3]

References:

[1] Gabriel Puiu, Contributions to the development of an Asset management system of power system, Iasi, 2010.

[2] http://www.rasfoiesc.com/inginerie/electronica/Studiul-privind-exploatarea-si68.php

[3] www.wind-energy-the-facts.org/operation-and-maintenance-costs-of-wind-generated-power.html

[4] The Economics of Wind Energy, A report by the European Wind Energy Association

MODULE 4: WIND ENERGY

CHAPTER 2. Economic aspects

Subchapter 2.3. Analysis of economic efficiency and profitability

Petru Gabriel Puiu

„Vasile Alecsandri” University of Bacau, Romania

Summary: This chapter presents a model for the analysis of investment profitability and of the benefits from energy production.

INDEX

1. Introduction……………………………………………………………………… 2

2. Economic analysis………………………………………………………….... 2

3. Electricity benefit………………………………..…………………………. 3

References………………………………………………………………… 4

1. Introduction

Along with photovoltaic systems and biomass, small wind turbines (SWT) are the solution for energy production meant to ensure energy independence. It is always necessary to solve the cost problem to substantiate the investment decision of households.

SWT offers a number of advantages including energy independence. In Germany, for example, the owners of wind plant in rural areas can receive food for animals in exchange for the power supplied in the network [1].

2. Economic analysis

The profitability of the investment options is evaluated based on the NPV criterion given by:

$$NVP = -I_0 + \sum_{i=0}^{r} \frac{CF_t}{(1+i)^t)}$$

where:
- I0 are the investment costs at t=0,
- CFt is the cash flow at time t and
- i is the interest rate, which is initially assumed to be 3% p.a.

The time span for the NPV is 20 years.

The plant is characterized by specific parameters which affect the economic feasibility. The NPV calculations consider the performance curves, the overall investment costs of installing the system I0,total (consisting of the investment costs of the plant and the costs for the optional use of an energy storage system) and the respective operation costs, C_{op}. According to this, I_0total is given by:

$$I_{0,total} = I_{0,plant} + \Delta_{sp} \times P_{stor}$$

where the energy storage capacity (kWh) is given by P_{stor} and Δ_sp are specific storage costs (€/kWh) (see Figure 1). The operation costs consist of the overall investment costs, $I_{0,total,}$ and an operation and maintenance factor, α_0:

$$C_{op} = \alpha_0 + I_{0,total}$$

The role the state plays in sustaining investment is of major importance. In Germany, for example, the government has a coherent policy to support small investments in renewable energy.

The basic tariff for feeding-in electricity produced by wind power plants is € 4,83 ct/kWh, and in the first five years of operation even € 8,93 ct/kWh. An additional bonus of € 0,48 ct/kWh is granted if the generated electricity meets the technical requirements of the bylaw SDLWindV (Ordinance on System Services by Wind turbines, in Germany (Verordnung zu Systemdienstleistungen durch Windenergieanlagen (Systemdienstleistungsverordnung - SDLWindV)).

Germany also developed a modified tariff scheme for SWT that provides three tariff classes, dependent on the nominal capacity of the plant. The support scheme is illustrated in Figure 2. [www.rwth-aachen.de]

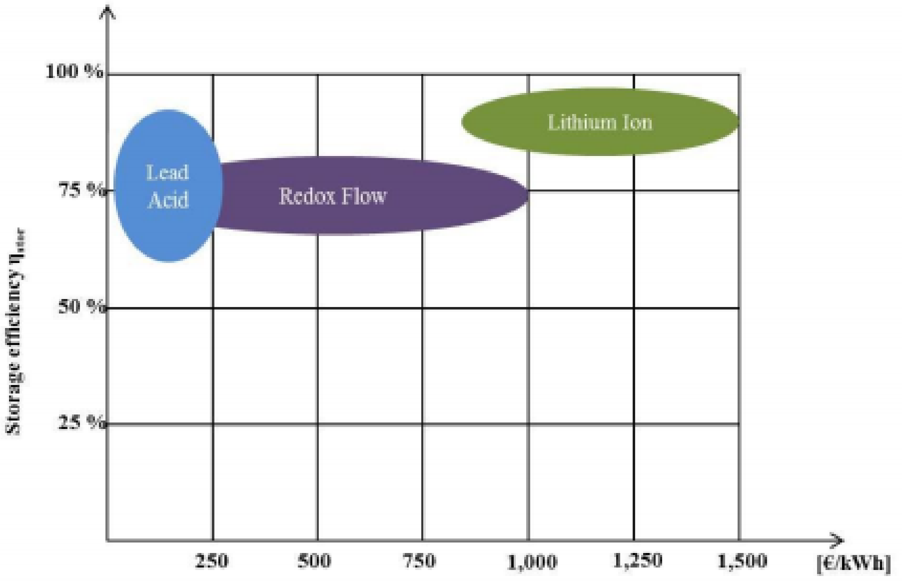


Figure 1. Storage efficency and specific costs
Source: [2]

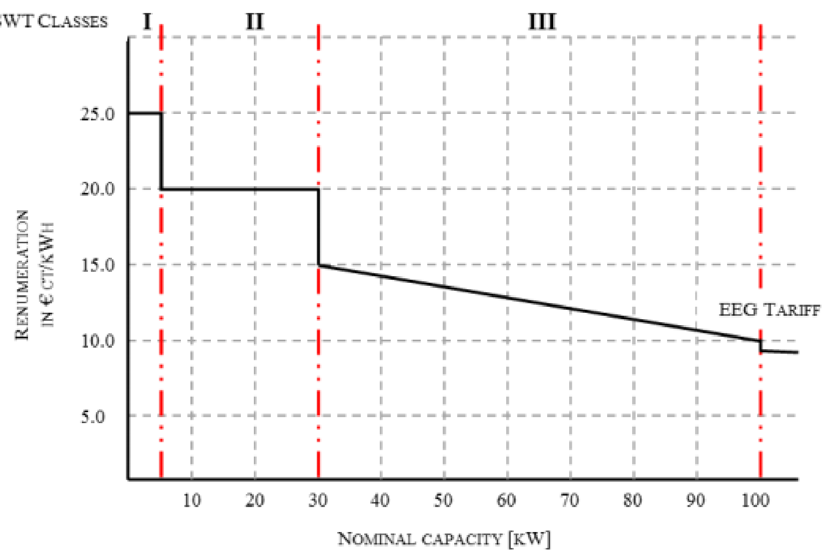


Figure 2. The SWT support scheme
Source: [2]

3. Electricity benefit

The average household benefit for the produced electricity is given by:

$$B_{electr} = \alpha_1 \times P_{electr} + (1 - \alpha_1) \times B_{feed-in}$$

Where:

- P_{electr} is the price of electricity
- $B_{feed\text{-}in}$ indicates the revenue from feeding the produced electricity into the grid, and
- α_1 denotes the share of electricity produced that accounts for private consumption.

Without any electricity storage option, the share of private electricity consumption, in Germany, is assumed to be 30% [1]. By contrast, considering electricity storage, the share of produced electricity that accounts for private consumption is expected to be higher, due to a better match of supply and demand compared to the situation without storage system. Indeed, recent field tests conducted in Germany showed that linking storage facilities with intelligent load management to SWT increased this share substantially from about 30% to 65% (SWT Portal, 2012). This corresponds to a factor of:

$$\Delta_{pc} = 716 \frac{kWh}{kW}$$

The upper limit of the share of private consumption is assumed to be 70%. In addition to it, both the prediction of yields $\tilde{R}$ and the storage efficiency η_{stor} enter this calculation. The share of private consumption of the produced electricity α_1 is, therefore, given by:

$$\alpha_1 = 0{,}3 \; if \; P_{stor} = 0; otherwise, \alpha_1 = \begin{cases} \dfrac{\tilde{R} \times 0{,}3 + \Delta_{pc} \times P_{stor} \times \eta_{stor}}{\tilde{R}}, & \alpha_1 < 0.7 \\ 0.7, & \propto_1 \geq 7 \end{cases}$$

References

[1] Benno Grieser1 , Reinhard Madlener2 and Yasin Sunak, Economics of Small Wind Power Plants in Urban Settings: An Empirical Investigation for Germany, Economics of Small Wind Power Plants in Urban Settings: An Empirical Investigation for Germany, January 2013

[2] www.rwth-aachen.de

[3] Bhattacharyya, S. (2011). Energy Economics - Concepts, Issues, Markets and Governance. Springer, London, UK.

Co-funded by the Erasmus+ Programme of the European Union

MODULE 4: WIND ENERGY

CHAPTER 3. Social and enviromental aspects of eolian systems for rural development

Subchapter 3.1.Assesment of enviromental impact. Emmisions and LCA

Petru Gabriel Puiu

„Vasile Alecsandri" University of Bacau, Romania

Summary: This chapter presents some aspects of the influence of wind energy on the environment.

INDEX

1. The enviromental impact………………………………………………….. 2
   1.1.The setting into the landscape……………………………………………. 2
   1.2.The impact on the flying animals………………………………………… 2
      1.2.1. Barriers in movement…………………………………………….. 2
      1.2.2. The change or loss of habitats……………………………….… 2
   1.3.The impact on the soil and subsoil………………..................................... 3
   1.4. Noise and vibrations…………………………………………………… 3
   1.5. Electromagnetic interference…………………………………………….. 4
   1.6. The phenomenon of reflection and shadowing………………………….. 4
   1.7. Weather and climate changes……………………………………………. 4
   1.8. The "wind turbines syndrome"………………………………………………5
   1.9. Positive effects on the quality of air……………………………………… 5
2. Emissions and the analysis of the cycle of life……………………………..... 5
   References……………………………………………………………………… 10

1. The enviromental impact

Since the oldest times, the wind has been a power resource used in various fields of activity, from maritime to agriculture (pumping water) and grist (grain wind mills).

Nowadays, wind power is transformed in electrical power, with a minimum impact on the environment. The economic efficiency of a turbine depends in a great measure on the average wind speed, the statistic distribution of speed and intensity of turbulences. To exploit as much as possible these parametres, wind turbines are realised with a diameter of the rotator as large as it can be and are installed on poles as high as they can be. These aspects produce the first series of inconveniences such as acoustic and visual pollution, shadowing and electromagnetic interference that negatively influence the environment. Some of these negative aspects have been ameliorated through innovative techniques of producing different parts of the turbines. For example, the research done in the air-acoustic field led to the achievement of some blades with a profile that makes movement more silent. Also, the materials used are composite materials with a good mechanic resistance and at the same time much lighter than the metallic ones.

All these aspects of the evaluation of the impact over the environment and of pollutant emissions are discussed in the following.

1.1.The setting into the landscape

The density of the wind turbines is given by the average distance imposed between two units (6-10 rotary diametres). So, according to the power of the turbine, the distance can vary from a few dozen to hundreds of metres.

Visually, the turbines must have an elaborated attractive design, and that is why they are painted in pastel colours or white (most often). The occupying of the field should be at all times at the minimum in the area so that it can be still used for agriculture or grazing.

1.2. The impact on the flying animals

1.2.1. Barriers in movement

Many times, wind turbines are set between the feeding, hibernating and breeding areas of birds, which leads to the extension of flights around wind generators and, consequently, the energetic consumption of birds is intensified.

A certain problem is related to the movement of bats. In 2009, the number of bats killed by such wind power stations raised the interest of the population in protecting the species. A study iniated in April 2009 by the Bats Cooperative and Wind Energy in USA showed that the mortality of bats dropped with 73% during the periods in which wind had a lower speed although their activity intensified in such environment conditions. This fact is due to the stop of wind turbines in conditions of reduced wind.

1.2.2. The change or loss of habitats

The establishment of wind turbines involves the construction of necessary infrastructure. The European legislation imposes the study of the negative impact over habitats and over biodiversity before choosing the location. The impact of rotary wind turbines in movement on birds, as well as the disruption of the ground habitat, if in the area there are an important number of bird colonies, generated disputes in the west European countries that promote the wind technology. Due to this reason, many countries made multiple studies of impact with birds [1].

At the same time, the recommendations regarding the emplacement of wind installations include the avoidance of the following locations:

- Special Protected Area (SPA) and Important Bird Areas (IBA)
- Sites such as "Nature 2000" or national sites for the conservation of nature: "National Parks", "Natural Reservations" and "Strictly protected areas in biosphere reservations"
- Other important locations for some bird species identified by Bird Life International as having the status of unfavourable conservations in Europe
- Habitats where it is known that the position of wind power stations presents high risks of collision for birds (e.g. humid areas, hilltops)
- Locations across main migration routes, especially the so-called migration bells where a large number of birds is concentrated (there can be seaside paths and passages in mountain areas)

The negative impact on biodiversity must be avoided through a total evaluation of the acceptable alternatives; it is necessary to identify species and sensitive areas, in order to mark the areas where the emplacement of wind generators is not indicated, for example, the avoidance of migration bells. The impact of adjacent infrastructure must be taken into account as well.

There is the urgent need to effectively protect the maritime areas of wildlife importance so that the agreed criteria should be applicable not only to coast area but to those close to the coast and the shore as well.

"If a proposed investment has a potential negative effect over any species/habitat that qualifies a site SPA/Nature 2000", it is required to do a study of a corresponding impact. If after this it cannot be said certainly that there will not be a negative effect, then this investment will not take place. There is a small probability that there will not be other alternative locations." [2]

1.3. The impact on the soil and subsoil

Construction work supposes the uncovering of the fertile superficial layer and the storing of it until the construction of the foundation. The cement dust and the oils used to lubricate can indirectly affect the surfaces of the adjacent field. That is why it is necessary to make a minimum uncovering and to remake the fertile layer as soon as the work has been finished.

The issue of placement of access ways is also under discussion. These works must be done with a minimum impact on the fields.

1.4. Noise and vibrations

Wind turbines functionally produce noise, due to the mechanic systems in work, to the splitting of air from the blades in rotation or their moving in front of the sustaining pole, when a compression of the air is produced.

To minimize the negative impact especially in the areas that are densely populated, a rigorous control of the sources of noise is required, by means of application of some special technological measures. The producers guarantee farms over the superior limit of noises produced by the turbine, most of them guaranteeing that the level of the turbine rotary noise does not exceed 100dB equivalent to the noise in every processing industry.

In the case of wind that blows in the direction of the receiver, the level of the sound pressure at a distance of 40 m from a typical turbine is of 50-60dB that is equivalent to the average human conversation. At 150m the noise decreases to 45,5dB equivalent to the average noise in a living place, and at the distance of over 300m the functioning noise of a turbine is confused for the noise of the respective wind. If the wind blows from the opposite direction the level of noise received decreases by about 10dB.

According to the specific conditions of each emplacement, in order that the noise level should be at an optimum level, there must be maintained a sufficient distance from the human living space, different household annexes, public institutions, historic monuments and architecture, parks, hospitals and other settlements of public interest.

In terms of vibrations, these are insignificant to the environment.

1.5. Electromagnetic interference

Communication and services provided through radio waves can be influenced by the presence of wind turbines. These metallic structures of large dimensions can produce electromagnetic interference through the reflection of electromagnetic signals by the turbine blades, so that the receptors nearby can take over the direct signal as well as the reflected one. The interference is produced because the reflected signal is delayed by the length of the turbine frequency as well as by the Doppler effect of the rotation of blades. The interference is more pronounced with metallic materials and weaker for wood and epoxy, because of their absorbing qualities. To avoid this phenomenon, the producers adopted an innovative technology of the blades. On a durable metallic body (longeron), they ground a layer of polyester armed with glass filament. This construction becomes partially transparent to electromagnetic waves.

For the communication frequencies not to be significantly affected it is required that the wave length of the emitter should be at least 4 times higher than the total height of the turbine. At the installation of a wind park it is necessary to obtain the summonses from the competent authorities in the field of civil and military communications.

1.6. The phenomenon of reflection and shadowing

On sunny days there can appear the phenomenon of light reflection across the turbine that can disturb the local people near the wind parks. So, the producers paint across turbines in white to minimize this effect. Moreover, the reverse phenomenon can be manifest, that of shadowing due to the high tower and basket. This negative aspect can be eliminated by preserving a large enough distance between the wind park and the closest community.

1.7. Weather and climate changes

Wind parks can affect the weather in the nearby area due to the generation of some horizontal and vertical turbulence by the training in movement of the warm air currents and water steam by the turbine blades. This phenomenon provokes changes in the direction of the wind that could lead to a rise in temperature in the continental area by a degree and in the maritime area by 0,15 degrees if there were used as many Aeolians as needed to satisfy 10% of the global need of power.

1.8. The "Wind turbines syndrome"

There is a reason of a medical nature that contributes to the rise of the sum of negative effects on the environment: the so called "wind turbines syndrome", provoked by a low frequency perceived by the internal ear. Nina Pierpont, a specialist in the American Academy of Pediatrics considers that long term exposure to this noise generates dizziness, migraines, a higher pulse, sickness, vision problems, panic attacks and crankiness.

To eliminate these negative aspects, specialists consider that there must be imposed restrictions at the emplacement of Aeolian parks. A distance of 500-600 meters is sufficient between a group of maximum 5 turbines that produce a noise while functioning of maximum 100 Db and human communities.

For a group of over 10-25 turbines there must be a distance of minimum 1500 m. For a group of over 10-25 turbines, a study must be made on the sound impact [7].

1.9. Positive effects on air quality

Most wind turbines have the blade system mounted in front of the nacelle, because this disposition has a simple construction and gives the best results at great strength [6]. At the passage of the wind through the rotary of the turbine, this loses approximately 30% of its kinetic energy, and in avale of the turbine the speed decreases by about 15 %. This decrease generates a raise in the air humidity, that can lead to the development of the vegetation in the area. An abundant vegetation creates good conditions for the whole food chain.

Due to this drop in the wind speed it is to be expected that the relative local air humidity will increase by a few percentages. Due to the rise in humidity, vegetation develops better, which has benefic effects on the whole food chain in the area.

2. Emissions and the analysis of the life cycle (LCA)

The estimates of total global warming emissions depend by some factors, including wind speed, percent of time wich wind is blowing, and the material composition of the wind turbine. Most estimates of wind turbine life-cycle global warming emissions are between 4,971 - 55,143 g of carbon dioxide equivalent per kilowatt-hour. Compared them to produce 1 kWh of gas, is generated between 27,215 and 907,184 g of carbon dioxide equivalent per kilowatt-hour and to produce 1 kWh of coal is generated between 635,029 and 1632,932 g of carbon dioxide equivalent per kilowatt-hour [11], Figure 1.

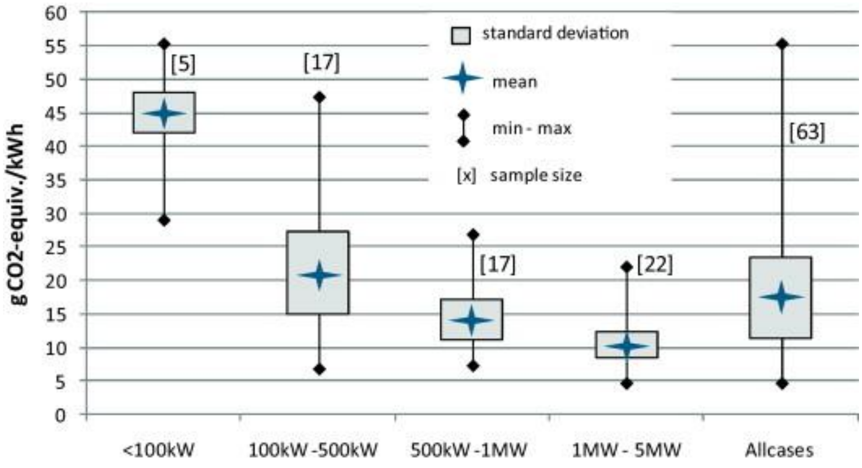


Figure 1. GHG emissions from wind power, Source: [13]

From this perspective, energy payback is an important indicator to assess the impact of minimum that produces a wind turbine over the entire lifetime.

Energy payback is used to measure how long a system must operate to generate sufficient energy to offset the amount of energy required during its entire life . Life cycle energy are considered to include those for each of the activities described below (production, transportation, operations and maintenance and dismantling and recycling)

The calculation formula for energy payback, P is:

$$P = \sum_{k=1}^{n} \frac{E_k}{E_{annual}}$$

Where,

- Ek is the energy required for life cycle stage k
- E_{annual} is the annual electricity generated by the wind turbine

The most important environmental impacts throughout the production to decommissioning chain it has the manufacturing process. This is due to the large amount of steel used to the achievement of tower and nacelle. The iron ore and steel processing involves a high energy consumption and major emissions of: SO_2 , eutrophication potential (EP), NOx, and FAETP (cobalt, nickel and vanadium emissions), photochemical oxidant creation potential (POCP) due to emissions of CO and SO_2 and terrestrial ecotoxicity potential (TETP) is due to emissions of heavy metals to air, predominantly chromium.

Significant emissions occur in the manufacture of nacelle due to CO_2 emissions from the energy used: global warming potential (GWP), human toxicity potential (HTP) due to emissions of chromium to air.

Ozone layer depletion potential (ODP) represents another component of emissions due to emissions of halons during the transport of the fixed parts and the production of the concrete, fibreglass and steel, [11]

The LCA analysis leads to evaluate the environmental impact of wind energy.

An LCA considers not only the direct emissions from wind farm construction, operation and dismantling, but also the environmental burdens and resources requirement associated with the entire lifetime of all relevant upstream and downstream processes within the energy chain [9]. The life cycle analysis studies energy and material flows in raw material acquisition and processing, product design, product manufacture, product distribution, product use, maintenance and repair and product recycling/disposal, Figure 2.

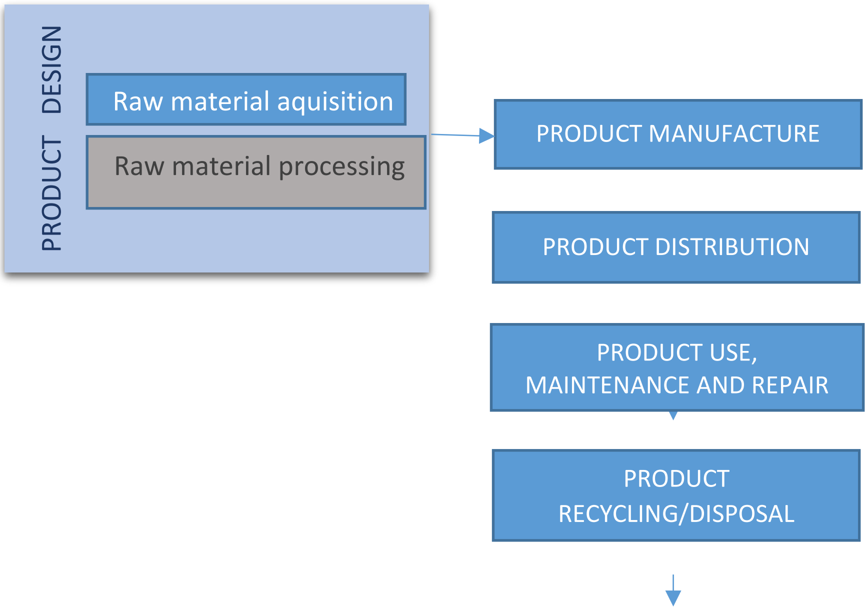


Figure 2. The material flows in LCA

There are many software tools for the study of LCA and emissions along the entire chain from production to decommissioning:

- GaBi
- RETScreen
- LCAit
- KCL-ECO
- PEMS
- TEAM
- Umberto
- Boustead Model
- SimaPro

For example, in the case of a 6 kW turbine (Figure 3), using the RETScreen (Figure 4) was obtained a net annual GHG (greenhouse gas emissions) reduction from power generation by 5,7 tCO_2 eq. (Figure 5).

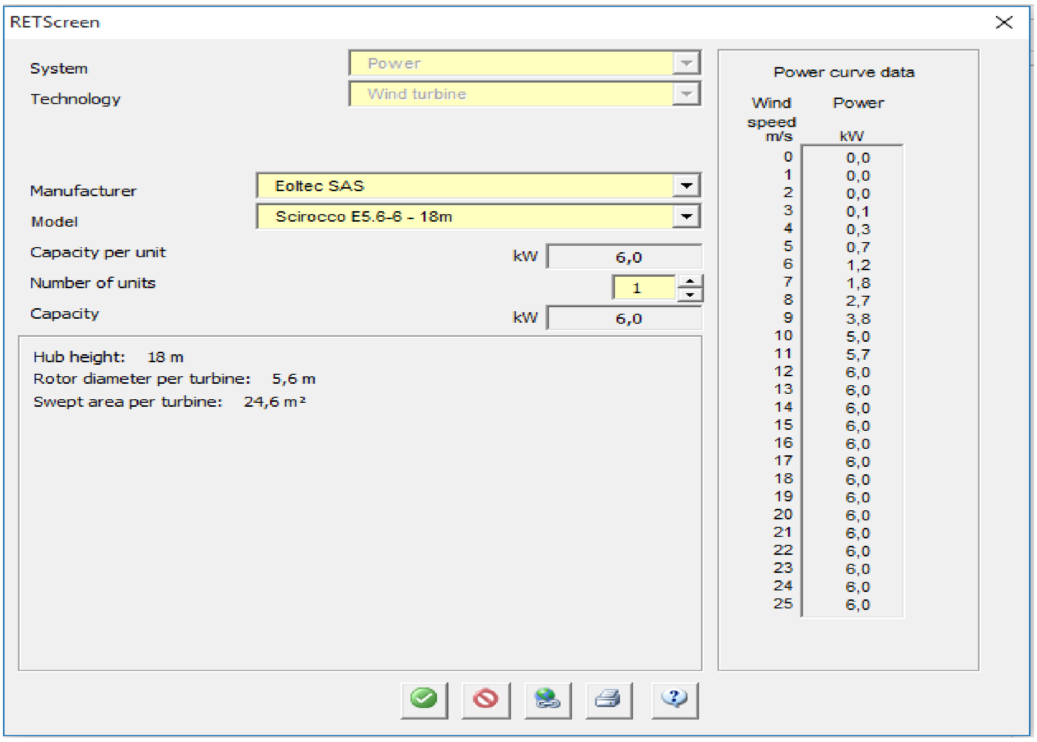
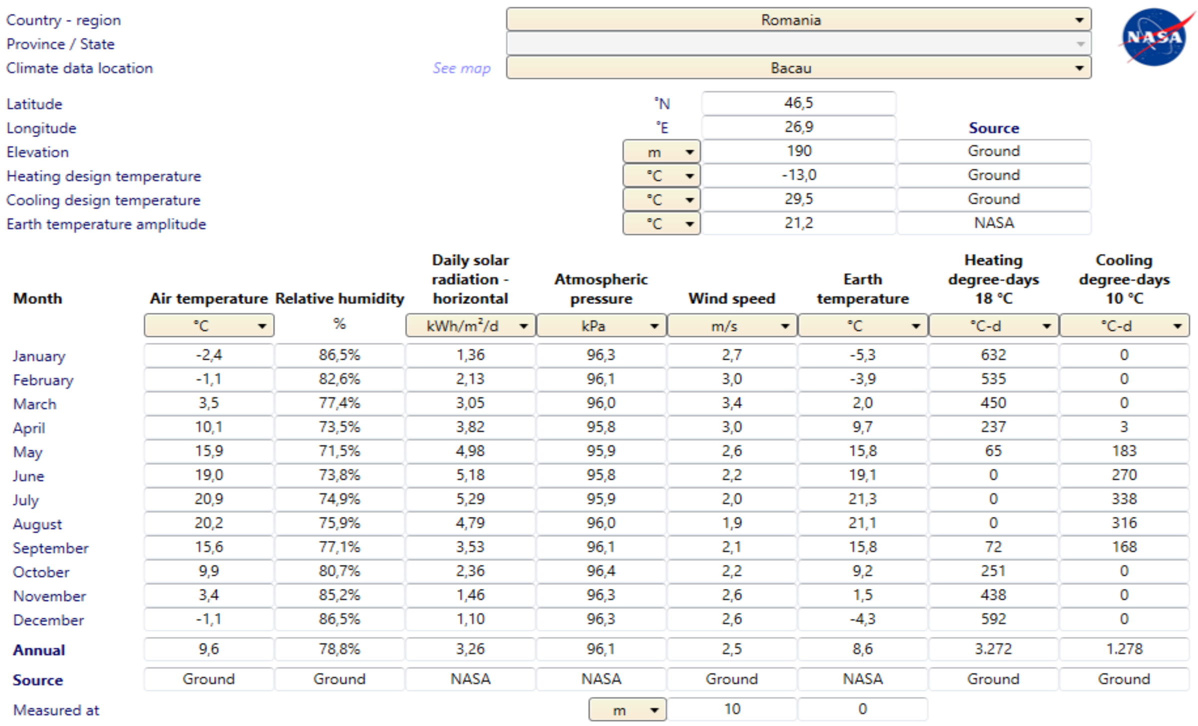


Figure 3. The RETScreen selection system and technology window. Source: Our exercise in RETScreen



Country - region		Romania	
Province / State			
Climate data location		Bacau	
Latitude	°N	46,5	Source
Longitude	°E	26,9	
Elevation	m	190	Ground
Heating design temperature	°C	-13,0	Ground
Cooling design temperature	°C	29,5	Ground
Earth temperature amplitude	°C	21,2	NASA

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	-2,4	86,5%	1,36	96,3	2,7	-5,3	632	0
February	-1,1	82,6%	2,13	96,1	3,0	-3,9	535	0
March	3,5	77,4%	3,05	96,0	3,4	2,0	450	0
April	10,1	73,5%	3,82	95,8	3,0	9,7	237	3
May	15,9	71,5%	4,98	95,9	2,6	15,8	65	183
June	19,0	73,8%	5,18	95,8	2,2	19,1	0	270
July	20,9	74,9%	5,29	95,9	2,0	21,3	0	338
August	20,2	75,9%	4,79	96,0	1,9	21,1	0	316
September	15,6	77,1%	3,53	96,1	2,1	15,8	72	168
October	9,9	80,7%	2,36	96,4	2,2	9,2	251	0
November	3,4	85,2%	1,46	96,3	2,6	1,5	438	0
December	-1,1	86,5%	1,10	96,3	2,6	-4,3	592	0
Annual	9,6	78,8%	3,26	96,1	2,5	8,6	3.272	1.278
Source	Ground	Ground	NASA	NASA	Ground	NASA	Ground	Ground
Measured at				m	10	0		

Figure 4. The characteristics of the area selected for analysis. Source: Our exercise in RETScreen

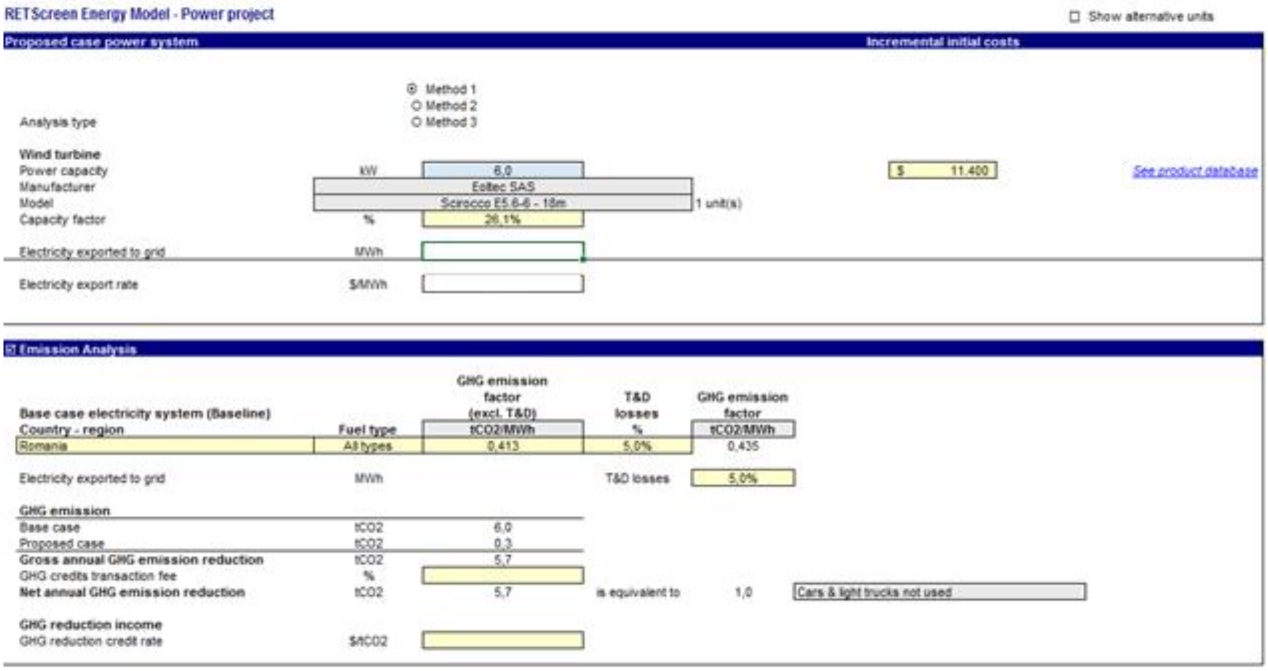


Figure 5. The net annual GHG reduction from power generation. Source: our exercise in RETScreen

Another possibility to achieve the LCA analyze and emissions calculating, perhaps more laborious and most commonly is GaBi, Figure 6.

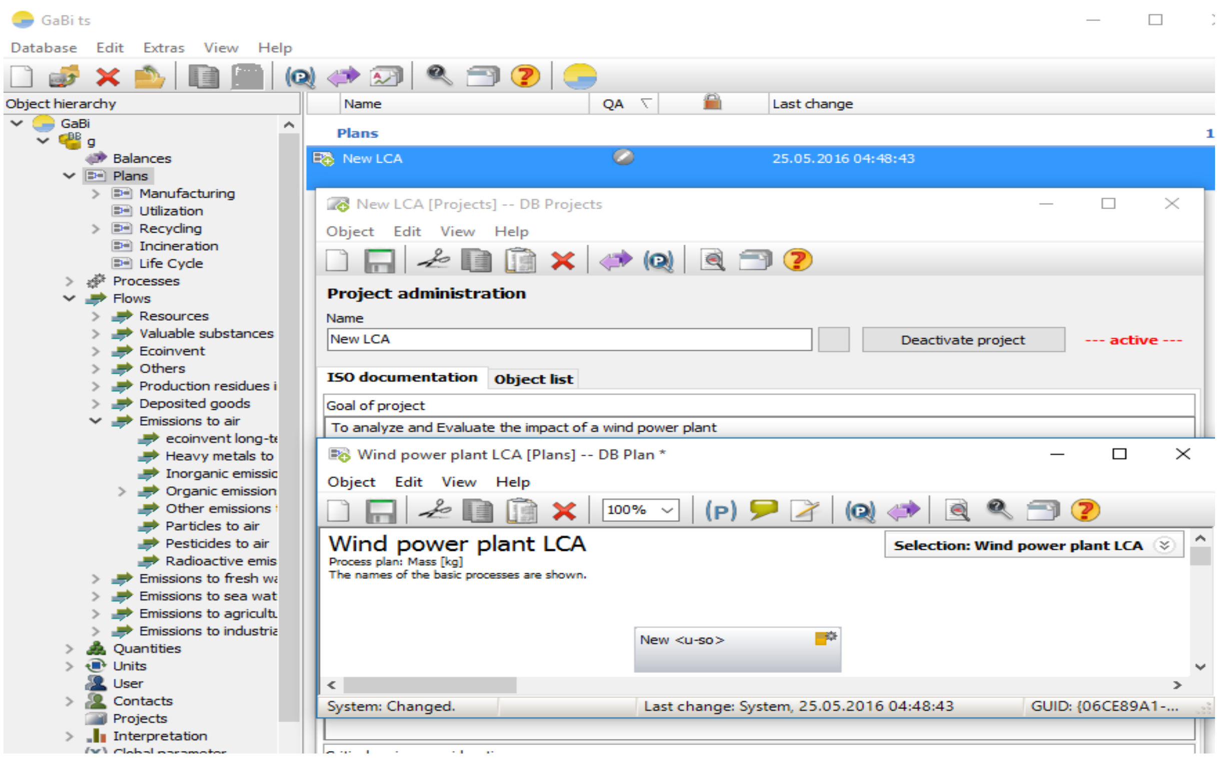


Figure 6. The Gabi application

The contribution of different life cycle stages of the wind turbine, resulting from the Gabi software analysis is presented in Figure 7.

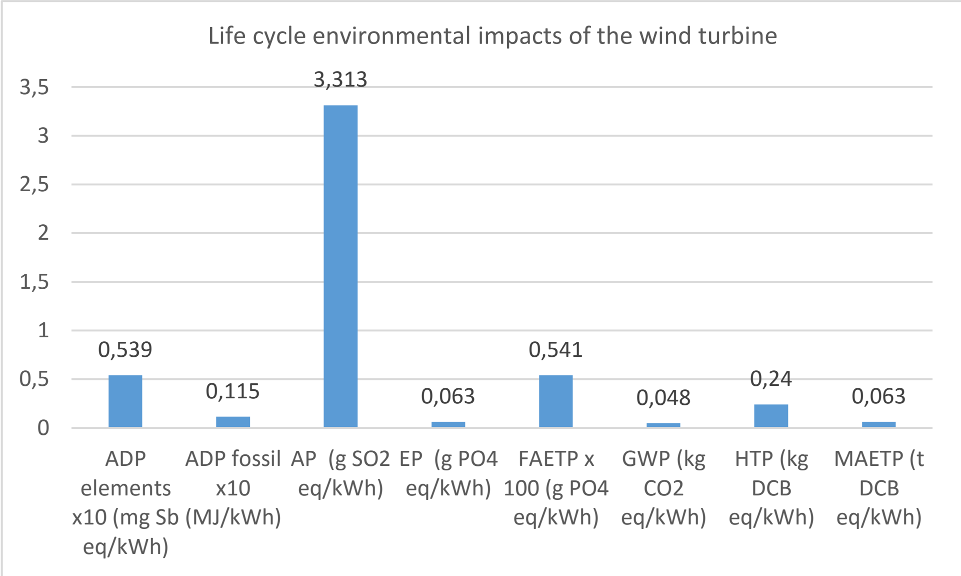


Figure 7. Life cycle environmental impacts of the wind turbine. Source [11]

ADP elements: abiotic resource depletion of elements; ADP fossil: abiotic resource depletion of fossil fuels; AP: acidification potential; EP: eutrophication potential; FAETP: fresh-water aquatic ecotoxicity potential; GWP: global warming potential; HTP: human toxicity potential; MAETP: marine aquatic ecotoxicity potential; ODP: ozone layer depletion potential, POCP: photochemical oxidant creation potential; TETP: terrestrial ecotoxicity potential. DCB: dichlorobenzene.

GaBi is a software approach capable to highlight the emissions on the entire cycle, from production to decommissioning.

References

[1] http://www.revista.forter.ro, 2016

[2] European Commission (2001): Assessment of Plans and Projects Significantly Affecting "Natura 2000" Sites.

[3] H.G. nr. 443 din 10 aprilie 2003 privind promovarea producţiei de energie electrică din surse regenerabile de energie.

[4] http://www.ictcm.ro, 2016

[5] http://energreen.strainu.ro, 2016

[6] http://www.agir.ro/buletine/1863, 2016

[7]www.financiarul.ro/2013/03/12/centralele-eoliene-o-tehnologie-verde-care-isi-are-contestatarii-sai, 2016

[8] Bakos Alexandru Claudiu, Impactul parcurilor eoliene asupra mediului, http://documents.tips/documents/impactul-parcurilor-eoliene-asupra-mediului, 2016

[9] LCA in Wind Energy: Environmental Impacts through the Whole Chain, http://www.wind-energy-the-facts.org/lca-in-wind-energy

[10] PE International, (2008), www.gabi-sofwtare.com

[11] National Renewable Energy Laboratory (NREL). 2016

[12] Benjamin Greening, Adisa Azapagic, Environmental impacts of micro-wind turbines and their potential to contribute to UK climate change targets, Energy Volume 59, 15 September 2013, Pages 454–466

[13] Hanne Lerche Raadal , Luc Gagnon, Ingunn Saur Modahl, Ole Jørgen Hanssen, Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power, Renewable and Sustainable Energy Reviews, Volume 15, Issue 7, September 2011, Pages 3417–3422

MODULE 4: WIND ENERGY

CHAPTER 3. Social and environmental aspects for rural development.

Subchapter 3.2. Social and Rural Development impact.

Petru Gabriel Puiu

„Vasile Alecsandri" University of Bacau, Romania

Abstract: Starting from a study by the OECD, this chapter shows that a large part of investments in rural areas is due to ER. Next it shows some aspects of rural development based on renewable energies.

SUMMARY:

1. The OCED study……………………………………..…………………… 2
2. What gives rural renewable energy…………………………………………… 3
   2.1. New income sources……………………………………………………… 3
   2.2. New jobs and business opportunities……………………………………… 3
   2.3. Innovations in products, practices and policies in rural areas……………. 3
   2.4. Acquiring new skills………………………………………………………. 4
   2.5. Accessible energy prices…………………………………………………… 4
3. Inclusion of rural development based on renewable energies in national policies 4
   References……………………………………………………………………. 5

1. The OECD study

The Organisation for Economic Cooperation and Development (OECD) carried out a study designed to quantify the impact of renewable energy on regional economies particularly in rural communities. This was possible by creating an international network of case studies that reflect the link between energy produced from renewable sources and production and rural development (economic development and employment, human capital, etc.)

These regional case studies were chosen in collaboration with national and regional authorities, in order to cover a full range of examples from all sectors of renewable energy and in all degrees of rurality. The research did not include hydropower. Special attention was given to governance mechanisms, institutional relationships and policies regarding renewable energy production in rural areas.

The renewable energy is increasingly being championed as a new source of jobs in OECD countries, as well as addressing concerns with energy security and climate change. In most OECD member countries, governments have invested large amounts of public money to support renewable energy development, and have also required that significant quantities of renewable energy be sold by energy providers [www.oecd.org].

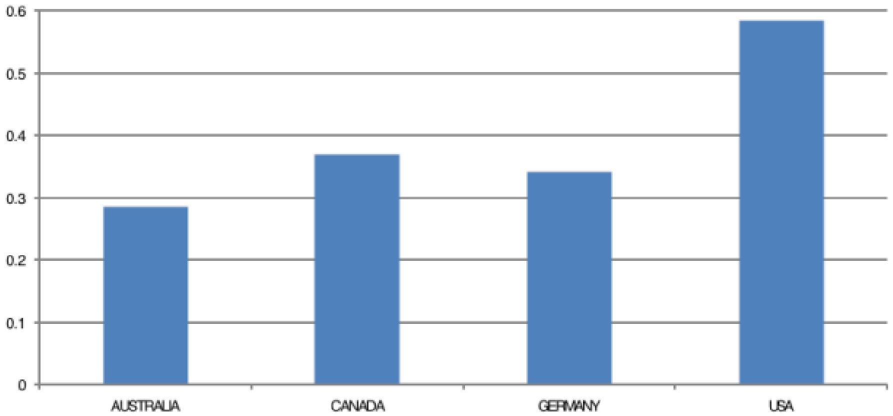


Figure 1. Share of total investment in renewable energy going to rural areas, 2016, Source: www.oecd.org

Drawing on case studies of renewable energy in 16 rural regions across Europe and North America (Figure 2), the report shows that renewable energy does not automatically create employment in rural regions. For renewable energy to trigger rural economic growth, a coherent policy framework and the right set of local conditions are required.

Positive impacts of renewable energy and coherent local policy: local revenue, local jobs, innovations in products, processes and policies, capacity building and local empowerment, affordable and reliable energy.

The overall impact on economic growth is generally much lower than expected. National and regional renewable energy policies have set very ambitious targets and high incentives for renewable energy production that have caused distortions. Incentives have triggered rentseeking behaviours, and installations often compete with agriculture and tourism for the use of land or landscape amenities. In this context, many local communities have started opposing further deployments [www.oecd.org].

Figure 2. The OECD regional case studies, Source: www.oecd.org

2. What gives rural renewable energy

Globally renewable energies (RE) registered a rapid expansion. A concrete example is the electricity sector which grew by 26% between 2005 and 2010 and provided globally over 20% of total world power from renewable sources (including hydropower). [OECD]

Sparsely populated rural areas attract a great deal of investment to develop energy from renewable sources. The case studies found that the implementation of RE can offer some advantages to hosting communities, including:

2.1. New income sources

First, ER increases the tax base, which helps to improve services provided to rural communities. Also, it produces additional income for landowners. Farmers and forest owners can integrate energy production from renewable sources and being able to diversify activities, and thus stabilize the revenue.

2.2. New jobs and business opportunities

Development of RE also contribute to creating new jobs and business opportunities. ER can directly create jobs in operation and maintenance. If the jobs created directly are limited to exploitation and maintenance, jobs created indirectly cover a greater span related to the entire production chain (sourcing, manufacturing, specialized services).

2.3. Innovations in products, practices and policies in rural areas

As hosts of the RE, rural areas are places where new technologies are tested. In addition, there may be new challenges and new approaches to policy and local practices. There are a large number of actors in renewable energies in these areas that can cause enriching resources for learning in the region. The Small and medium enterprises (SME) are active in finding business niches.

2.4. Acquiring new skills

Local companies and rural communities as a whole may specialize by acquiring new skills required by RE development in rural areas. Moreover, you can organize specific institutions, bodies and authorities to deal with implementing RE in response to large investments and top-down national policies.

2.5. Accessible energy prices

RE provides remote rural regions the opportunity to produce their own energy (electricity and / or heat). These production facilities are reliable and cheap energy can trigger economic development.

3. Inclusion of rural development based on renewable energies in national policies

The rural development strategy is made based on regional and local strategies.

EU policies take into account national and regional policies. Therefore it is better for rural development based on renewable energies to be included in regional and national policies, as shown in Figure 3.

Figure 3. Sample of the national program for rural development, including the RES.

References

OECD, Linking Renewable Energy to Rural Development, www.oecd.org/regional/regional-policy/Renewable-rural-energy-summary.pdf

MODULE 4: WIND ENERGY

CHAPTER 3. Social and environmental aspects of photovoltaic systems for rural development.

Subchapter 3.3. A vision for the future. Ideas and new suggestions.

Petru Gabriel Puiu

„Vasile Alecsandri” University of Bacau, Romania

Summary: This chapter covers problems of wind energy prediction methods to determine wind duration and intensity and wind energy and experimental research.

INDEX

1. Wind energy and prediction methods to determine wind duration and intensity ……………………………………………………………….... 2
2. Wind energy and experimental research………………………………….. 3
3. Public Policies……………………………………………………………….. 5

References...…………………………………. 6

1. Wind energy and prediction methods to determine wind duration and intensity

The power market is increasingly taken over by the renewable power produced with the help of innovative cheap and non-polluting technologies. This tendency imposes investments in networks to manage wind power and other renewables (such as photovoltaic, geothermal, biomass, etc.) in conditions in which countries such as Italy move only to the use of renewable powers.

Studies have explored the possibility of efficient use of wind power through elaborating some methods of shaping wind power. The analytic model is made on the weather forecast and it allows the integration of a larger quantity of renewable energy in the power network. Such a solution, called "Hybrid Renewable Energy Forecasting"(HyRef) was developed by IBM on the basis of advanced technologies of Imagistics of clouds and monitoring wind speed, direction and temperature.

The HyRef technology combines advanced power and weather computer modeling, sophisticated cloud imaging, sky-facing cameras, and on-site sensors to accurately predict solar power and wind energy output and increase the amount of renewable electricity flowing onto grids across the world, as can be seen from Figure 1 [1].

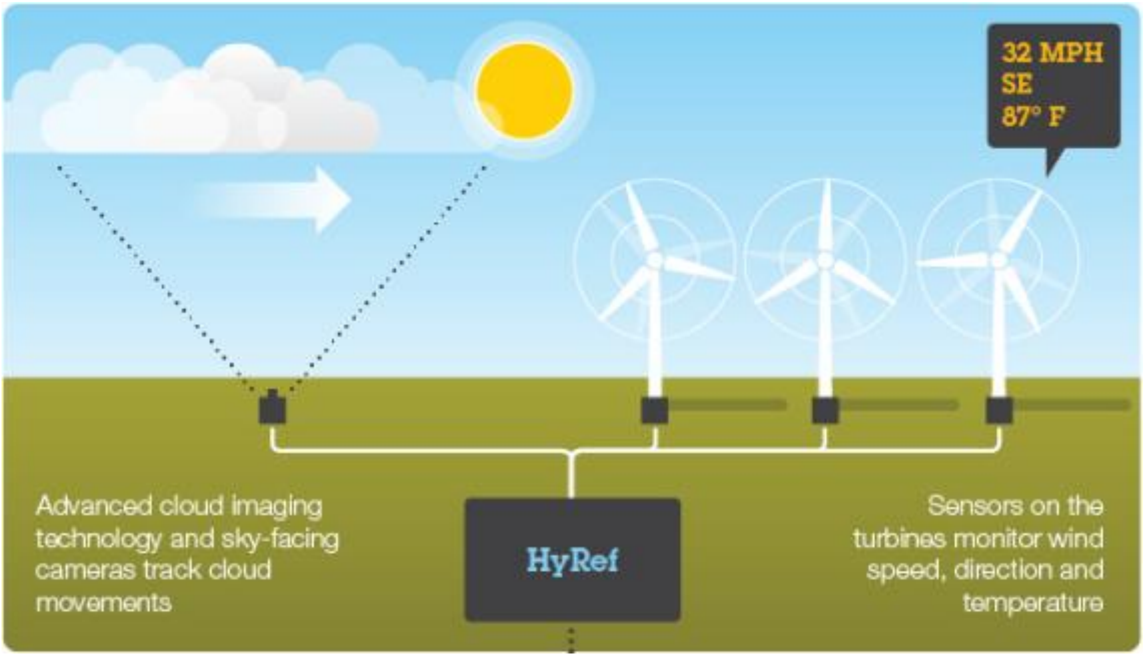


Figure 1. The system proposed by IBM.

Source: http://www.altenergymag.com

The results are local weather forecasts that are very exact, with up to a month in advance or every 15 minutes.

Through local weather forecasts, HyRef can forecast the individual performance of each wind turbine and the quantity of renewable energy it produces. This level of perception will allow institutions to handle much better the variable nature of wind and solar power, as well as to obtain more precise statistics over the quantity of electric power that can be redirected or stocked in electrical networks. Also, the consumer can easily integrate other conventional or unconventional resources.

This task is meant to fulfill the hope of transmission system operators from networks around the world that, by 2025, 25% of the used energy will come from renewable resources [2].

As mentioned earlier, wind prediction is a determined factor in optimizing the use of wind power. Researchers do not stop because of this aspect. Researchers at Riso DTU finalized their first test on a wind turbine with a laser anemometer, built on a screw, to increase the production of electrical power. This system allows the increase of produced electrical power, decreasing at the same time extreme tasks, by using the laser system called LIDAR. With its help, turbines will be capable to “see” the wind before it hits the blades, so that the attack angle will be modified for a more efficient use. It is assumed that this industry will rise extensively in the next years due to the attention paid to the renewable power and climate changes globally [3].

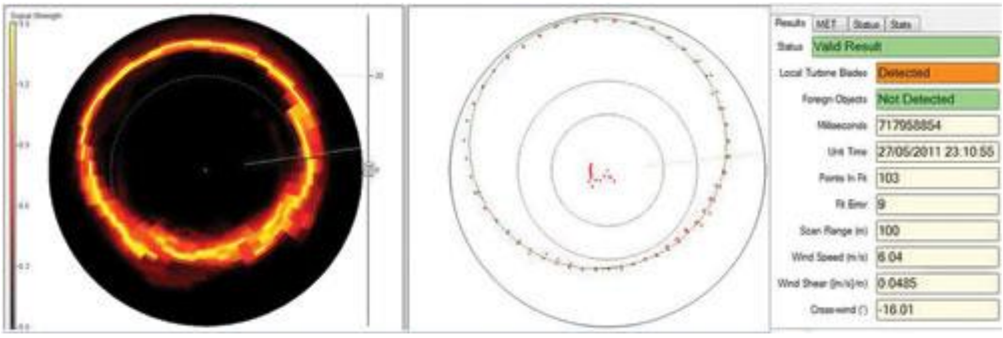


Figure 2. A real-time display shows measured Doppler data and wind model outputs from a ZephIR lidar mounted on a wind turbine nacelle.

Source: http://www.laserfocusworld.com/

2. Wind energy and experimental research

Major changes can also appear at other levels. The portability of solar power due to solar kits for mobile power supply achieved with rigid and manageable panels, for heating or generating power, is well known. The challenge was launched in the field of wind power as well. The Polish company Omni3d designed and realized a wind turbine printed in 3D. The small dimension turbine can be folded and put in a backpack to manage transportation. It can produce up to 30 W, enough for charging some gadgets, laptops or other devices with a minimum power consumption, Figure 3 [4].

Figure 3. AirEnergy 3D Turbine. Source: http://totb.ro

Another company, from Tunis, Saphon Energy, presented a second version of a wind generator prototype named Saphonian. The device looks like a satellite antenna, it produces less noise and is cheaper. According to the developers, this construction solves many problems and promises to make a real revolution in the field. The company obtained an international certificate for the invention in March 2012, according to http://ecology.md. The kinetic power of the wind is directed to the piston through a concave element with micro-perforation. The pistons generate hydraulic pressure that can be stocked as potential power in a hydraulic accumulator or directly converted in electric power, Figure 4.

Figure 4. Wind Generator Saphonian. Source: http://ecology.md

The researchers at Vortex Bladeless are proposing a model a bit strange to stock wind power. These devices involve the realization of pillars – cones from fiberglass and fiber carbon that oscillate as a result of the wind, determining the pole vibration, Figure 5.

Figure 5. Wind Generator Mini Vortex, Source: www.touchnews.ro

At the base of the cone there are 2 magnet rings that act by rejecting the cone pushed by the wind vibration in the opposite direction, sending the pole irrespective of the speed of wind. This kinetic power is transformed in electric power through some alternator that multiplies the oscillation frequency of the pole, improving the efficacy of power collecting. The height of such constructions is of about 12,5 meters and can hold a maximum of 40 % of the wind power [6].

3. **Public Policies**

Europe enjoys only 9% of the available wind potential in the world, but in 2002 it owned 72% of the installed power worldwide. Technical wind potential available in Europe is 5.000 TWh per year. If we take into account that wind class 4 (lower speed) is characterized by a speed of 5,8 m/s at a height of 10 m and that many areas with low speed are located in agricultural areas or rural communities, Figure 6, it would be desirable to develop local policies that encourage regional implementation of small systems that meet local needs and thus lead to the development of these rural areas. Another argument is the fact that these Class 4 areas are closer by the connection points than Class 6.

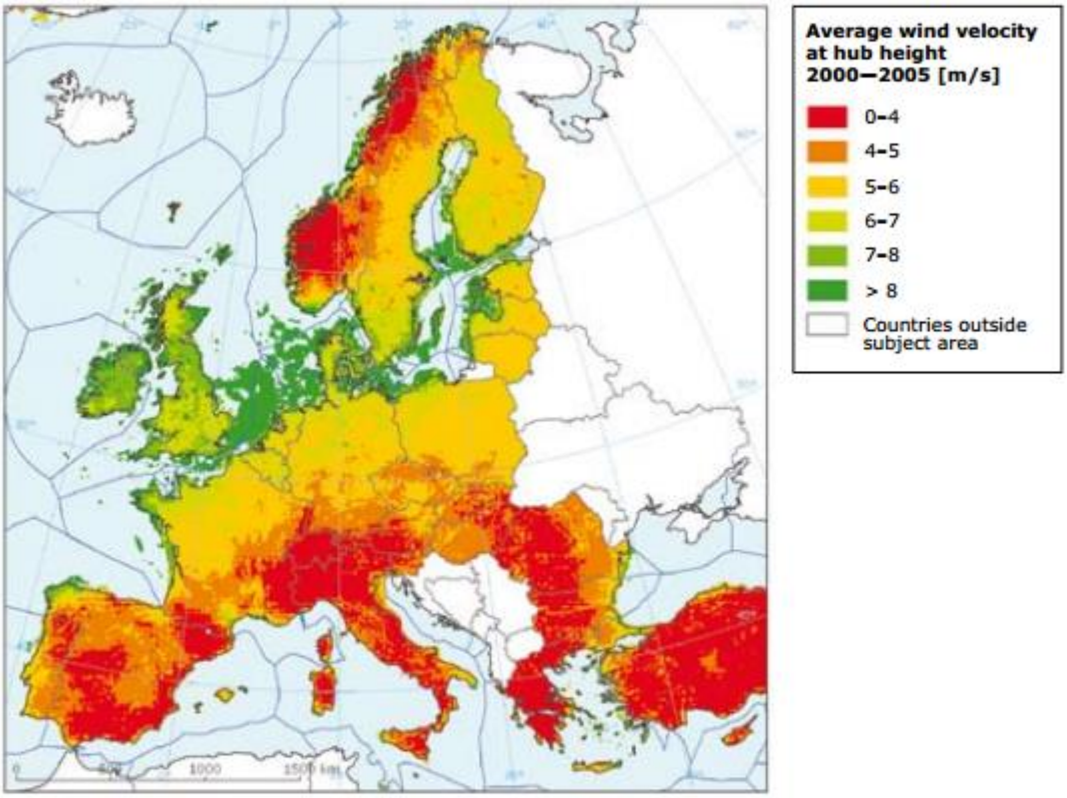


Figure 6. Average wind velocity. Source www.energy.eu

References

[1] http://cleantechnica.com/2013

[2] www.agora.ro

[3] www.solar-magazin.ro, 2016

[4] http://totb.ro/turbina-eoliana-imprimata-3d-care-incape-intr-un-rucsac/, 2016

[5] http://ecology.md/md/page/generator-eolian-fara-elice-o-noua-viziune-asupra-energiei-alternative, 2016

[6] www.touchnews.ro, 2016

Co-funded by the Erasmus+ Programme of the European Union

MODULE 4: WIND ENERGY

CHAPTER 4. Fully developed case study of application of wind energy for rural development

Subchapter 4.1 – Introduction and technical aspects of the case study

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

Summary: In chapter 4 of this module, a specific case study application of wind energy technology for supplying energy to a farm in Millán (Lugo, Spain) is developed to follow the chapters throughout this module.

Thus, in this subchapter a description of the end-use of the facility, the design parameters, and calculations will be performed for sizing the installation.

INDEX

1. Introduction 2
2. Technical Aspects of the Case Study 2
    2.1. Location 2
    2.2. Design Parameters 2
    2.3. Calculations and Design 3
        2.3.1. Energy requirements 3
        2.3.2. Wind energy potential 3
        2.3.3. Wind turbine selected 6
        2.3.4. Wind power generation 7
        2.3.5. Number of wind turbines 10
        2.3.6. Choosing the batteries 11
        2.3.7. Selecting the inverters 12
        2.3.8. Generator 13

1. Introduction

This chapter presents a case study of a wind energy installation for supplying energy to a rural farm.

The farm, which is located in Lugo (northwest of Spain), manages the feeding, milking and breeding of more than 150 head of cattle thanks to robotic and automatic systems.

When the automation and modernization of the installations started, their owners decided to bet on renewable energies as a source of electric generation. At that time, a PV installation of 15 kW covered the most part of the energetic demand. In addition, a diesel generation of 30 kVA was supporting the PV installation.

Following this, due to the energy needs of the farm, an extension project of the energy generation system was decided on. The new installation consists of various small wind turbines with horizontal and parallel axis that are connected to the PV panels. THese have been installed with the goal of reducing the working hours of the diesel generation.

2. Technical aspects of the case study

2.1. Location

Location:	Millán, Lugo (Spain)
Geographic Coordinates:	42º 44’ 31’’ North
	7º 46’ 35’’ West
Elevation:	586 m a.s.l.

2.2. Design parameters

PV installation: PV installation of the first phase of the project has a nominal power of 15 kW, having the following energy production values.

Fixed system: inclination=15°, orientation=0°				
Month	E_d	E_m	H_d	H_m
Jan	24.20	749	2.00	62.1
Feb	37.60	1050	3.13	87.5
Mar	53.40	1650	4.56	141
Apr	58.70	1760	5.08	152
May	65.80	2040	5.78	179
Jun	73.50	2210	6.58	198
Jul	74.40	2300	6.70	208
Aug	71.30	2210	6.42	199
Sep	60.60	1820	5.37	161
Oct	42.50	1320	3.67	114
Nov	27.20	816	2.27	68.1
Dec	23.40	726	1.94	60.2
Yearly average	**51.1**	**1550**	**4.47**	**136**
Total for year		**18700**		**1630**

Table 1. PV energy production values

E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

2.3. Calculations and design

2.3.1. Energy requirements

To calculate the energy demand of the farm, the table 1 shows in a simplified way the power and working hours/day of the different services of the homestead.

SERVICE	Power [W]	Hours/day	kWh/day	kWh/month
Lighting	600 W	5 h	3.0 kWh	90 kWh
Milking machine	4000 W	6 h	24.0 kWh	720 kWh
Cold Tank	1200 W	14 h	16.8 kWh	504 kWh
Cleaning Conveyor Belt	4000 W	4 h	16.0 kWh	480 kWh
Air circulation	1000 W	10 h	10.0 kWh	300 kWh
Water pumping	3000 W	4 h	12.0 kWh	360 kWh
Others			9.5 kWh	285 kWh
		TOTAL	**91.3 kWh/day**	**2,739 kWh/month**

Table 2. Summary of estimated energy requirements

2.3.2. Wind energy potential

To carry out the calculus and sizing of the wind installation, different maps and historic databases of wind in the region, supplied by the Renewable Energies National Center

(CENER, Spain) and by the Institute of Diversification and Saving Energy (IDAE, Spain), were used.

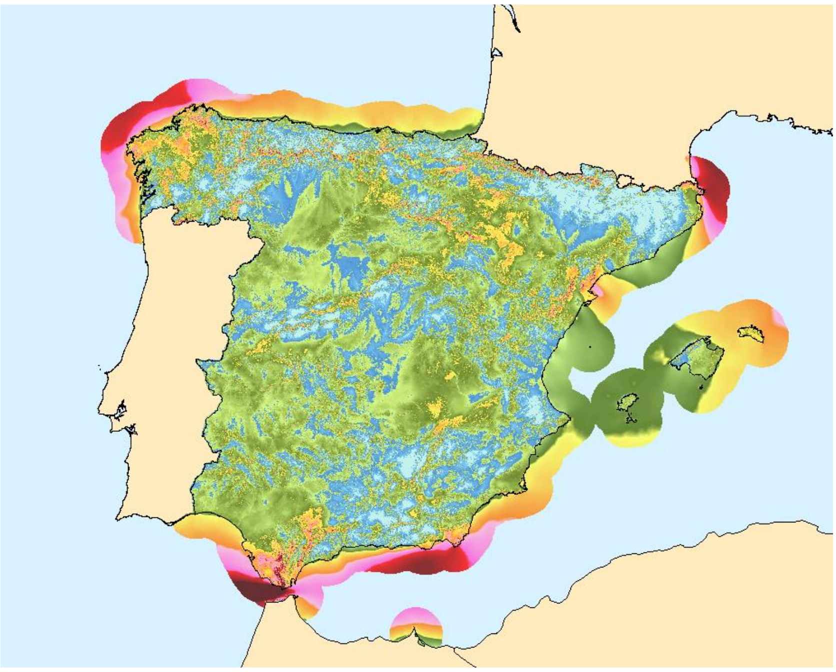


Figure 1. Wind map Spain. (http://atlaseolico.idae.es/meteosim/)

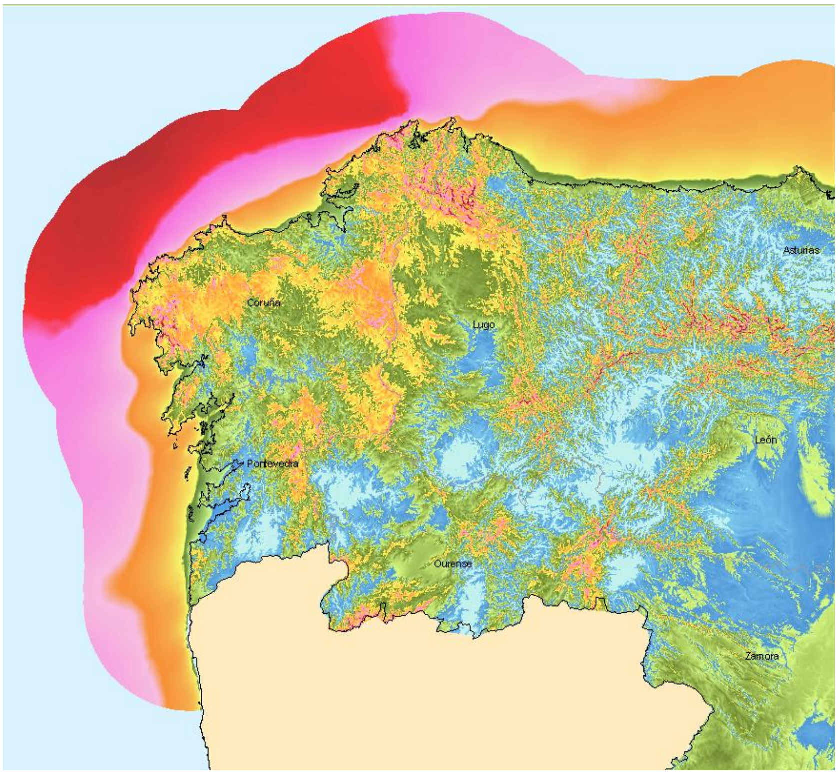


Figure 2. Wind map North-West Spain. (http://atlaseolico.idae.es/meteosim/)

By referring to the databases and the wind maps, the wind rose, the frequency of the wind and the histogram of the velocities were obtained.

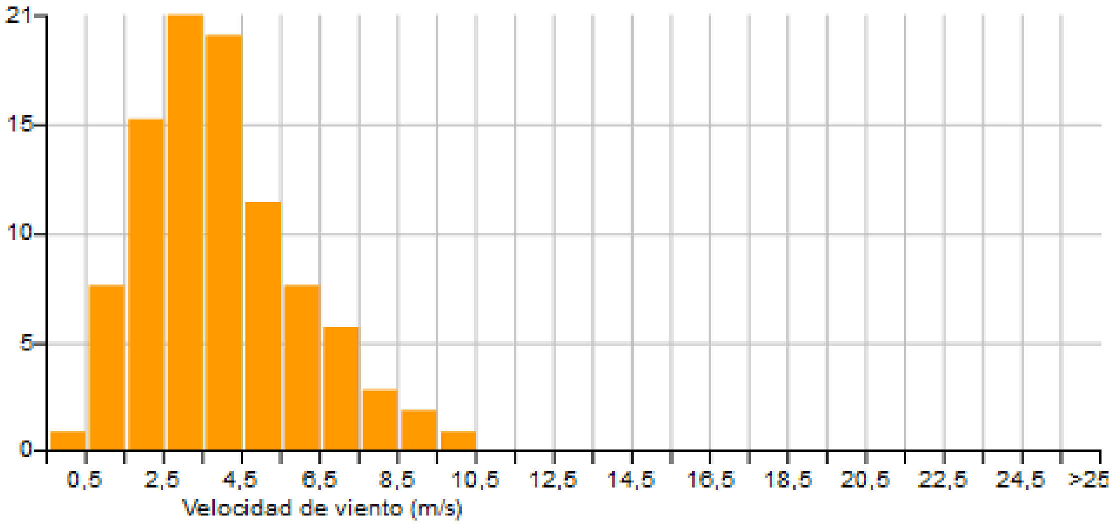


Figure 3. Wind speeds histogram

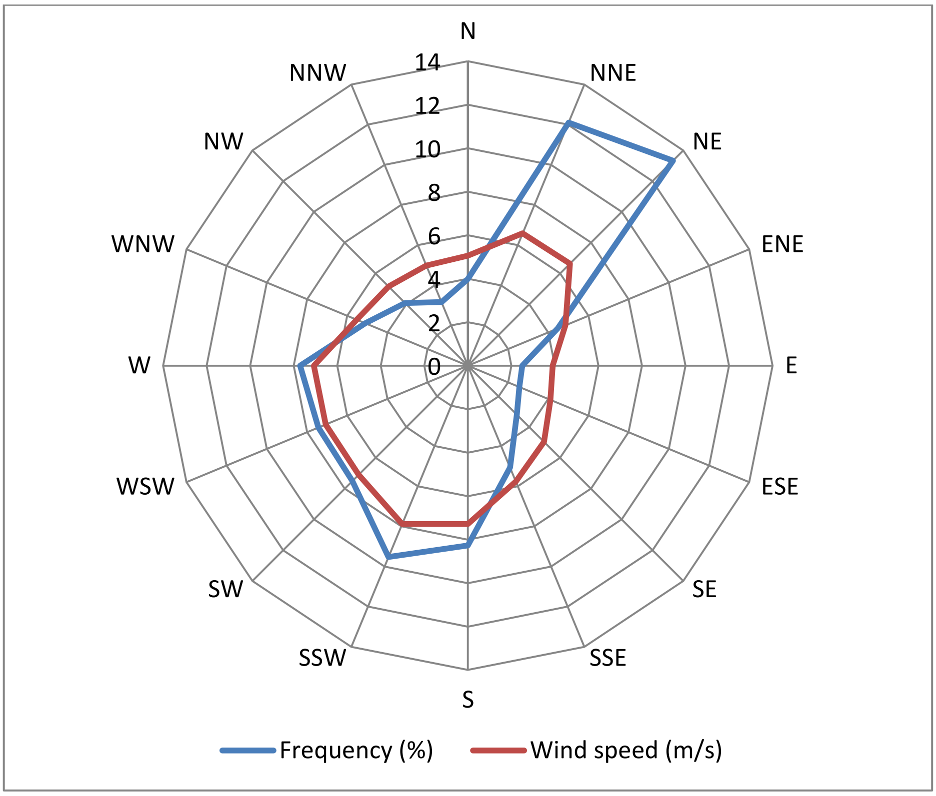


Figure 4. Wind rose diagram

Based on the information extracted from the previous databases, histograms and diagrams, the following values of the wind and its annual frequency were obtained:

Speed (m/s)	Frequency (%)	Yearly hours (h/year)
1,5	1.5%	120
2,5	8.0%	640
3,5	15.5%	1240
4,5	21.0%	1680
5,5	20.0%	1600
6,5	12.0%	960
7,5	7.7%	616
8,5	6.0%	480
9,5	3.0%	240
10,5	2.0%	160
11,5	1.5%	120
12,5	0.0%	0
13,5	0.0%	0
14,5	0.0%	0
15,5	0.0%	0
16,5	0.0%	0

Table 3. Wind frequency and yearly hours for the location selected (own elaboration)

2.3.3. Wind turbine selected

For this project, the wind turbine selected is an Enair 70 of Enair Energy S.L. (www.enair.es). The characteristics of this Enair 70 wind turbine are the following:

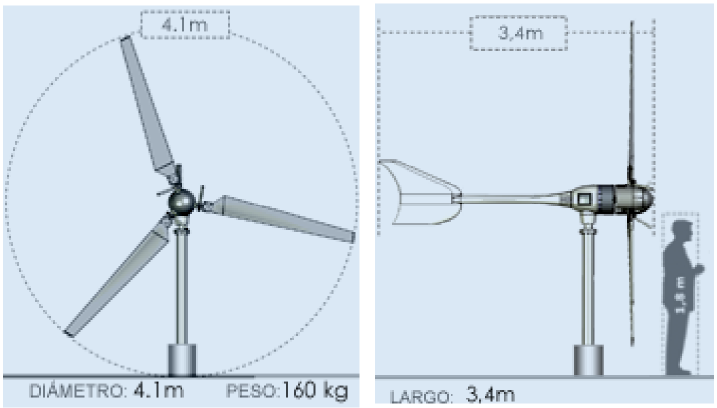


Figure 5. Enair 70 dimensions

SPECIFICATIONS	
Number of blades	3
Diameter	4.1 m
Swept area	13.2 m^2
Material	Fiberglass and epoxy resin
Alternator	250 rpm | neodymium magnets
Nominal power	5,500 W
Voltage	24/48/220 V
Turn on Windspeed	2 m/s
Nominal power Windspeed	12 m/s
Windspeed for automatic brake system	14 m/s
Windspeed survival	>60 m/s
Pillar	15 m

Windspeed (m/s)	Coeficient Power (Cp)
1,5	0,000
2,5	0,079
3,5	0,144
4,5	0,271
5,5	0,372
6,5	0,473
7,5	0,469
8,5	0,433
9,5	0,390
10,5	0,353
11,5	0,293
12,5	0,241
13,5	0,196
14,5	0,162
15,5	0,135
16,5	0,112
17,5	0,093
18,5	0,079
19,5	0,068
20,5	0,058
21,5	0,050
22,5	0,044
23,5	0,039
24,5	0,034

Table 4. Enair 70. Technical data sheet

2.3.4. Wind power generation

As is mentioned in the Subchapter 1.3 of this module, the power supplied by the wind turbine directly depends on the power coefficient. The area swept by the rotor, cubic wind speed and air density also affects the power as we can see in the following equation:

$$P_t(W) = \frac{1}{2} \cdot C_p \cdot \rho \cdot A \cdot v^3$$

Where C_p: the power coefficient

ρ: air density (1.225 kg/m^3)

A: the area swept by the rotor in square meters (13.2 m^2)

v: wind speed in m/s

With the technical information of the wind turbine, one can proceed to calculate the power curve.

Windspeed (m/s)	Coeficient Power (Cp)	Power (W)
1.5	0.000	0
2.5	0.079	10
3.5	0.144	50
4.5	0.271	200
5.5	0.372	500
6.5	0.473	1050
7.5	0.469	1600
8.5	0.433	2150
9.5	0.390	2700
10.5	0.353	3300
11.5	0.293	3600
12.5	0.241	3800
13.5	0.196	3900
14.5	0.162	4000
15.5	0.135	4050
16.5	0.112	4050
17.5	0.093	4050
18.5	0.079	4050
19.5	0.068	4050
20.5	0.058	4050
21.5	0.050	4050
22.5	0.044	4050
23.5	0.039	4050
24.5	0.034	4050

Table 5. Enari 70. Power curve results

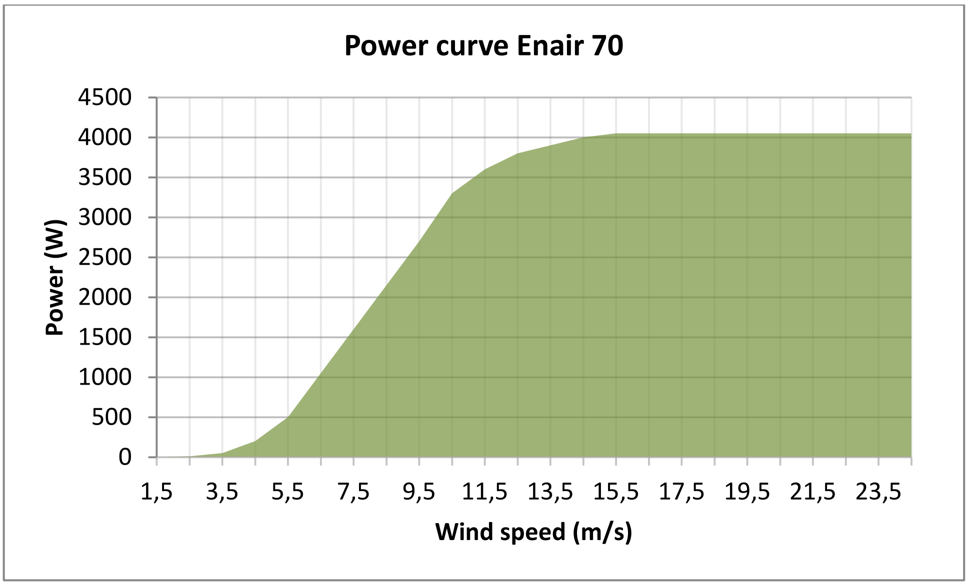


Figure 6. Enair 70. Power curve

Co-funded by the Erasmus+ Programme of the European Union

If we combine the power curve of the Enair 70 wind turbine with the velocity, frequency and yearly hours of wind information, we obtain the following production of annual energy:

Windspeed (m/s)	Yearly hours (h/year)	Energy (Wh/year)
1.5	120	0
2.5	640	6400
3.5	1240	62000
4.5	1680	336000
5.5	1600	800000
6.5	960	1008000
7.5	616	985600
8.5	480	1032000
9.5	240	648000
10.5	160	528000
11.5	120	432000
12.5	0	0
13.5	0	0
14.5	0	0
15.5	0	0
16.5	0	0
17.5	0	0
18.5	0	0
19.5	0	0
20.5	0	0
21.5	0	0
22.5	0	0
23.5	0	0
24.5	0	0
	ANNUAL ENERGY	**5,838 kWh**

Table 6. Calculated energy production of the installation

Therefore, the annual energy produced by one Enair 70 wind turbine in such a location is:

Annual energy = 5,838 kWh/year

This means a daily energy production of:

Daily energy = 16 kWh/day

2.3.5. Number of wind turbines

The number of wind turbines is calculated from the daily energy production of one Enair 70 wind turbine, the PV daily energy production and the energy requirements can be seen in the next equation:

$$N_t \cdot E_t + E_{PH} = E_{needs}$$

Where: N_t: number of wind turbines

E_t: Daily energy production for one wind turbine (Wh/day)

E_{PH}: Photovoltaic daily energy production (Wh/day)

E_{needs}: Energy requirements for the farm (Wh/day)

$$N_t = \frac{E_{needs} - E_{PH}}{E_t}$$

$$N_t = \frac{91.3 - 51.1}{16} = 2.51 \; wind\ turbines$$

Finally, installing 3 Enair 70 wind turbines was decided, obtaining the following averaging values of energy production:

Average daily energy	48	kWh/day
Average monthly energy	1,440	kWh/month
Annual energy	17,520	kWh/year

Table 7. Wind energy production for 3 wind turbines

Figure 7. Installed wind turbines

2.3.6. Choosing the batteries

In a simplified way, the following parameters for the battery requirements calculus are considered:

Energy requirements (E_g)	41,000 Wh/day
Battery bank voltage (V_{bat})	48 V
Depth of discharge (DOD)	50%
Number of days without wind production (D)	2

Table 8. Batteries requirements and parameters

As already seen in previous modules of the course, the required capacity for the batteries is determined with the following relation:

$$C_{bat}(Ah) = \frac{E_g \cdot D}{V_{bat} \cdot DOD_{max}} = \frac{41{,}000 \cdot 2}{48 \cdot 0.5} = 3{,}417\ Ah$$

Based on the batteries capacity, the next battery bank is chosen:

Batteries	
Make and model	Hoppecke 2V 19 OPZS 2375
Voltage	2V
Capacity C100	3,580 Ah
Depth of Discharge (DOD)	50%
Battery Bank	
Total no. of units	24 units
Units in series	24 units
Parallel series	1
Battery bank voltage	48 V
Total Capacity	3,580 Ah

Table 9. Battery bank configuration

Figure 8. Installed battery bank

2.3.7. Selecting the inverters

The existing PV installation, before wind turbines installation, is equipped with a 15 kW inverter.

If we consider that the installation can supply a maximum peak power of 18 kW more or less, and we consider a margin of 5 kW for possible future extensions, we have a total power of 23 kW. Therefore, the necessary power of the inverters, calculated with a safety factor of 25%, is:

$$P_{inv}[W] = \left(\sum P_{eq\ sim}\right) \cdot 1.25 = 23 \cdot 1.25 = 28.75\ kW$$

Thus, installing the following inverters was finally decided on:

Inverter	
Make	SMA Solar Technology AG
Model	Sunny Island 6.0H
Continuous Output Power	4,600 W
AC Output Voltage	230 VAC
Units	3
Total Power	13.80 kW
Total Inverters Group	
Total Units	4 units
Total Power	28.8 kW

Table 10. Inverter configuration

Figure 9. Installed inverters

2.3.8. Diesel Generator

As mentioned previously, to support the designed PV-wind system, a generator of the following specifications was installed:

DIESEL Generator	
Continuous Power	24 kW / 30 kVA
Fuel	Diesel
Motor start	Automatic by inverters signal
Fuel Consumption	7.9 kg/h

Table 11. Diesel Generator

Figure 10. Image of the wind generators installed

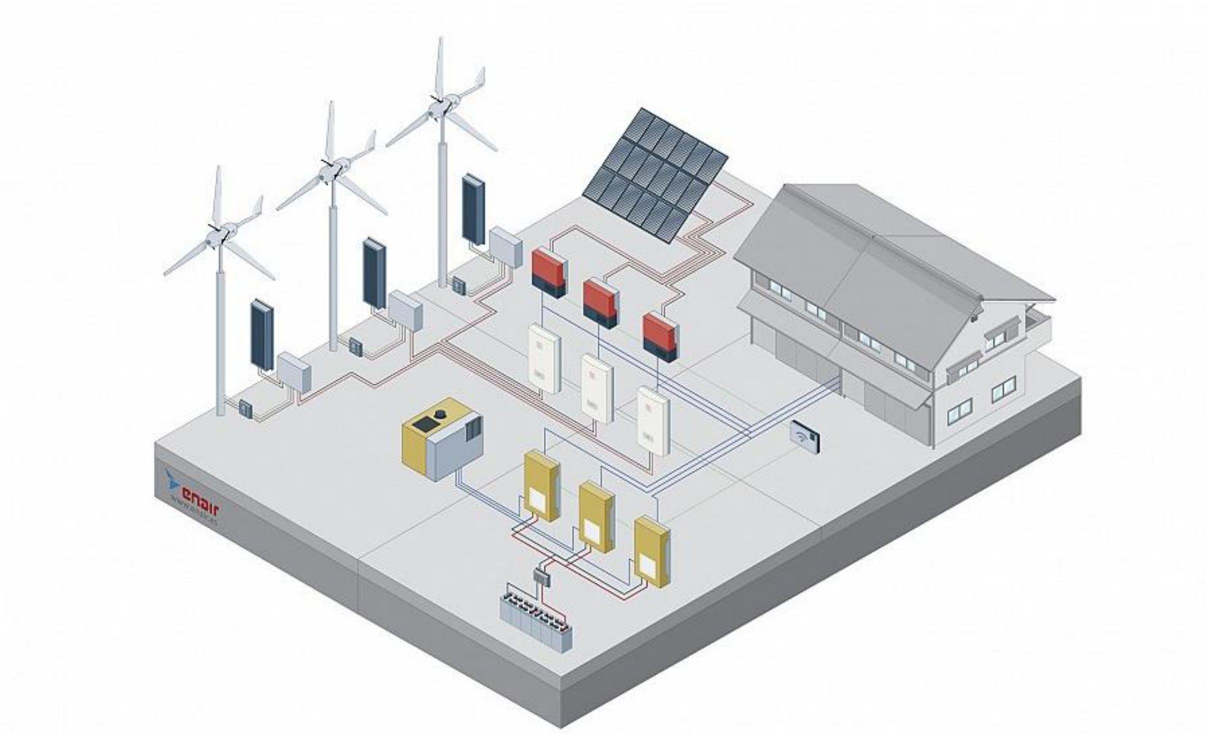


Figure 11. Full plant sketch

Co-funded by the Erasmus+ Programme of the European Union

MODULE 2: WIND ENERGY

CHAPTER 4. Fully developed case study of wind energy for rural development

Subchapter 4.2 - Economical aspects of the case study

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

Summary: This subchapter develops the key economic parameters explained for the case of the wind energy system for isolated remote power supply to the farm in Lugo (Spain).

INDEX

1. Introduction 2

2. Net Present Value (NPV) 4

3. Conclusions 5

1. Introduction

This section provides a survey of the most important economic aspects of the project.
To do so, the total budget of the wind power system must be known. This is shown below.

DESCRIPITON	UNITS	UNIT COST	TOTAL COST
WIND TRUBINE Enair 70 and charge controller	3	8,828.57 €	26,485.71 €
PILLAR 15m height	3	2,050.93 €	6,152.79 €
INVERTER Sunny Island 6.0H	3	3,582.01 €	10,746.03 €
BATTERIES OPZS 2375	24	850.00 €	20,400.00 €
COMBINER BOX & ELECTRICAL COMPONENTS	1	2,350.00 €	2,350.00 €
SITE PREPARATION AND SYSTEM INSTALLATION	1	4,250.00 €	4,250.00 €
DESIGN, MANAGEMENT AND ADMINISTRATIVE COST	1	1,200.00 €	1,200.00 €
		TOTAL COSTS	**71,584.53 €**

Table 1. Wind turbine installation cost of capital

Knowing all the costs that take part with the installation execution, and the comparative with the use of the diesel generation instead of the wind turbines to calculate the economic viability of the installation is required.

For this purpose, the following considerations need to be taken into account:

<u>WIND INSTALLATION COSTS CONSIDERATIONS</u>

The installation achieves a grant of 30% of the installation cost from European funds for renewable energies installation development with a final investment cost (I_0) of 50,109.17 €.

INSTALLATION DATA		
Investment (I)	71,584.53	€
Grant and Subventions	21,475.36	€
Real Investment (I_0)	**50,109.17**	**€**
Electricity generation	17,520.00	kWh/year

Table 2. Investment data of wind power installation

For the cost of the diesel generator set, the minimum annual consumption for supplying punctual days when meteorological conditions do not let the supply of the energy required is estimated.

For this purpose, operation and maintenance costs are estimated at 0.7% of the investment cost (I), assuming a cost of € 501.09 / year.

On the other hand, the cost of the energy supplied by the generator is estimated to be 1,900 kWh annually. For this, the following parameters are considered:

DIESEL GENSET OPERATION COSTS WITH WIND TURBINES		
Diesel Genset generation needed (E_r)	1.900	kWh/year
Diesel Genset consumption (F_c)	0,28	kg/kWh
Diesel density (ρ_{diesel})	0,85	Kg/l
Diesel unit cost (C_{diesel})	0,90	€/l

Table 3. Diesel genset operation data with wind turbines

The unit price of the energy produced by the generator is calculated as follows:

$$Genset\ unit\ energy\ cost\ (E_{cost}) = \frac{F_c}{\rho_{diesel}} \cdot C_{diesel}$$

And

$$Genset\ fuel\ expenditures = E_r \cdot E_{cost}$$

Obtaining the following costs:

Genset unit energy cost	**0.30**	**€/kWh**
Genset fuel expenditures with wind turbines	**506.16**	**€/year**

Table 4. Genset operating costs with wind turbines

As a result, the following operational costs are obtained:

OPERATION COSTS WITH WIND TURBINES		
Operation & Maintenance (0.7% of investment)	501.09	€/year
Fuel expenditures	506.00	€/year

Table 5. Operating costs with wind turbines

COMPARATIVE COSTS WITHOUT WIND INSTALLATION

In order to carry out the economic viability studio of the wind installation, the costs of using the diesel generation set for supplying the energy produced by the wind turbines will be compared.

Thus, considering the parameters and calculations above, the following value can be shown:

OPERATION COSTS WITHOUT WIND TURBINES		
Diesel Genset generation needed	17,520	kWh/year
Diesel Genset consumption	280	gr/kWh
Diesel density	0.85	Kg/l
Diesel unit cost	0.90	€/l
Genset energy cost	0.30	€/kWh
Genset fuel expenditures without wind turbines	**5,194.16**	**€/year**

Table 6. Genset operating costs without wind turbines

2. Net Present Value (NPV)

The profitability of the investment is evaluated based on the NPV criterion given by:

$$NPV = -I_o + \sum_{i=0}^{r} \frac{CF_t}{(1+i)^t}$$

Where:

- I_0: is the investment costs at t=0
- CF_t: is the cash flow at time t
- i: is the interest rate, which is assumed to be 4%

The time span for the NPV is 20 years.

For the calculation of Cash Flow, the operating expenses of the wind installation is taken into account against the savings obtained by it in comparison to the use of the generator, obtained from the following equation:

$$CF_t = (Fuel\ expenditures)_{without\ wind\ turbines} - (O\&M + Fuel\ expenditures)_{with\ wind\ turbines}$$

$$CF_t = 4{,}187.07\ €$$

With all of the above, the following results can be obtained:

	WIND SISTEM SAVINGS			WIND SYSTEM OPERATING COSTS			PROFITABILITY			
YEAR	ENERGÍA PRODUCTION [kWh/year]	GENSET ENERGY COST [€/kWh]	ESTIMATED SAVINGS [€/year]	GENSET COST [€/year]	O&M COST [€/year]	TOTAL COST [€/year]	CASH-FLOW	CUMULATED CASH-FLOW	PAYBACK	NET PRESENT VALUE [NPV]
0							-50,109			
1	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	4,187	-45,922	-44,311
2	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	8,374	-41,735	-40,588
3	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	12,561	-37,548	-37,009
4	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	16,748	-33,361	-33,568
5	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	20,935	-29,174	-30,259
6	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	25,122	-24,987	-27,077
7	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	29,309	-20,800	-24,017
8	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	33,497	-16,613	-21,076
9	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	37,684	-12,426	-18,247
10	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	41,871	-8,239	-15,527
11	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	46,058	-4,051	-12,912
12	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	50,245	136	-10,397
13	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	54,432	4,323	-7,979
14	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	58,619	8,510	-5,655
15	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	62,806	12,697	-3,419
16	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	66,993	16,884	-1,269
17	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	71,180	21,071	797
18	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	75,367	25,258	2,785
19	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	79,554	29,445	4,696
20	17,520	0.296	5,194	506.00	501.09	1,007.09	4,187	83,741	33,632	6,533
TOTAL	350,400	0.296	103,883	10,120	10,022	20,142	83,741	83,741	33,632	6,533

Table 7. Profitability results of the investment

Obtaining the following values for the Net Present Value and installation Payback:

NPV = 6,533.06 €

PAYBACK = 12 Years

3. Conclusions

Starting off with the previous calculus, the following graph is obtained. It shows the evolution of the costs derived from the wind installation in comparision with the diesel generation cost for the production of the energy needs.

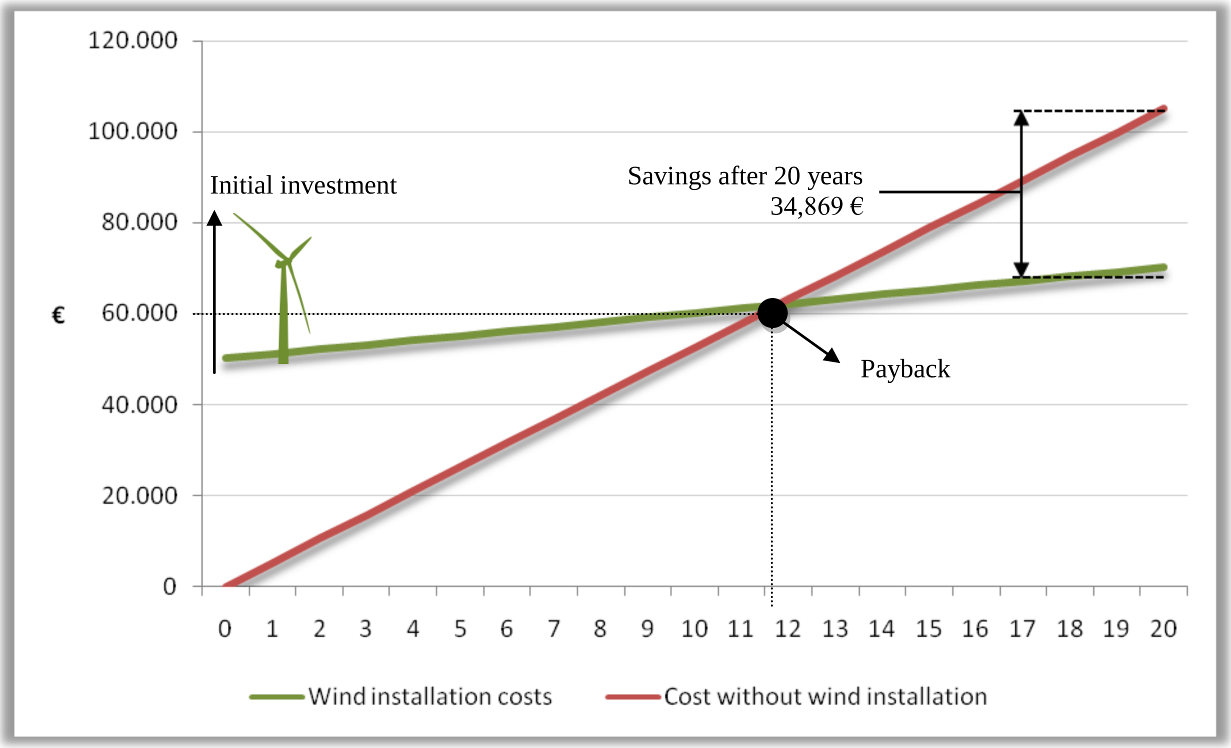


Figure 1. Graphic illustration of comparative costs between wind energy and genset energy

As we can see in the graph, the payback of the wind installation investment will be 12 years, generating a saving of 34,869 € in 20 years in respect to the use of the diesel generation set.

The value of the Net Present Value (NPV=7,634.88 €) obtained is positive, being at the same time not very high. This value indicates that the investment has more profitability than the interest rate of 4% and obtains an interest of 5.66%.

Therefore, from a point of view of profitability, we can say that the investment is interesting provided that other types of investment (with minimum risk) don't have a higher interest than 5.66%.

MODULE 2: WIND ENERGY

CHAPTER 4. Fully developed case study of wind installations for rural development

Subchapter 4.3 – Environmental, social and rural development impact of the case study

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

Summary: In this subchapter the main environmental, social and rural development impacts, as outlined in chapter 3, for the case of the wind power system to supply energy to the farm will be developed.

INDEX

1. The environmental impact 2
   1.1. The setting and the landscape 2
   1.2. The impact on flying animals 2
      1.2.1. Barriers to movement 2
      1.2.2. The change or loss of habitats 2
   1.3. Impact on the soil and subsoil 2
   1.4. Noise and vibrations 3
   1.5. Electromagnetic interference 3
   1.6. The phenomenon of reflection and shadowing 3
   1.7. Weather and climate change 3
   1.8. "Wind turbine syndrome" 3
   1.9. Positive effects on the quality of air 3
2. Air pollution and greenhouse gas emissions 4
3. Social and rural development impacts 5
   3.1. New income sources 5
   3.2. New jobs and business opportunities 5
   3.3. Innovations in products, practices and policies in rural areas 6
   3.4. Acquiring new skills 6
   3.5. Accessible energy prices 6

1. The environmental impact

Wind power is transformed into electrical power with a minimum impact on the environment, however, following the analysis scheme detailed in "Chapter 3: Social and the environmental aspects of eolian (wind) systems for rural development", the environmental impact of the installation is analyzed from different aspects as detailed bellow.

1.1. The setting and the landscape

According to the wind turbine manufacturer, the turbines were installed in a 15m high tower, more than 5 meters more in height than the farm, thereby avoiding the same turbulence generated by the wind on the building itself.

As for the separation of turbines, they are installed with a spacing of 15 meters between them. According to manufacturer, this avoids the generation of turbulence between them.

The space occupied by each of the wind turbines on the ground is minimal, approximately 1.5 m^2 including its foundation, leaving the rest of the land available for use.

1.2. The impact on flying animals

1.2.1. Barriers to movement

The location of the farm in the study is not characterized as an area for migratory birds nor is it located in a Special Protected Area or park.

Even so, the impact on animals flying site is minimal, since the installed wind turbines are small, and occupy only 13.2 m^2 each in the direction perpendicular to the blades respectively. This represents a total occupied space occupied by these of about 40 m^2 in the worst case.

Likewise, the spacing between wind turbines and the installation’s low-altitude location minimizes the impact on flying animals. Therefore, the impact on birds is considered to be minimal.

1.2.2. The change or loss of habitats

Unlike large wind parks, which require large infrastructures and space for installation and operation, the installed wind turbines do not require such large infrastructure because of their small size and proximity to the consumer. Therefore the change to habitat or habitat loss is zero, because they are installed in a place where existing infrastructure is in place on the agricultural holding, so not affecting any factor that might influence the loss of habitat and biodiversity.

1.3. Impact on the soil and subsoil

The impact on the soil and subsoil of the installation is minimal, since the foundation of each wind turbine occupies an area of just 1.5 m^2 which is negligible when considering the size of the livestock area and the farmhouse. Likewise, the installation does not require the execution of a new access road.

1.4. Noise and vibrations

Installed wind turbines are designed to be quiet, having a rotation speed of between 200 and 250 rpm. Considering their height, these vibrations are virtually undetectable by anyone underneath them.

In the wind turbine installers´ manual measurements made by the certifying center are detailed. As a representative figure it is maintained that at a distance of 40 meters from the wind turbine and with a steady wind of 8 m/s, 40.6 dB (A) of noise arises, equivalent to the noise recorded in a library. At 150 meters away, this noise decreases to 29 dB (A), equivalent to the noise of a whispered conversation.

Generally, the noise produced by installed wind turbines increases noise in dB (A) by 1% compared to the ambient wind noise.

As for the vibrations produced by the wind turbines, these are considered negligible.

1.5. Electromagnetic interference

Communications and services provided through radio waves can be influenced by the presence of wind turbines. In this case, given the small size of the wind turbines, electromagnetic interference is minimal. Furthermore, the blade design and the material they are made of (fiberglass with epoxy resin) cause electromagnetic interference to be minimal or non-existent.

1.6. The phenomenon of reflection and shadowing

The installed wind turbines are pained matt white, which eliminates the phenomenon of the reflection of light.

Furthermore, the shadows produced by the wind turbines are minimal due to their small size.

1.7. Weather and climate change

Because of the characteristics, quantity and size of the installed wind turbines, the turbulence effect on the climate is nil or negligible.

1.8. “Wind turbine syndrome”

Studies on the effects of wind turbines on the health of people around them, called "wind turbine syndrome" are studies of nearby large wind turbine parks, which fall beyond the scope of the installation carried out.

1.9. Positive effects on the quality of air

Like other effects on the environment that can be studied, and given the nature, size and number of the installed wind turbines, the positive effect on air quality due to the increased moisture effects of pressure variation and air velocity are considered negligible, whereas this effect can be considered on large wind farms.

2. Air pollution and greenhouse gas emissions

The calculation of greenhouse gases only takes into account emissions from the generator to produce the annual energy considered necessary at a time when weather conditions require it.

To this end, the emission factor for stationary Diesel-fuelled combustion equipment indicated by the Ministry of Agriculture, Food and Environment of the Government of Spain are used.

$$\text{Diesel Emission factor} = 0.287\ kgCO_2/kWh$$

From this, the annual Diesel generator emissions for powering the operation of the generator set are obtained.

ANNUAL GENSET EMISSIONS	
Genset annual output (kWh/year)	1,900
Diesel genset consumption (gr/kWh)	280
Diesel annual consumption (kg/year)	532
Diesel emission factor (kgCO_2/kWh)	0.287
CO_2 emission (kgCO_2/year)	**545**

Table 1. Annual genset emissions with wind turbines

To give a clearer picture of the environmental benefits of the installation concept, the values of emissions of greenhouse gases should be compared to the emissions produced by the wind turbine system and without it, considering that the energy produced by wind turbines should otherwise be provided by the diesel generator.

ANNUAL GENSET EMISSIONS WITHOUT WIND TURBINES	
Genset annual output (kWh/year)	17,520
Diesel genset consumption (gr/kWh)	280
Diesel annual consumption (kg/year)	4,905.6
Diesel emission factor (kgCO_2/kWh)	0.287
CO_2 emission (kgCO_2/year)	**5,028**

Table 1. Annual genset emissions without wind turbines

Therefore, there is an annual greenhouse gas emission reduction of 4,483 kg of CO_2.

The following chart shows the accumulated emissions that result over 20 operating years of the wind power system compared with the use of a diesel genset to produce the energy deeded.

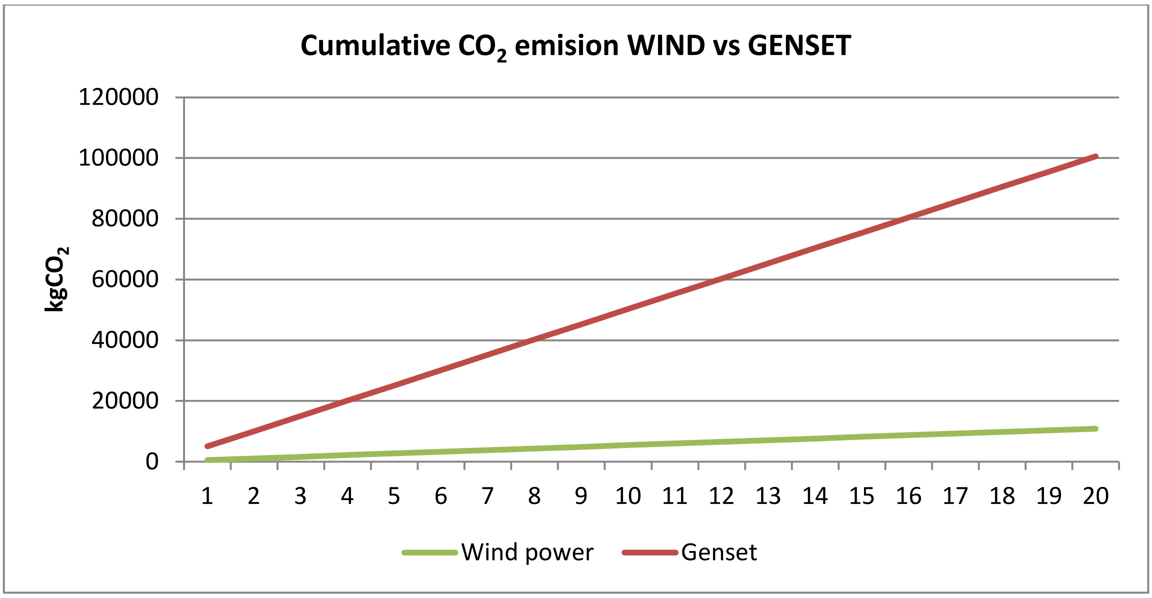


Figure 1. Cumulative CO_2 emissions. WIND POWER vs. DIESEL GENSET. Source: Own elaboration.

3. Social and rural development impacts

3.1. New income sources

In the case study, the integration of wind energy, together with the existing photovoltaic system allows the farm-owner to integrate various renewable energy technologies, diversifying and increasing this activity, resulting in significant economic savings that allow the strengthening of their economic activity and improved business competitiveness.

In this sense, thanks to the energy produced by the wind farm, the farm achieves annual cost savings of approximately € 4,250, creating a payback on the investment made of 12 years.

It also indirectly affects all further development in the rural area where it is located, in turn strengthening indirect service activities and the supply of materials for the farm.

3.2. New jobs and business opportunities

Firstly, it is clear that the performance of the wind turbine system contributed to the creation of qualified jobs that are required for its execution:

- Technical personnel for the design and dimensioning of the installation
- Qualified personnel for the construction and installation of the system
- Qualified personnel for the operation and maintenance of the facility

Likewise, the wind turbine system indirectly contributes to maintaining employment in the farm and auxiliary industry as it results in its greater economic viability.

On the other hand, since the farm is situated in a region where many farms coexist, the current installation can benefit the effect of technology diffusion, and can thereby achieve a greater number of facilities and therefore higher employment in companies in the renewable energy sector and the operation and maintenance of facilities.

3.3. Innovations in products, practices and policies in rural areas

Since the industrialization of the livestock sector, small farms have been affected by prices marked by large farms, reduced their business competitiveness in the sector. In the case study, linking the business activity with technology companies that offer new innovative solutions for both the process itself and for power generation has been essential for improving the competitiveness and continuity in livestock farming.

Also, as discussed above, the case study can serve as an example of the installation benefits of renewable energy technologies for the development of the mainly rural sector, which in the community of Galicia represents about 34,500 farms of which 72% belong to livestock activities in rural areas.

Therefore, it is logical to think that the application of appropriate policies for promoting and encouraging the use of renewable energy technologies can promote the strengthening and growth of the livestock sector in the region and therefore in the social and economic development of the areas rural involved.

3.4. Acquiring new skills

The completion of the installation of wind turbines directly affects the acquisition of new technical knowledge about this technology by staff working on the farm.

Likewise, the use of this type of renewable energy technologies involves an acquisition of knowledge regarding the efficient use of energy, raising awareness to all users and visitors of the importance of streamlining, efficiency and efficient energy management.

On the other hand, the actual installation creates a diffusion effect in the rural region where it is located, presenting the characteristics and advantages of the installation to the local population. All of this results in greater awareness in the rural population about the importance of efficient energy use, and the benefits that renewable energy systems offer in this regard.

3.5. Accessible energy prices

In addition to the economic savings of the wind turbine installation in respect to the use of the generator for generating electricity for the farm, this type of facility involves stable energy prices by reducing their dependence on continuing changes in fuel costs and energy.

Similarly, the actual installation contributes to:

- Rural electrification, enabling access to energy at an affordable price and in a respectful way to the environment.

- Distributed generation (distributive generation model).
- The energy independence and own decision making on energy sovereignty on the generation, distribution and consumption in a way that is appropriate to the ecological, social, economic and cultural circumstances provided that these do not affect others negatively

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.1 – Case Study 1

José Segarra Murria, Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 1

An operation and management company of sewage treatment plants requires the installation of a waste water treatment plant in Pina de Montalgrao (Castellón), a Spanish village with a population of 129 inhabitants.

The costumer decides to study the possibility of installing a wind system to supply part of the power required by the installation and try to reduce the energy costs.

This area suffers from a high level of unemployment and steady strong winds so this combination of installation of a waste water treatment and installation of a wind system will help the local community.

One wind system is formed by 4 wind vertical turbines as can be seen in the image. The decision to install this system has been taken because it is designed and constructed by a local company.

I. INPUT DATA

LOCATION

Village: Pina de Montalgrao (Spain)

ENERGY NEEDS

The energy needs of the treatment plant are simplified as follows:

SYSTEM	POWER [W]	DAILY OPERATION [h/day]	DAILY ENERGY DEMANDED [Wh/day]
Biodisc Reactor	1,000 W	20.0 h	20,000 Wh
Sieve	400 W	0.5 h	200 Wh
Pump	400 W	0.5 h	200 Wh
TOTAL	1,800 W		20,400 Wh/day

CONSTRUCTION FEATURES

In the following table, the different average wind speeds a year are shown:

Wind Speed	Hours per year
2	100
3	250
4	450
5	650
6	750
7	950
8	800
9	550
10	350
11	150

II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.
- In case you don't find the information you require, use the information below:

Wind Speed	Cp
2 m/s	0.036
3 m/s	0.234
4 m/s	0.276
5 m/s	0.323
6 m/s	0.303
7 m/s	0.286
8 m/s	0.278
9 m/s	0.258
10 m/s	0.234
11 m/s	0.201

Max. Power per turbine: 400 W

Nominal Power per turbine: 300 W

Diameter: 1.2 m

Height: 1.9 m

- The information provided before is for one savonius wind turbine. One wind generation system is formed by 4 wind turbines. Consider that all the wind turbines will function in the same way.
- Optimize the energy production to get 70 % of the total energy demand. Maximum number of wind generation systems: 3 (maximum number of wind turbines: 12).

- In order to carry out the economic analysis, it should be considered that the cost of the connection to the electrical grid would be of 22,000€ and the cost of the power consumed would be of 0.15 €/kWh.
- The CO_2 impact avoided thanks to the installation should be taken into account. In addition, talk about the installation's visual and noise impact.
- Consider a local government grant of 15%.
- For the installation cost calculus you should consider that a wind generation system of savonius wind turbines has an approximate cost of 11,000 €.
- Argue if the installation must have a battery storage system and if it should have another energy source supporting.
- Talk about the advantages of working with local companies for local projects.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.2 – Case Study 2

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 2

Sustainable greenhouse based on renewable energies.

A rural company have a cultivation of different types of lettuces and vegetables in the province of Almería (Spain). It intends to install a power plant of renewable energies based on small wind generation in order to obtain an economic saving in the electric bill.

Currently, they have a consumption of 150 kWh/day and they would like to cover 20% of the energy as a minimum.

The installation will be connected to a three-phase net, like a self-consumption system. This type of connection allows them to save money directly on the electric bill.

In order to legalize the installation, special environmental permission will be necessary. This permission is given by “la Junta de Andalucía” (autonomic government) after the verification of the affect on the environmental and landscape impacts.

In addition, the installation will have a monitoring system in a way that the small wind production will be visible and managed by software.

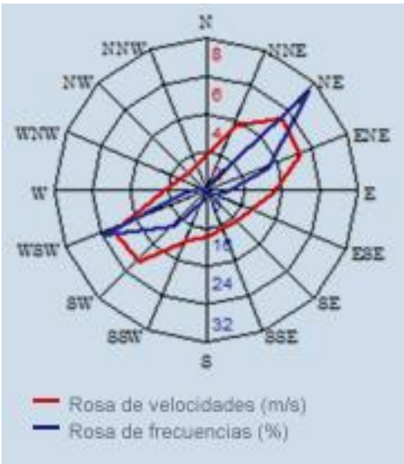
I. INPUT DATA

LOCATION

Town: Nijar - Almería (Spain)

FEATURES

Wind Speed (m/s)	Hours per year
1	0
2	300
3	540
4	820
5	1600
6	1540
7	600
8	400
9	100



II. CONSIDERATION FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.
- In case you don't find the information you require, use the information below:

Cp:

Wind Speed (m/s)	Cp
1	0.000
2	0.076
3	0.691
4	0.878
5	0.738
6	0.586
7	0.537
8	0.515
9	0.458

Max. Power: 10.5 kW
Nominal Power: 7.5 kW
Diameter: 6.1 meters

- Optimize the energy production to get the 20% of the total energy using 3 wind turbines as maximum.
- Talk about the installation's visual impact, noise and environmental impact of this installation and the selected wind turbines.
- Consider a price of the energy from the grid of 0.15€/kWh for the economic analysis.
- There is a grant for this installation: It amounts to 30% of the costs.
- Talk about the social aspects such as how the installation affects employment in the vegetable farm and in the region.
- The installation cost needs to be calculated by the student based on the ratios indicated in the module of the course.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.3 – Case Study 3

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 3

Installation of telecommunications between Portugal and Azores Islands.

In Santa María Island of the Azores Islands (Portugal) a telecommunications centre in order to improve the conditions of the islanders has been constructed.

The energy demand is supplied by an isolated renewable energies installation. This installation is formed by a mixed system of small wind and PV. It has 1 small wind turbine and 16 PV panels of 150 Wp.

The three-phase wind turbine is connected to a specific regulator while the PV panels have other solar regulator. Moreover, the system has a bank of batteries.

The installation has carried out with a view to minimize the visual and noise impact.

I. INPUT DATA

LOCATION

Location: Isla de Santa María - Islas Azores (Portugal)

CONSTRUCTION FEATURES

Wind Speed (m/s)	Hours
4	910
5	1.254
6	1485
7	726
8	126
9	50

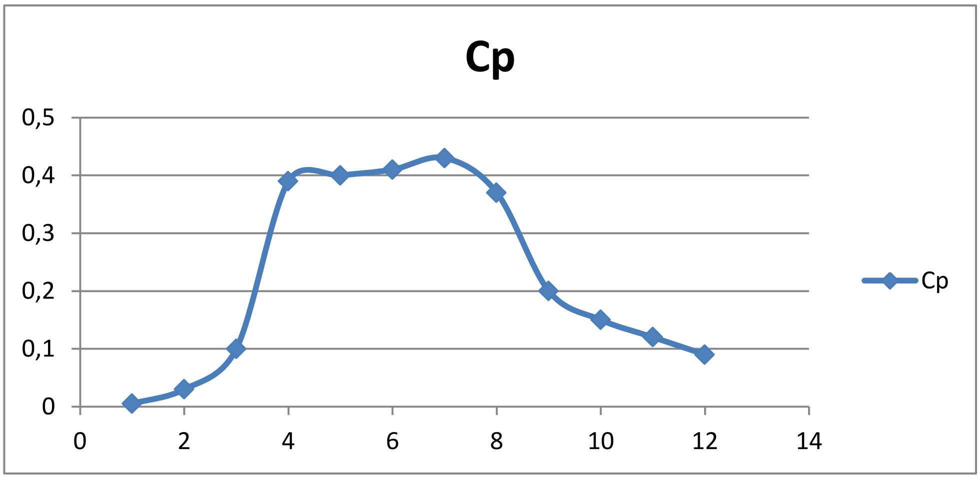
The PV panels produce an average energy of 4.5 kWh/day during summer months and an average energy of 2.8 kWh/day during winter months.

The minimum energy needs of the meteorological station are 10 kWh/day, but it is recommendable to obtain more than 12 kWh/day.

II. CONSIDERATION FOR THE STUDY

- Try to select a suitable wind turbine on the web. Justify your selection.
- If you don´t find the needed information, then use this information below:

Cp:



Diameter: 2.86 meters
Max. Power: 1.1 kW
Nominal Power: 750 W

- To optimize the energy production for the station you must consider a maximum number of 3 small wind turbines.
- Talk about the installation’s visual impact, noise and environmental impact of this installation and the selected wind mills.
- Calculate the price of the wind mill installation based on the ratios of the module of this course.
- In the case of grid connection, the connection cost would be 35,000€ and the price of the energy from the grid would be 0.15€/kWh.
- Talk about social aspects such as how the installation socially affects the region.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.4 – Case Study 4

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 4

The installation was carried out in the region of Castilla la Mancha (Spain) and it consists of a rural complex of 3 apartments with a maximum capacity of 16-18 people. This installation is optimized in order to maximize the quantity of energy that the small wind turbine can produce. For this purpose it is necessary to have a complete study of the turbulence and the location of the small wind mill.

This optimization is focused in order to produce the maximum energy in a day (kWh/day). Independently of the punctual power that the turbine can produce in a windy day, it is important the quantity of daily energy generated must be constant and the greatest amount possible.

The characteristics of the installation are that the nacelle is located at 21.5 m and the tower has a distance of more than 140 m in straight line. This means a wire distance of 180 m.

The study and the optimization of this type of installation together with the adequate wind turbine make it possible to maximize the efficiency of the components of the system. The installation supplies energy for:

Consumption	Units	Power (W)	Hours/day	Energy (Wh/day)
Fridge	3	120	10	3600
Illumination	20	9	4	720
TV	3	70	3	630
Water pump	1	370	3	1100
PC	1	80	6	480
Others	1	400	10	4000
			TOTAL	10530

It must be considered that the rural complex also has PV panels. These PV panels produce 4.5 kWh/day in summer and 2.9 kWh/day in winter.

I. INPUT DATA

LOCATION

City: Tejadillos (Spain)

CONSTRUCTION FEATURES

In the following table, the different average wind speeds in a year are shown:

Wind Speed	Hours per year
1	50
2	100
3	250
4	600
5	900
6	750
7	550
8	400
9	250
10	150
11	50

II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.
- In case you don't find the information you require, use the information below:

Wind Speed	Cp
1 m/s	0
2 m/s	0.04
3 m/s	0.10
4 m/s	0.39
5 m/s	0.40
6 m/s	0.41
7 m/s	0.44
8 m/s	0.38
9 m/s	0.20
10 m/s	0.15
11 m/s	0.11

Max. Power: 1.1 kW
Nominal Power: 750 W
Diameter: 2.86 m

- Consider a three-blade mill with a circular section.
- Optimize the energy production considering the energy production of the PV panels. Maximum number of wind turbines: 3.
- In order to carry out the economic analysis, it should be considered that the cost of the power consumed would be of 0.15 €/kWh. The connection to grid has a cost of 15,000 €.
- Consider a grant provided by the government of 10%.
- The CO_2 impact avoided thanks to the installation should be taken into account. In addition, talk about the installation's visual and noise impact.
- The installation cost calculus shall be based on the ratios of the module of this course.
- The hostel workers know how the small wind installation works and they show it to visitors. In addition, talk about these social and environmental aspects.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.5 – Case Study 5

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 5

The Mas de Noguera hostel is a rural place located near to Caudiel (Castellón) which has been working in isolation with renewable energy systems to date. The hostel is greatly concerned with environmental education and its relationship with nature, which are some of its hallmarks. It is necessary to install a submersible centrifugal pump DC powered using small wind energy for an irrigation application. This pump will raise an average daily flow of 80 m^3/day between two ponds with a slope of 18m. Once the flow is raised, irrigation is done by means of gravity. The hostel contacts with a renewable energy rural enterprise to determine the small wind system needed to carry out the pumping application.

I. INPUT DATA

LOCATION

Address: PD. Mas de Noguera S/N, 12440
Town: Caudiel (Castellón)

ENERGY NEEDS

In order to get an average flow of 80m^3/day, the average power consumption is 10.25 kWh/day.

CONSTRUCTION FEATURES

In the following table, the different average wind speeds in a year are shown:

Wind Speed	Hours per year
1	100
2	300
3	400
4	550
5	600
6	750
7	450
8	300
9	200
10	150
11	100
12	50

II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.

- In case you don't find the information you require, use the information below:

Wind Speed	Cp
1 m/s	0.27
2 m/s	0.48
3 m/s	0.41
4 m/s	0.39
5 m/s	0.44
6 m/s	0.48
7 m/s	0.44
8 m/s	0.40
9 m/s	0.39
10 m/s	0.37
11 m/s	0.36
12 m/s	0.30

Max. Power: 5.5 kW
Nominal Power: 3.5 kW
Diameter: 4.1 m

- Consider a three-blade mill with a circular section.
- Optimize the energy production to get the 75 % of the demanded total energy. Maximum number of wind mills: 3.
- In order to carry out the economic analysis, it should be considered that the cost of the connection to the electrical grid would be 20,000€ and the cost of the power consumed would be of 0.15 €/kWh.
- The CO_2 impact avoided thanks to the installation should be taken into account. In addition, talk about the installation's visual and noise impact.
- The installation cost calculus shall be based on the ratios of the module of this course.
- Argue if the installation must have a battery storage system and if it should have another energy source supporting it.
- The hostel workers know how the small wind installation works and they show it to schools and visitors. In addition, talk about social and environmental aspects.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.6 – Case Study 6

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 6

Off grid detached house with renewable energy.

This house is in a rural area with an occupied space of 100 m^2 with an agricultural storage area.

This house sits at the foot of Mount Orsaro in the region of Emilia-Romagna (Italy), the distance to the nearest power grid power is (3.5 km), for which investment required for connection to the network is very high. For this reason, the installation of a series of solar panels and Cubiro mini wind turbines for the different energy needs has been chosen.

The daily energy requirements are 1.92 kWh/day for lighting and 7.2 kWh/day for other loads, which wind installation will provide 80% of. The installation will not be connected to any network, ie; this is an isolated connection, allowing complete independence from electrical distributors.

There will also be a monitoring system to know the energy that is produced, consumed and stored at all times. In case of emergency, there will be an emergency generator to meet basic needs.

I. INPUT DATA

LOCATION

City: Monte Orsaro – Emilia- Romagna (Italy)

CONSTRUCTION FEATURES

Wind Speed (m/s)	Hours
2	400
4	500
6	1100
8	950
10	500
12	100
14	40

II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.
- In case you don't find the information you require, use the information below:

Wind Speed (m/s)	Cp
2	0.31
4	0.33
6	0.326
8	0.323
10	0.25
12	0.15
14	0.09

Max. Power: 5.5 kW
Nominal Power: 3.5 kW
Diameter: 4.1 meters
Pillar height: 7 meters

- Optimize the energy production to get the 80% of the total energy using a wind mill.
- Talk about the installation's visual impact, noise and the environmental impact of this installation and the selected wind mills.
- Considerations for the economic analysis should only take into account the energy demand covered by the power the wind turbine generates.

Installation maintenance: 100 €/año

- To carry out the comparative economic study, take into account that if the turbines are not installed the alternative options are:

Option 1: Petrol powered diesel generator:

Generator Cost (to cover 80%): 150 €
Average petrol consumption by the generator: 0.8 litres/hr
Price of petrol: 1.3 €/litre

Option 3: Electricity grid connection

Average network connection cost: 20,000 €/km
Grid energy cost: 0.15 €/kWh

- The price of the installation is based on the ratios of the module of this course.
- There is a grant for this installation of 30% of the costs.

- Talk about the social aspects such as how the installation affects employment in the region.
- The installation cost must be calculated by the student based on the ratios indicated in the module of the course.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.7 – Case Study 7

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 7

Ceutí is a town located in the province of Murcia (Spain) and it has a population of 11222 residents. This year, they decided to reduce the electric bill after an energy audit. The measures that have been adopted are a reduction of the contracted power and the installation of LED streetlights.

Thanks to that, the energy demand has decreased from 1.27 MWh to 0.6 MWh in a year. Moreover, they have managed to save 265,000 € per year in the electric bill.

Now, in order to approach the self-consumption model, the local government intends to install small wind generators to supply electricity for 40% of the streetlights in a neighborhood. Later, the energy needs will be shown.

I. INPUT DATA

LOCATION

Town: Ceutí (Murcia).

ENERGY NEEDS

Only the neighborhood:

- Installed power: 63 LED lights of 50 W; total power of 3.15 kW.
- Consumed energy in 10 daily hours (3650 h/year): 11,497.5 kWh/year.
- 40% of the energy demand is supplied by the small wind generators.

CONSTRUCTION FEATURES

In the following table, the different average wind speeds in a year are shown:

Wind Speed	Hours per year
1	200
2	400
3	500
4	750
5	850
6	750
7	500
8	450
9	350
10	250
11	200
12	100

II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.

- In case you don't find the information you require, use the information below:

Wind Speed	Cp
1 m/s	0.27
2 m/s	0.48
3 m/s	0.41
4 m/s	0.39
5 m/s	0.44
6 m/s	0.48
7 m/s	0.44
8 m/s	0.40
9 m/s	0.39
10 m/s	0.37
11 m/s	0.36
12 m/s	0.30

Max. Power: 5.5 kW
Nominal Power: 3.5 kW
Diameter: 4.1 m

- Consider a three-blade mill with a circular section.
- Optimize the energy production to get 40 % of the demanded total energy. Maximum number of wind mills: 3.
- In order to carry out the economic analysis, it should be considered that the cost of the power consumed would be of 0.15 €/kWh.
- Consider a grant provided by the government of 30%.
- The CO_2 impact avoided thanks to the installation should be taken into account. In addition, talk about the installation's visual and noise impact.
- The installation cost calculus shall be based on the ratios of the module of this course.
- Talk about the advantages of the project developed.
- The local government will try to attract young people to the town by offering jobs as installation maintenance service workers.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.8 – Case Study 8

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 8

Sustainable stables with renewable energy.

A stable intends to expand its installations by building a new stable that is completely sustainable and self-sufficient to stable 20 horses.

The stables are located in Soba province in Cantabria (Spain), and they will be used to house horses and provide riding hire services and care for privately owned horses. This construction consists of a covered area of 300 m^2, housing horses at one end and at the other a room for cleaning horses and changing rooms.

The required energy demands are 11.27 kWh/day for lighting and 15.34 kWh/day of other energy consumption, of which the wind farm will cover 65%.

The installation will consist of solar panels, small wind turbines and solar thermal panels that can operate in isolation.

There will also be a monitoring system to know the energy that is produced, consumed and stored at all times.

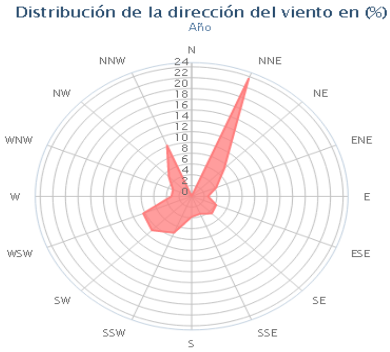
I. INPUT DATA

LOCATION

City: Soba – Cantabria (Spain)

CONSTRUCTION FEATURES

Wind Speed	Hours
2 m/s	1400
4 m/s	1500
6 m/s	1100
8 m/s	150
10 m/s	80
12 m/s	10



II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection. Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.

- In case you don't find the information you require, use the information below:

Wind Speed (m/s)	Cp
2	0.07
4	0.27
6	0.42
8	0.35
10	0.26
12	0.13

Max. Power: 5.5 kW
Nominal Power: 3.2 kW
Diameter: 4.36 meters
Pillar height: 9.2 meters

- To optimize the energy production to get the 65% of the total energy using 4 wind mills as maximum.
- Talk about the installation's visual impact, noise and environmental impact of this installation and the selected wind mills.
- Considerations for economic analysis taking into account only the energy covered by the turbines.

  Installed turbine maintenance: 100 € / year

- To carry out a comparative economic study, note that in the case of not installing wind turbines, the options are:

  Option 1: Use a petrol generator:

  Generator cost (to cover 65%): 175 €
  Average generator consumption: 0.95 litres/hr
  Fuel price: 1.3 €/litre

  Option 2: Grid connection

  Grid energy cost: 0.15 €/kWh
  Grid connection average cost: 24,500 €

- The price of the installation is based on the ratios of the module of this course.
- There is a grant for this installation. 45 % of the costs.
- Talk about social aspects such as how the installation affects employment in the stables and in the region.

- The installation cost shall be calculated by the student based on the ratios indicated in the module of the course.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.9 – Case Study 9

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 9

Ordis is a town located in the province of Girona (Spain) and it has a population of 380 residents. The inhabitants of the town decided to develope a project called "Sustainable Ordis". This project consists of achieving self-consumption in all of the village thanks to renewable energy resources. In addition, it is looking for energy efficiency in this consumption. With this project, the town wants to reduce the effects of climate change at the same time that they set a good example for other villages.

Ordis has a biogas power plant and PV panels but a few years ago they were interested in small wind energy because the village has favorable gusts of wind.

I. INPUT DATA

LOCATION

Town: Ordis (Girona).

ENERGY NEEDS

- It is estimated an energy demand of 30 kWh supplied only by small wind energy.

CONSTRUCTION FEATURES

In the following table, the different average wind speeds in a year are shown:

Wind Speed	Hours per year
1	150
2	300
3	450
4	600
5	750
6	850
7	800
8	650
9	400
10	300
11	150
12	100

II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.

- In case you don't find the information you require, use the information below:

Wind Speed	Cp
1 m/s	0.000
2 m/s	0.076
3 m/s	0.691
4 m/s	0.878
5 m/s	0.738
6 m/s	0.586
7 m/s	0.537
8 m/s	0.515
9 m/s	0.458
10 m/s	0.404
11 m/s	0.314
12 m/s	0.255

Max. Power: 10.5 kW
Nominal Power: 7.5 kW
Diameter: 6.1 m

- Consider a three-blade turbine with a circular section.
- Optimize the energy production to get the 40 % of the demanded total energy. Maximum number of wind turbines: 4.
- In order to carry out the economic analysis, it should be considered that the cost of the power consumed would be of 0.15 €/kWh.
- Consider a grant provided by the government of 10%.
- The CO_2 impact avoided thanks to the installation should be taken into account. In addition, talk about the installation's visual and noise impact.
- The installation cost calculus shall be based on the ratios of the module of this course.
- Talk about the advantages of the project developed.
- The local government will try to attract young people to the town by offering jobs as installation maintenance service workers.
- Consider that Ordis is the first ecotown in the province, so talk about ecotourism impacts.

MODULE 4: WIND ENERGY

CHAPTER 5. Proposed case studies

Subchapter 5.10 – Case Study 10

José Segarra Murria

Juan Jorro Ripoll

Heliotec 2006 S.L., Spain

CASE STUDY 10

Generation facility using Renewable Energy.

An energy service company (ESCO), developed a small wind farm in a rural area for the supply of energy to a community of local farmers in order to meet the energy needs on their farms some years ago.

In the last year the energy demand has increased and there is a wish to expand the generation facility by incorporating more mini wind turbines to meet demand. This energy will also be consumed by different consumption by the agricultural cooperative and interested persons located in the vicinity of the plant.

This mini wind farm will be located on unused farmland in the province of Zaragoza (Spain). For the first phase, a number of mini wind turbines were installed to generate a quantity of power close to 30 MWh / year. The current aim is to increase this amount to get a total energy of 43.6 MWh / year or so.

The facility already has a system for monitoring environmental conditions, production monitoring and network connection points for distribution.

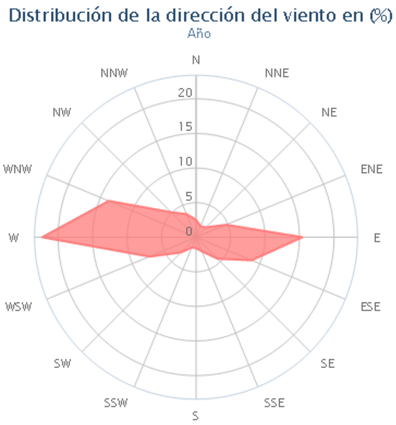
I. INPUT DATA

LOCATION

City: Farlete – Zaragoza (Spain)

CONSTRUCTION FEATURES

Wind Speed	Hours
2 m/s	1300
4 m/s	1600
6 m/s	1400
8 m/s	500
10 m/s	90
12 m/s	50
14 m/s	20



II. CONSIDERATIONS FOR THE STUDY

- Try a web-search to look for different wind turbines and choose the one you consider is best. Justify your selection.
- In case you don't find the information you require, use the information below:

Wind Speed (m/s)	Cp
2	0.46
4	0.47
6	0.45
8	0.42
10	0.38
12	0.35
14	0.2

Max. Power:	5.5 kW
Nominal Power:	3.5 kW
Diameter:	4.36 meters
Pillar height:	9.2 meters

- Calculate the number of mini wind turbines to be added to cover the energy difference due to the increased annual demand.
- Talk about the installation's visual impact, noise and environmental impact of this installation and the selected wind mills.
- The price of the energy that the ESCO supplies is 0.135€/kWh for the economic analysis.
- Maintenance cost for the wind turbine: 100 €/yr
- There is a grant for this installation. 20% of the costs.
- Talk about social aspects such as how the installation affects employment in this farming area and in the region.
- The installation cost shall be calculated by the student based on the ratios indicated in the module of the course.

IN2RURAL

Co-funded by the Erasmus+ Programme of the European Union