Czech Technical University in Prague

Faculty of Electrical Engineering; Department of Economics, Management and Humanities

Analysis of installation of small wind turbine on premises

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Abstract

This project has three different ways of study, which explain the current situation of low wind power turbines.

The first target is to explain one of the newest technologies in this sector called Vortex Wind collector, which is going to be introduced in the wind turbine market focusing on low power. The operating analysis and the environmental impact of this kind of turbines are not clear yet because they only started to be promoted in facilities as prototype. There exist prototypes, which are being currently studied and this project is going to show some results, opinions and comparisons with other technologies until now.

Secondly, it is important to analyse the other technologies are being developed at the same time for comparing the efficiency and some economic features among them. This part of the study is focused on knowing the way to implement the Vortex technology in the most efficient way.

The last part covers the hypothesis of installing the Vortex turbine in a specific location under certain conditions in Madrid (Spain) and Prague (Czech Republic). The aim is to compare the turbine behaviour in each location and decide which is more profitable according to economic and production aspects. It is kept in mind the current Spanish and Czech law. Furthermore, it has been added a case study which determines what would be the optimal wind features for determining this kind of facilities as profitable investments.

Index

Picture index

Graph index

Table index

Equation index

List of abbreviations

AC: Alternate current

AEE: Asociación empresarial eólica; Wind bussines association

CWAT: Compact Wind Acceleration Turbines

˚C: Celsius degrees

dBA: decibels corrected or weighted for sensitivity of the human ear

DC: Direct current

DOE: Depends on experience

E.F: Electromotive force

EU: European Union

GHG: Green House Gases

HAWT: Horizontal axis wind turbine

IDAE: Instituto de diversificación y ahorro de la energía; Diversification and energy saving institute

LCA: Life Cycle Assestment

LCOE: Levelized cost of electricity

LPWS: Low Power Wind Systems

MPO: Ministerstvo Prumyslu a Obchodu; Ministry of Industry and Trade

OP EIC: Ministry of Industry and Trade

OP PIK: Operational Program Enterprise and Innovation for Competitiveness

PV: Photovoltaic panel

RPM: Revolutions per minute

TPA: Third-Party Access Contract

UNO: United Nations Organization

VAWT: Vertical axis wind turbine

1. Introduction

In the last decade, especially in Europe and in many parts of the rest of the world, issues such as the conservation of natural resources and the protection of the environment have reached great importance. One of the most famous topics in our society is the generation of energy environmental friendly and the efforts that must be promoted in order to articulate a more hopeful next for future generations. Therefore, one of the most significant achievements is, without doubt, the development of new attitudes regarding the rational use of energy that maximizes the use of renewable energies also called green or clean energies, such as wind, solar or hydraulic, that reduce the emissions of gases, which raise global warming.

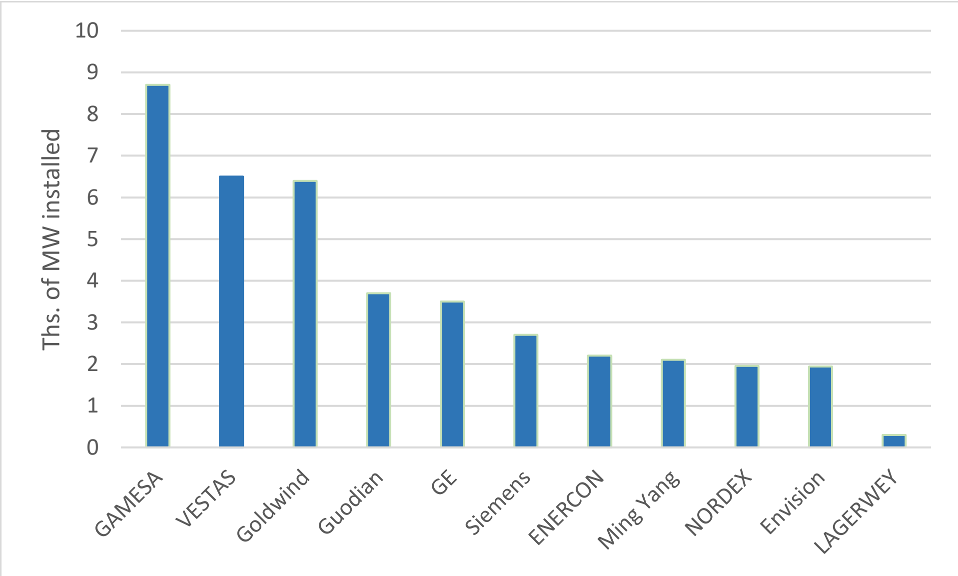
Another important aspect is the approach that each country has reached using and generating with alternative energies. There are policies proposed by world organizations (UNO) whose aim is to substantially reduce carbon dioxide emissions and promote environmental friendly policies [1], which have programs with specific objectives to increase the use of these renewable energies. In this context, in recent times there has been a strong impulse in the development and use of different generation technologies, particularly those related to renewable sources.

Regarding wind power generation systems, has increased notably in this last decade, it is not only among public opinion, also among the most reluctant sectors of the energy business [2]. Wind power is seen by the public as a source of local employment and a way of keeping the environment, without serious impacts on the environment. The great acceptance of this energy by public opinion along with the profitability of the facilities has contributed and is contributing to its rapid development.

1.0.1 Wind energy in Europe

The wind energy industry in Europe began in 1979 with the serial production of wind turbines by the manufacturers Kuriant, Vestas, Nordtank, and Bonus. Today there are more than 15 companies dedicated exclusively to the manufacture and assembly of turbines and wind turbines throughout the continent and it is important to highlight some names due to their volume of development in recent years as Acciona Windpower; Dwind; ALSTOM; Acciona Windpower; GAMESA; ENERCON or Siemens among many others [3]. The graph showed below represents the main world manufacturers in onshore technology.

Graph 1. Onshore turbine main manufacturers

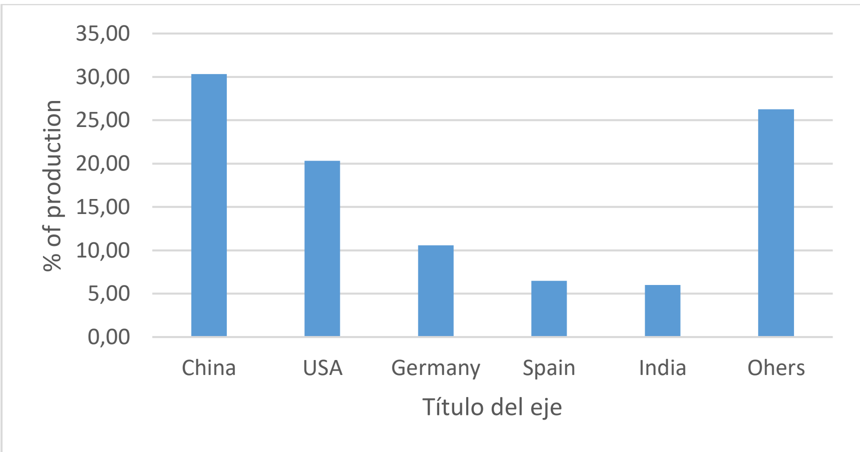


Source: Bloomberg new energy finance [4]

The technological level achieved from the beginning and the needs for electricity production, placed Europe from the nineties as the most developed wind energy producer which represents a total of 25% of the world power.

Nowadays the European Union (EU) represents 43% of installed wind power compared to the 55% that it was represented at the beginning of the century, the truth is that the energy use of the wind is no longer a matter of each continent. The incorporation of technologically powerful countries such as China, India, Australia or Canada have established a new world order in the development of electricity production using wind energy.

Graph 2. Largest country wind energy producers in 2016



Source: IDAE Instituto de diversificación y ahorro de la energía [5]

1.0.2 Situation about low power wind turbines

Small wind turbines are a great method of supplying renewable energy to small electric systems like households, buildings, small distribution systems or grid- off devices. When these devices are settled-up in favourable conditions they can provide clean energy in the most satisfying way.

Most of low power wind turbines have traditionally horizontal axis wind turbines but currently vertical axis wind turbines are a growing up in the small turbine markets as a type of wind generator. Manufacturers of vertical axis wind turbines such as WePower, Urban Green Energy, Helix Wind, and Windspire Energy, have reported increasing sales over the previous years [6].

In this project, it is going to take a look at the best small wind turbine systems available and which Small scale turbines for residential scale use are working right now and being competitive in the low power wind turbine markets.

Conventional low power wind blades are usually from 1.5 to 3.5 meters in diameter and are able to produce around 1 to 10 kW of electricity at their optimal wind speed [7]. Some units have been designed to be very lightweight in their construction, for instance, 16 kilograms, allowing sensitivity to minor wind movements and a quick response to wind gusts typically found in urban settings and easy installation process. It is claimed, and a few are certified, as being inaudible even a few feet under the turbine.

On the other hand, there exist vertical wind axis turbines, which have different features in comparation with the conventional ones. They are omnidirectional and do not need to track the wind. This means they don't require a complex mechanism and motors to yaw the rotor and pitch the blades. Furthermore, they have the ability to take advantage of turbulent and gusty winds because the structure suffers less when the wind hits it.

1.1 Motivation

The world is trying to change the energy model that, by guaranteeing the coverage of energy needs, do less aggressive activity with the environment.

It is betting on a progressive introduction of renewable energy sources as a generalized development keeping in mind the protection of the environment and measures control as: acid emissions, derivatives of the massive and uncontrolled use of coal and oil; increasing atmospheric carbon dioxide, whose most alarming consequence is the consequent increase in the greenhouse effect; decreasing the ozone layer and another serial problems, whose consequences could seriously alter both the climate and the quality of life on Earth.

The motivation of this project has been found within the framework of a developing technology application in energy generators. Because of the wind energy represents today one of the most economical and viable renewable energy sources, it is important to continue improving the wind turbine weakness.

In this project, wind bladeless turbine technology will be analysed for wind facilities which should still an economically viable alternative and competitive in comparation with conventional wind turbines, as well as of enormous interest from the social and environmental point of view.

The project of bladeless technology, allows to apply the knowledge of the entire wind generation process, as well as lessons learned during the academic years.

1.2 Main objective

- Explanation about the situation of Vortex wind turbine technology and business possibilities. It is pretended to present the main advantages and disadvantages which this new technology offers and give an opinion of which would be the best way to improve for being the one of the most competitive technologies in wind low power markets.

1.3 Specific objectives

- Comparison of wind potential (Spain and Czech Republic) for the suitability analysis of installing the Vortex low power turbine.

- Determining competitiveness of technologies in the low power wind turbine market.

- Study of environmental impact of the Vortex turbine from manufacture until the end of the lifetime

- Studying the Vortex wind turbine profitability for different scenarios.

1.4 Scope

The project is bounded to explanation of development about low power wind turbines using as base model Vortex technology until 100 W of nominal power.

There is a simply environmental study about the Vortex turbine life cycle which pretends to promote an overview of the technology impact.

It is included a case study about the comparison in the installation on Spain and Czech Republic with their own features and assumptions which are going to be explain in the proper chapter.

The results and conclusions are going to be settled with a particular opinion provided once the results have been obtained.

1.5 Methodology used

The project contains three different parts where it is possible to find a comparison research among different types of wind turbines currently available, environmental impact of the vortex turbine and a practical application of knowledge in the installation of the Vortex wind turbine in Madrid (Spain) and Prague (Czech Republic).

The structure of this study is divided in a theoretical and practical part. The first 2 chapters encompass the explanation of the new vortex technology and its components.

The chapter three is according to the analysis of the trending market in low power wind turbines, which are competitive against the vortex wind turbine.

The fourth chapter analyses the environmental impact of manufacturing the Vortex turbine based on simulated test developed by OpenLCA software.

Regarding the chapter number 5, is presented a case study about the comparison of wind potential between the implementation of Vortex technology in Spain and Czech Republic. It is kept into account the legislation and policies of each country according to renewables sources and wind features of each country. Furthermore, the economic analysis included in this part covers which would be the wind conditions for obtaining a profitable investment under the assumptions given.

The seventh chapter shows the main results and conclusions with an individual opinion about all the aspects covered in this project.

2. Vortex bladeless wind technology

The main idea of the vortex technology applied to wind energy absorption came from event occur in the Tacoma´s Bridge in 1938 [8]. The vibrational harmonic movement induced to a breaking activity in the bridge for failing in the measurement of the structure. If the energy generated for the proper movement of the bridge could have been collected and transformed into electric energy there would be an important energy source in that place. This is the origin the idea for the Spanish technology engineers, David Yañez and David Suriol also co-founders of the company Vortex Bladeless which develops the technology.

Vortex Bladeless is a technology that harnesses energy from one phenomena of vorticity called Vortex Shedding. Vortex Shedding is the process which vortices formed continuously by the aerodynamic conditions associated with a solid body in a gas or air stream which are carried downstream by the flow in the form of a vortex street

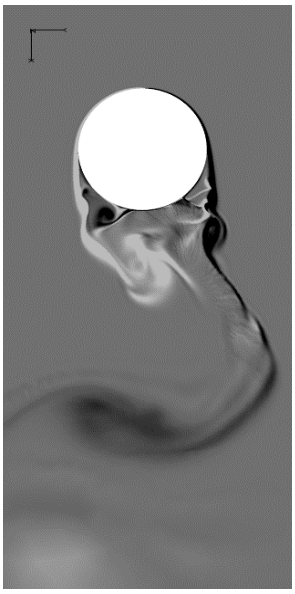
Vortex Bladeless consists on a conical cylinder fixed vertically with an elastic rod. The cylinder oscillates in the wind, which then generates electricity through a linear alternator system and then the electricity is used for low power distribution or self-consuming in small buildings [9].

2.1 Technical description

The outer conical cylinder is designed to be rigid and able to vibrate, remaining anchored to the bottom rod. The top of the cylinder is unconstrained and has the maximum amplitude of the oscillation. The structure is built using resins reinforced with carbon and/or glass fibre, materials used in conventional wind turbine blades.

The inner cylindrical rod, which may go through into the mast for 30% of its length, is anchored to it at its top and secured to the ground at its bottom part. It is built with carbon fibre, which provides the highest resistance to fatigue and has good mechanical quality factor allowing its elasticity to absorb the vibrations generated by the cylinder.

The device captures the energy of a vorticity phenomena, an aerodynamic effect called vortex shedding. As the wind passes through a blunt body, the flow is modified and generates a cyclical pattern of vortices. Once these forces are strong enough, the body starts to oscillate, and enter into resonance with the lateral forces of the wind. This is also known as Vortex Induced Vibration.



Picture 1. Vortex shedding phenome

Source: Vortex Bladeless [10]

Instead of avoiding these aerodynamic instabilities, the technology maximizes the resulting oscillation and captures the energy. Naturally, the design of such device is completely different from a traditional turbine. Instead of the usual tower, nacelle and blades, the device has a fixed, lightweight rigid mast made of fibreglass, anchored to a hollow and flexible rod made of carbon fibre fixed in its bottom end to the ground.

Based on these principles, and bearing in mind some other physical phenomena, such as Boltzmann law, finite bodies aerodynamics, turbulence regions and others.

Creating computational models that help to develop and improve the efficiency of Vortex.

2.2 The alternator

The electric machine must transform the mechanic energy created from movement into electric energy, generating AC current through electromagnetic induction.

The principle of the alternator operation is based in the electromotive force, which is a difference in potential that tends to give rise to an electric current.

When the magnetic field variates according to the time and there exist movement inside the electric circuit, the induced E.F. is equal to the sum of the force variations of each time and each movement.

Mathematically can be expressed as:

$$\varepsilon = \int_T Eef\, dl = \int_T (v\ x\ B) dl - \int_T \frac{\delta B}{\delta t} dS$$

Equation 1. Electromotive circulation

The first part of the equation is related with the movement and the second with the variation of the magnetic field according to the time. Both terms can be expressed as electromagnetic flow variation where the E.F would be:

$$\varepsilon = -\frac{\delta \phi}{\delta t}$$

Equation 2. Electromotive definition

The equation showed before is the expression to describe the Faraday Law [11].

Vortex generates electricity through an alternator system, made by coils and magnets, adapted to the vortex dynamics, without gears or any moving parts in contact. Although the generator technology is system innovative and patented. The solution does not use any kind of gear and is supported by a special procedure called theory of Rings Repulsion.

As it is explained before the device is designed with no moving parts in contact which discards the needs for greasing and maintenance. In any case, the preliminary tests show electrical conversion yields of about 70 % to 85 % of those obtained by a conventional rotary alternator.

Components of the alternator

The alternator has general components, which can be used for transforming the mechanical in electric energy. In this case, the mechanical energy comes from the movement of the wind passing through the structure of the stick:

The mobile part of the alternator, formed by an electromagnet that receives current from the regulator, through the rings, which are on the shaft. This electromagnet produces a magnetic field that reacts in the stator coils producing electric current.

The regulator is responsible for maintaining a maximum output voltage of the alternator. The higher the revolutions per minute (RPM) the greater the magnetic field and the more voltage is produced, which is why at higher RPM it supplies less current to the rotor (inductor).

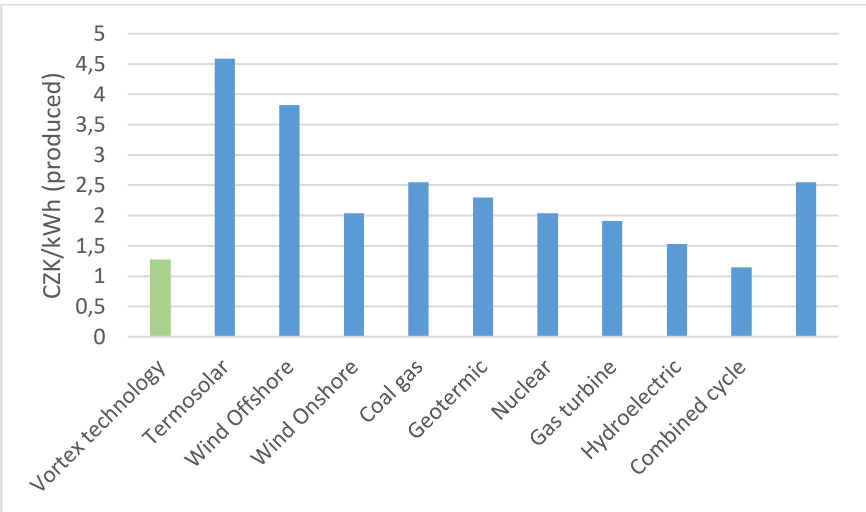
Stator is the fixed part on which the three phase winding is located. This can be constituted as star or triangle. The winding formed by the conductors of the shield is generally constituted by three separate windings and distributed perfectly isolated in slots forming the stator. These three windings, or phases of the alternator, can be connected according to the type: in star or in triangle, obtaining in both forms a three-phase alternating current, at the output of their terminals [12].

2.3 Economy description

One of the main advantages of Vortex are the low costs associated to the technology. In fact, the levelized cost of energy generation (LCOE) for a typical onshore facility is 35 €/MWh (about 900 CZK/MWh), including capital costs, operation and maintenance, performance, land leases, insurance and other administrative expenses [13].

This put the technology at the very low range of capital intensity for such projects; it also makes it highly competitive not only against generations of alternative or renewable energy, but even compared to conventional technologies, as shown in the graph below.

Graph 3. Specific cost for producing one kWh



Source: Vortex Technology Company [13]

The direct comparison should be done with Wind Onshore sources because until now, Vortex technology prototypes have been only installed on the land. It is important to remind that the most important fact for the comparison of other source technologies depends directly on the lifetime of the facilities.

It is important to highlight that there exist projects in parallel where it is possible to find Vortex devices prototypes on the sea, for instance, in United States but it is not one of the targets of this particular project so it is not going to compare this technology with offshore sources. Therefore, information about it can be found in the web space according to this reference [14].

2.3 Grid connections

The connections to the grid for low power Vortex wind turbines are described similarly to a photovoltaic panel connection.

A grid connected low power facility is an electricity system generated from wind that is connected to the utility grid. Grid connected low power wind systems always have a connection to the public electricity grid via a suitable device. As well as the solar panels, the additional components that make up a grid connected low power wind system compared to an isolated wind system are:

Inverter device for switching from AC generated by the wind turbine to DC to feed batteries or storage systems in case it is needed.

Electricity meter also called a Kilowatt hour (kWh) is used to record the flow of electricity to and from the grid. Twin kWh meters can be used, one to indicate the electrical energy being consumed and the other to record the wind electricity being sent to the grid. A single bidirectional kWh meter can also be used to indicate the net amount of electricity taken from the grid. A grid connected PV system will slow down or halt the aluminium disc in the electric meter and may cause it to spin backwards. This is generally referred to as net metering.

Low power wind system array will produce a voltage output in special conditions so it must be possible to disconnect it from the inverter for maintenance or testing with the proper safety switches and cabling features. Isolator switches rated for the maximum DC voltage and current of the array and inverter safety switches must be provided separately with easy access to disconnect the system. Other safety features demanded by the electrical company may include grounding and fuses. The electrical cables used to connect the various components must also be correctly rated and sized.

The facility consists on many devices as: Low power turbines, one or several inverters, also includes power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility scale solar power stations. Unlike stand-alone power systems, a grid connected system rarely includes an integrated battery solution, as they are still on of the most expensive devices. When conditions are right, the grid connected wind system supplies the excess power, beyond consumption by the connected load, to the utility grid.

A grid-connected wind turbine can reduce the consumption of utility-supplied electricity for lighting, appliances and electric heat. If the turbine cannot deliver the amount of energy needed, the utility makes up the difference. When the wind system produces more electricity than the household requires, the excess is sent or sold to the utility. With this type of grid connection, the wind turbine will operate only when the utility grid is available. During power outages, the wind turbine is required to shut down due to safety concerns.

Grid-connected systems can be practical if the following conditions exist:

- Living in an area where the average annual wind speed of at least 6.5 meters per second.
- Utility supplied electricity would be unusual expensive in the area.

The utility requirements for connecting the system to its grid are not prohibitively expensive. In some countries, there are good incentives for the sale of excess electricity or for the purchase of wind turbines. Nacional regulations (specifically, the Public Utility Regulatory Policies) require utilities to connect with and purchase power from small wind energy systems. However, it should contact the installation before connecting to its distribution lines to address any power quality and safety concerns. [15]

Wind power can be used also in off grid systems, also called stand-alone systems (Isolated power systems), not connected to an electric distribution system or grid. In these applications, small wind electric systems can be used in combination with other components, including a small solar electric system, to create hybrid power systems.

Hybrid power systems can provide reliable off-grid power for homes, farms, or even entire communities (Cohousing projects) that are far from the nearest utility lines.

Cohousing is an intentional community of private homes clustered around shared space. Each attached or single-family home has traditional amenities, including a private kitchen. Shared spaces typically feature a common house, which may include a large kitchen and dining area, laundry, and recreational spaces. Shared outdoor space may include parking, walkways, open space, and gardens. Neighbours also share resources like tools and lawnmowers. [16]

2.4 Technical implementation

The theoretical implementation of the wind Vortex collector device is easy to install due to it is not necessary to have a complex basement before to fix the structure.

The main advantage of the vortex stick is that it is not needed to have high wind speed, which facilitates the choosing place for installing the device. Furthermore, it is not necessary keep in mind the continuously orientation of the stick against the wind direction because is based in an harmonic movement and it can be all over the 360 degrees.

Small wind turbines used in residential applications typically range in size from 400 watts to 20 kilowatts (specially installed for farms or isolated facilities in self consuming systems), depending on the amount of electricity it is wanted to generate.

Households consume approximately an average of 10.000 kWh/year of electricity (about 830 kWh per month) [17]. Depending on the average wind speed in the area, a wind turbine rated in the range of 5 to 15 kilowatts would be required to make a significant contribution to this demand. A 1.5 kW wind turbine will meet the needs of a home requiring 300 kilowatt-hours per month in a location with 6.26 meters per second annual average wind speed.

Helping to determine what size turbine is the most proper, it is needed first to establish an energy budget. Because energy efficiency is usually less expensive than energy production, reducing home's electricity use will probably be more cost effective and will reduce the size of the wind turbine according to the customer needs.

The height of a wind turbine tower also affects to the quantity of electricity the turbine is able to generate. A manufacturer should help determining the features as the tower height needed and estimating the energy production expected.

Regarding the energy output required an estimate of the annual energy output from a wind turbine is the best way to determine whether it and the tower will produce enough electricity to meet the needs.

A wind turbine manufacturer can help to estimate the energy production expected. The manufacturer will use a calculation based on these factors:

- Particular wind turbine operating curve
- Average annual wind speed in the location
- Height of the tower planned for using

In addition, it is required a frequency study of the wind estimating the number of hours that the wind will blow at each speed during an average year.

The manufacturer should also adjust the calculation for the elevation of the site. To get a preliminary estimation of the performance of a wind turbine, it can be use the following formula:

$$AEO = 0.01328 * D^2 * V^3$$

Equation 3. Performance of wind behaviour.

Where:

- AEO = Annual energy output (kilowatt-hours/year)
- D = Rotor diameter, (m)
- V = Annual average wind speed, meter per hour (mph), in the location [18]

For the special measurement of wind potential for Vortex technology it is important to keep in mind the physical vorticity laws on flows, because it is not a conventional wind turbine. In the attachment of this project, it can be found a briefly explanation about the basics of this knowledge.

3. Market analysis of low power wind technologies

Low power wind turbines are a great method of supplying renewable energy to households, industrial facilities or other grid off systems when it is required. When set up is in favourable conditions they can provide clean energy in the most satisfying way.

Researching the best small wind turbine systems available right now, it is going to show the features of each technology where it is possible to compare the systems, and there are more detailed reviews following that. It has included home wind turbine kits that start at 100 Watts and go all the way up to 1600 Watts.

Beginning with the explanation is important to explain that exist two main groups of low power wind turbines: horizontal and vertical axis.

Horizontal axis wind turbines are the most common type used. All the components (blades, shaft, and generator) are on top of a tower, and the blades face into the wind. The shaft is horizontal to the ground. The wind hits the blades of the turbine that are connected to a shaft causing rotation. The shaft has a gear on the end which turns a generator. The generator produces electricity and sends the electricity into the power grid. The wind turbine also has some key elements that adds to efficiency. Inside the Nacelle (or head) is an anemometer, wind vane, and controller that read the speed and direction of the wind. As the wind changes direction, a motor (yaw motor) turns the nacelle so the blades are always facing the wind. The power source also comes with a safety feature. In case of extreme wind, the turbine has a break that can slow the shaft speed. This is to inhibit any damage to the turbine in extreme conditions [19].

Advantages

- Blades are to the side of the turbines center of gravity, helping stability
- Ability to wing warp, which gives the turbine blades the best angle of attack
- Ability to pitch the rotor blades in a storm to minimize damage
- Tower allows access to stronger wind in sites with wind shear
- Tower allows placement on uneven land or in offshore locations
- Can be sited in forest above tree-line
- Most are self-starting

Disadvantages

- Difficulty operating in near ground winds
- Difficult to transport (20% of equipment costs)
- Difficult to install (require tall cranes and skilled operators)
- Effect radar in proximity
- Local opposition to aesthetics

- Difficult maintenance

In vertical axis turbines the shaft and the blades are connected from its vertical structure to the ground. The main components are close to the ground. In addition, the wind turbine itself is near the ground, opposite to the horizontal one where everything is on a tower.

Inside the vertical wind technologies, there are two subtypes: Lift based and drag based. Lift based designs are generally much more efficient than drag.

The direct comparison between horizontal and vertical can easily observed almost without any experiment. The list which is going to be shown below analyses the results about the features of vertical against the horizontal axis.

Advantages

- Easy to maintain
- Lower construction and transportation costs
- Not directional
- Most effective at mesas, hilltops, ridgelines and passes

Disadvantages

- Blades constantly spinning back into the wind causing drag
- Less efficient
- Operate in lower, more turbulent wind
- Low starting torque and may require energy to start turning in some vertical types

Ducted wind turbines are positioned at the edge of the roof of a building and use the wind flow along a buildings side. Hugging the building wall then enters in the front of the duct. The devices are relatively small leaving little visual impact to the building [20].

The features which are going to be explained are the results of comparing the advantages and disadvantages about the foundation and location of VAWT against HAWT.

Advantages

- Less visual impact on buildings architecture than traditional HAW turbines
- Make use of unused roof space in cities
- Allows energy need to be met on-site avoiding transmission losses associated with centralized energy generation

Disadvantages

- Suitable for urban environments, but not households (only effective on urban high-rise buildings)

- Unidirectional. Fixed position and are dependent upon wind blowing in the correct direction
- Much more research and development is needed. Research in this field is growing as people become more interested in urban wind generation.
- Research has to be done to determine energy production potential

3.1 Comparison method

The analytical method used for the research and comparison of the different low power wind turbines is going to be according to the effectiveness, investments, operating costs and the output energy supply.

To assess the total possible electricity production, the grid-connected wind turbines are considered at the position where wind conditions are best for particular location.

It is important to highlight that not all the turbine models have the same nominal power that is why it is not going to compare directly for a specific customer who has to decide in which device would invest

The impact of different wind turbine characteristics on the total electricity production, investment price and economic feasibility, the data on the wind turbines available on the market have been gathered and analysed. It must be stressed that the small wind turbine market is expected to grow, while different producers are entering the market and numerous small wind turbines already exist. The analysis encompasses the most renounced small wind turbine producers, as well as those freely marketing their products, although it does not give deeper insight into the market situation.

The power curve shape and the turbine rated power are important factors to determine the annual volume of electricity produced. Locations with the same average wind speed but differing in wind speed probability distributions, can achieve higher performances using turbines with different power curves even if their rated power is the same. However, at the same location, a turbine with a lower rated power but with a more favourable power curve shape can yield more electricity than a turbine with a larger rated power but a suboptimal power curve shape.

The income of a wind facility is proportional to the amount of electricity it produces over the installation lifetime (determined by the turbine characteristics and wind characteristics at a given location) and the price of electricity, which is beyond the investors' control. In general, the primary expenditures of a wind power plant are related to its up-front investment, while the plant's operation and maintenance costs are usually not significant. The main part of the initial investment is the wind turbine itself and the system balance (structure and converter)

The small wind turbine market is in its early stage of trading and there are significant discrepancies between turbine manufacturers. The most important factors are the differences in specific rated power and the rated power relative to the rotor swept area.

Furthermore, in parallel to the wind turbine rated power and its price, the wind power curve and its swept area in relation to the nominal power should be considered in order to reach an overall better decision on investment.

Additionally, the importance of finding the appropriate power curve is confirmed by the obtained results, indicating that without independent power curve testing no wind turbine should be considered for wider application.

To evaluate the features of the different low power wind turbines is going to assume the main economic aspects which show each generator due to their different technical aspects:

Investment: The act of putting money, effort or time mainly, into something to make a profit, get an advantage, get the money, effort or time used to do this.

Specific unit cost: It is the amount of money, which is needed to produce an unit of energy with the specific technology.

Minimum price sold: Price offered to the customer for maintaining the business minimum profitable or not making losses.

Operating costs: Expenses associated with the maintenance and administration of a business on a short term basis.

Lifetime: Useful period of time which the device is expected to work.

3.2 Horizontal shaft wind turbine

The features of horizontal axis wind turbines (HAWT) are that have the main rotor shaft and electrical generator at the top of a tower, and may be pointed into or out of the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

There exist many brands which produce low power wind turbines:

3.2.1 Gearless blade tip (Developed by WindTronics)

Technology based on the better wind speed is greater at the tips of the blades. WindTronics capitalized on this aspect of wind power, by designing their Gearless Blade Tip Power System, is a unique design that allows the turbine to quickly react to wind speed changes, thus maximizing its energy capture. Using a gearless direct drive design, the turbine’s small magnets located at the tips of its blades capture wind where it is greatest while virtually eliminating mechanical resistance and drag by foregoing the need to turn an internal generator. Instead, power is generated when the blade tip magnets spin around its perimeter frame.

Picture 2. Gearless Blade Tip power system

Source: Solaripedia [21]

WindTronics wind turbine utilizes a system of magnets and stators surrounding its outer ring capturing power at the blade tips where speed is greatest, practically eliminating mechanical resistance and drag. Rather than forcing the available wind to turn a generator, the perimeter power system becomes the generator by swiftly passing the blade tip magnets through the copper coil banks mounted onto the enclosed perimeter frame. The Blade Tip Power System addresses past constraints such as size, noise, vibration and output.

The turbine data for energy generation is measured for wind speeds at steady state, (10 meters high, unobstructed) however many factors will affect the output of the turbine at each location depending on placement.

The location can be affected by trees, terrain and obstructions such as buildings next door, even placement on one end of a building or the other can affect the output. Correct site assessment is important to enhance the performance of the turbine regardless of the product choice.

Picture 3.Gearless turbine device installation

Source: Energy efficient choices blog [22]

Summarising, It is important to seek the highest elevation and lowest obstruction field as possible 10 meters minimum [23].

WindTronics company systems are breaking traditional technological barriers across multiple markets, for homes and businesses, for both energy generation and energy recapture even in moderate winds.

Electrical connection is very similar to a backup generator connected to the building or solar power to the grid.

An average annual wind rating from 14.5 m/s would be recommended as a good minimum wind speed to keep in mind on systems connected to the grid. However, for the case of isolated systems (off grid locations) might consider less [24].

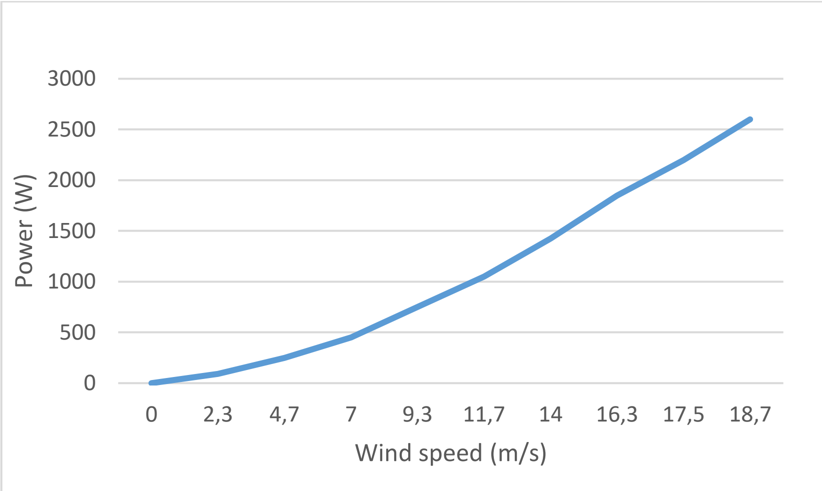
The Blade Tip Power System addresses past constraints such as size, noise, vibration and output. The enclosed perimeter shrouds the system and is more distinguishable to wildlife.

The main features of this turbine which is based in the model BTPS6500 and can be summarised as [25]:

- It has a breakthrough wind energy system for home and business for collecting the wind energy and transformed in electric energy with DC connected system to buildings and households
- Energy can be stored in utility batteries of 12/24/48V
- The turbine offers different ways and models to mounting the device but the standard HAWT is at 64 kg and 1.8 m versatile.
- For the case of Grid tie connected is necessary to install 1 to 3 turbines with direct DC 12/24/48 V battery charging
- Non-Grid tie connects to the building Flat Roof, which is the most commercial product, and includes all the specific devices required for Residential electricity uses.
- Available for all environments from hot to cold temperatures (-30 to 60 ˚C) and from coastal locations to mountaintops.

This turbine model is billed as the “highest output, lowest cost per kWh installed turbine in class and size” developed by Windtronics. The turbine can start-up at a speed of 0.2 m/s, a mere wisp of wind, and generate electricity between 0.9 to 20 meters per second. That compared to traditional gearbox turbines that require minimum start up speeds of 3.35 meters per second means this gearless model is capturing a lot of wind when other turbines aren’t. In addition to its extremely low start-up speed, Windtronics claims their turbine performs without the same amount of noise and vibration as a traditional wind turbine.

Graph 4. Power curve Gearless blade tip



Source: Windtronics catalogue [26]

The cut in wind speed for this kind of turbines is around 0.2 meters per second depending on the model. As it is mentioned before all technologies have been shown based on models of the main manufacturers.

The cut-out speed (18.5 m/s) which is the maximum wind speed at which the turbine is allowed to deliver power, limited by engineering design and safety constraints. Power curves for existing machines can normally be obtained from the manufacturer, derived from field tests using standardized testing methods. The process of determination of power characteristics of the wind turbine components and their efficiencies is always very complex because of the factors affecting to the measurements.

The working range (from 0.2 to 18.5 m/s) of this turbine makes it one of the most competitive in the current market.

3.2.2 Compact wind acceleration technology (Developed by Optiwind)

Optiwind was a venture backed start-up that developed a new class of wind turbine with a simple purpose to deliver commercial scale, on-site electricity for an unsubsidized cost that is lower than the local grid.

Beginning in 2007, the company designed and built its first full scale prototype in Connecticut and developed a licensing model to distribute this breakthrough technology around the world. With a focus on commercial and institutional customers, Optiwind 300 kW wind turbines were designed to produce up to 1 MWh of power per year and due to their ultra low cost, ease of installation, and limited service requirement, could even be installed in remote areas with relatively low wind speeds where power wasn't previously available.

The Optiwind turbine was specifically engineered for use in populated areas with slow, class 2 wind speeds, around 5.4 m/s. This turbine increases the amount of wind power generated by 75 percent using an innovative wind acceleration technology.

Traditional three blade turbines are great if there exist lots of space to play with, but the Compact Wind Accelerating Turbine is ideal for high density and low wind areas. The series of small turbines, five bladed fans funnel in wind and accelerate it, thereby cranking up wind speeds to generate more power.

Picture 4. Compact wind accelerating turbine

Source: Inhabitant paper [27]

This new technology offers additional benefits. The turbines do not need to be high size to generate electricity, the small blades are not as likely to harm birds and bats since they are only as wide as the tower, and the turbine is quiet and simple to operate.

Designers and manufacturers of Compact Wind Acceleration Turbines (CWAT), a revolutionary device that captures and utilizes wind energy in a more efficient and cost effective manner than conventional turbines. The quiet, compact, and simple Optiwind 150 model, generates 250 megawatt hours of electricity per year, making it ideal for onsite applications like schools and healthcare facilities [28].

Nowadays, Optiwind company closed its doors and went out of the market but is important to highlight that its technology is still valid especially in farms and spaces with isolated systems.

Compact wind acceleration technology is focused on isolated households as can be seen in United states where the grid is not enough for covering all the demand and it is needed extra electricity generation for consuming in water pumps or light systems on buildings where are not used to live like farms, summer houses.

The operating curve for this kind of turbine is not showed because manufacturers and developers of this technology determined that it is not profitable according to the current market conditions. As it is explained before, wind accelerating technology requires huge spaces which are only reached in landscapes for feeding farms or off- grid places.

3.2.3 Multiple rotor

Though larger rotors capture more wind, they are much heavier. Selsam designers believe that since the slower rate of rotation does not make the greater wind capture worthwhile, they designed a system with multiple small, light rotors mounted on a single driveshaft.

The shaft is pointed downwards and the rotors are sufficiently spaced apart so that each rotor receives fresh wind. The model generated the same amount of power at half the wind speed as a typical horizontal turbine. At the same wind speed, six times as much.

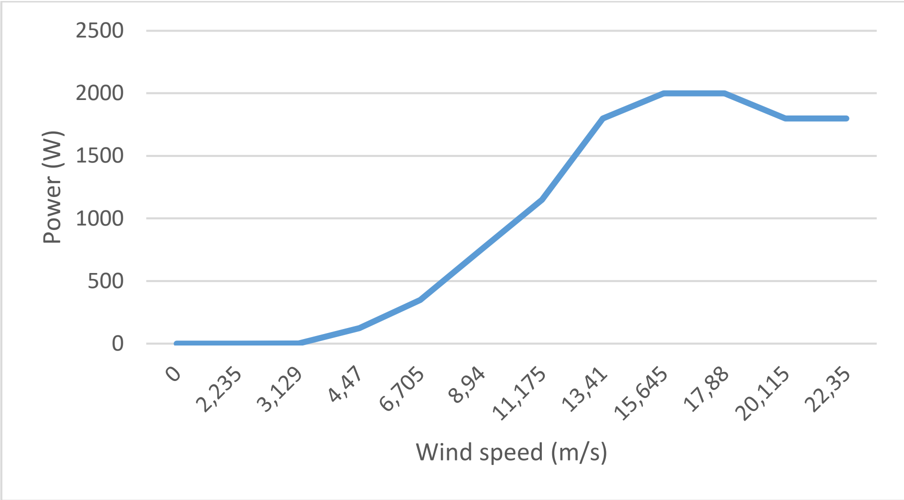
Picture 5. Multi rotor low power turbine

Source: Selsam company [29]

There have been several attempts to develop modern scaling models for HAWTs. However, wind turbines have changed in size and configuration so rapidly, many models are out of date before they can be used effectively by designers. Currently the configuration for utility scale turbines began to stabilize around the three bladed, upwind design.

The most common model tested with this technology is the California SuperTwinTM developed by Selsam, it has around 13 square meters. This turbine is a serious power producer and could potentially power most or all of a whole cottage or small home that conserves well, in a high wind area. The power rating is 2000 Watts according to making real, serious power. "Swept area" is the first factor that determines output having dual rotors doubles the swept area. SuperTwinTM generates more power than similar sized turbines even claim, let alone deliver [30].

Graph 5. Operating curve multirotor technology model



Source: Selsam company [31]

The cut in wind speed for this kind of turbines is around 3.2 meters per second depending on the model. As it is mentioned before all technologies have been shown based on models of the main manufacturers.

The cut-out speed (22.35 m/s) which is the maximum wind speed at which the turbine is allowed to deliver power, limited by engineering design and safety constraints. As it is well-known power curves are obtained from the manufacturer. The process of determination of power features of the wind turbine components and their efficiencies depends on many factors which can change each standard condition used by the developer.

3.2.4 Direct-drive

The D400 is a direct-drive wind generator, designed for a variety of marine, rooftop or terrestrial applications. It is exceptionally quiet and vibration free in operation, qualities that are of paramount importance for any wind generator operating in close proximity to people.

The features of this model contain a powerful 3 phase alternator and computer designed rotor blades optimized for low speed, friendly user operation. This innovative machine is extremely efficient in low wind speeds, yet is capable of sustained high power outputs of up to 500 Watts in higher winds.

Regarding rooftop installations, the D400 computer designed rotor blades that are specifically optimized for low speed operation run a 400-Watt direct drive generator [32].

In testing done by yachtsmen off the United Kingdom south coast, an area with average wind speed of 4.63 m/s, the D400 outperformed the other eight turbines tested. Its output was more than double the next best turbine, despite being smaller. The manufacturer also claims that this model is extremely silent and vibration-free, making it a safe bet for the rooftop.

Picture 6. Five blades wind turbine model

Source: Eclectic energy company [33]

US, Germany, China, Spain and India collectively account for more than 50% share of the global installed base. Emerging markets like Asia Pacific and Eastern Europe will gain considerable market share during the forecast period. Latin America is a nascent market.

Rapid technological advancements, improvements in the generator technology along with the strong economic growth and governmental initiatives will lead the direct drive wind turbine market to expand at a robust CAGR during the forecast period from 2015 to 2025 [34].

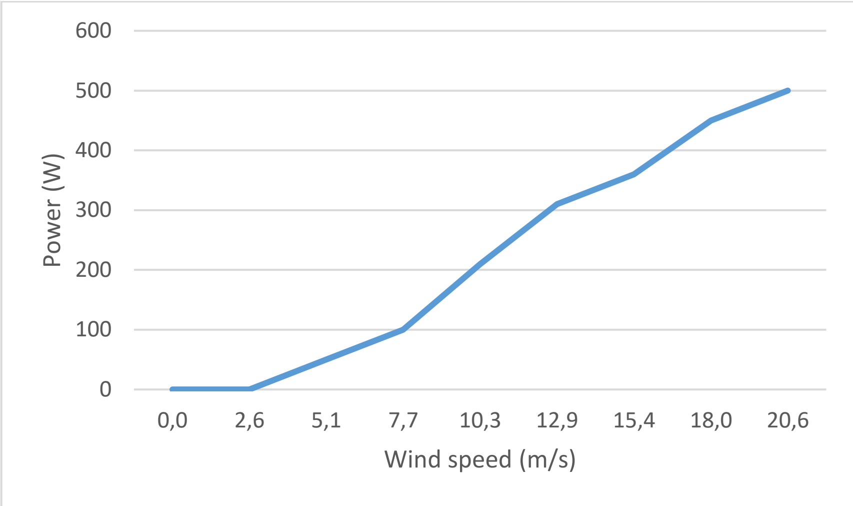
Picture 7. D400 installation on households

Source: Energy and buildings. [35]

The main features of the D400 turbine are:

- Five micro blades (1.1 meters diameter)
- Virtually silent and vibration free in operation
- High efficient and productive at all wind speeds
- Low maintenance ‘fit and forget’ engineering
- Robust constructed for a long service life
- Corrosion-resistant materials used throughout
- Flexible mount tower options

Graph 6. Operating curve direct drive technology



Source: Renewables energies [36]

As can be seen in the table above, the engine starts to work from 2.6 m/s of wind speed. It is recommended to disconnect at 20.5 m/s for technical aspects of the turbine.

3.2.5 Micro wind turbine

Made specifically for low wind performance, the Wren utilizes low TSR rotor blades proven to perform in 8 m/s winds to power its small direct drive micro turbine. Being a micro turbine, this model provides limited power, making it an ideal choice for applications such as powering an electric fence.

The most popular model for this kind of turbines is LE-300 manufactured by Wren. The Small Wind Turbine is an extremely lightweight and attractive micro wind generator. Furthermore, it is a very affordable, extremely sturdy and suitable for both domestic and small-business uses as well as for powering signalling or measuring equipment, webcams, weather cams, weather stations, caravans and remote cabins [37].

Picture 8. Standar microwind turbine

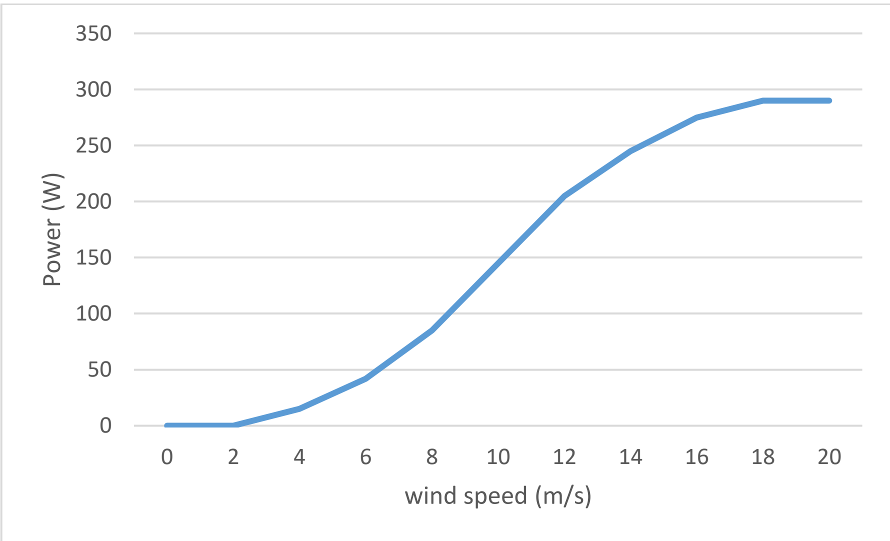
Source: Voltec Energy Company [38]

The Wren small size makes for an attractive, low profile design. Despite its small stature, this sturdy turbine can handle severe weather conditions, all the while running smoothly and silently.

Micro wind turbines can be very powerful, but as they are very sensitive to wind speed they produce very little power at low wind speeds or none. This can be a problem for off grid installations. They also require an area of high enough average wind speed that is not near any obstacles such as trees or buildings which can reduce wind speed. Planning issues can be a problem as they often need to be sited on promontories where wind speed is higher but this increases their visual disruption to the landscape [39].

Smaller turbines, in a random region of a few kilowatts could not have cut out wind speeds but the aerodynamics of the blades mean they become less efficient at high wind speeds. This is the reason for the drop in power production of both power curves at high wind speeds [40].

Graph 7. Operating curve microwind technology



Source: Leading Edge [41]

The cut in point in the working curve of this model is around 2.2 m/s wind speed. This kind of technology represents the conventional wind generators used for power plants used for individual customers (in low power) which means that it is the most developed technology in the current market.

The typical cut out for this turbine type is 20 m/s at the maximum power production around 300 Watts.

3.3 Vertical shaft wind turbine

The micro wind market has taken its share of lumps in the past, but the industry has developed new standards in recent years with an assist from the United States Energy Department and other stakeholders.

The average onshore wind turbine is a good source of energy, but the same cannot be said of their smaller cousins. To some, the smaller, cylindrical wind turbines are too inefficient to be of any real use. To others, that need not be the case. It is asserted that well designed vertical axis wind turbines can be useful in urban and suburban settings. Not just in terms of performance capabilities, but in monetary benefits as well [42].

The basic working of a fluid turbine comprises a rotor rotatable in use about an axis transverse to the direction of fluid flow. The rotor has a first part carrying a plurality of arcuate blades and a second part installed in a base structure by means of two or more bearings. All the bearings are arranged on the same side of the blades so that the first part of the rotor is cantilever supported in the base structure.

3.3.1 Savonius rotor wind turbine

The Savonius rotor is widely considered to be a drag-driven device. This indicates that the wind drag, acting on its blades, is the only driving force. However, it has been observed that at low angles of attack the lift force also contributes to the overall torque generation.

Picture 9. Savonius low power turbine

Source: Egerdach. Youtube platform [43]

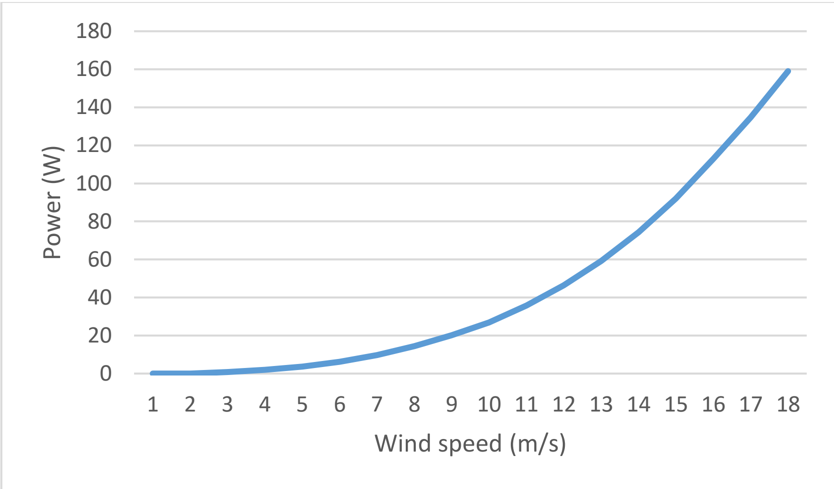
The main advantages of this type against the horizontal shaft turbines are [44]:

- Independence on wind direction, no additional control mechanisms are required
- Ability to operate in a wide range of wind conditions (turbulence level, wind speed)
- Electrical equipment can be placed at ground level
- Low noise emission
- High starting torque
- Compact size
- Simple and cheap construction

The use of Savonius wind turbines in micro power generation is within of this context, but it is still not widespread. The Savonius turbines have been proposed as an alternative, considering the distributed power generation. Recent studies on Savonius wind turbines are developed with this purpose, as the research presented by Menet [45], where a prototype of a Savonius turbine is developed.

Results of the experiments indicated the relationships between wind speeds and tip speed ratio or actual torque shows that the three blades wind turbine model has the highest tip speed ratio. In general, the three wind turbine models have significant tip speed ratio at lower wind speed and more stable at wind speed of 7 m/s. It means that the wind turbine model has optimal rotational speed at the wind speed above 7 m/s.

Graph 8. Savonius operating curve



Source: Democritus University of Thrace, School of Engineering [46]

The approximation of the operating curve for this kind of turbines depends on the manufacturer, because Savonius turbine is used more as prototype for developing other VAWT than for using as unique technology inside the device.

3.3.2 Daerrius rotor wind turbine

A Darrieus is a type of vertical axis wind turbine generator. Unlike the Savonius wind turbine, the Darrieus is a lift type VAWT. Rather than collecting the wind in cups dragging the turbine around, a Darrieus uses lift forces generated by the wind hitting aerofoils to create rotation.

When the rotor is stationary, no net rotational force arises, even if the wind speed rises quite high, the rotor must already be spinning to generate torque. Thus, the design is not normally self-starting. Under rare conditions, Darrieus rotors can self-start, so some form of brake is required to hold it when stopped.

Darrieus wind turbines are not usually have 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 aerofoils starts to generate torque and the rotor is driven around by the wind. The alternative to solve this problem is to add two small Savonius rotors which would be mounted on the shaft of the Darrieus turbine to start rotation. These slow down the Darrieus turbine when it gets going however they make the whole device a lot simpler and easier to maintain.

One problem with the design is that the angle of attack changes as the turbine spins, so each blade generates its maximum torque at two points on its cycle (front and back of the turbine). This leads to a sinusoidal (pulsing) power cycle that complicates design. In addition, almost all Darrieus turbines have resonant modes where, at a particular rotational speed, the pulsing is at a natural frequency of the blades that can cause them to (eventually) break. For this reason, most Darrieus turbines have mechanical brakes or other speed control devices to keep the turbine from spinning at these speeds for any lengthy period.

Another problem arises because most of the mass of the rotating mechanism is at the periphery rather than at the hub, as it is with a propeller. This leads to very high centrifugal stresses on the mechanism, which must be stronger and heavier than otherwise to withstand them [47].

picture 10. Daerrius wind turbine in a farm

Source: Pinterest company (Italy) [48]

There is not any type of micro wind turbine model using this technology due to the complex set up. It is thought that is important to mention the existence of this technology for explaining the next one (Hybrid Savonius- Daerrius) which is based on the mix of these two vertical axis technologies explained before.

3.3.3 Hybrid Savonius- Daerrius rotor wind turbine

As is mentioned at the beginning of vertical axes chapter there are two fundamental ways that a vertical axis wind turbine converts a passing wind into rotation and they are either being pushed by the wind, or using the lift the wind provides to turn. A good example of a vertical axis wind turbine that is pushed by the wind is the Savonius wind turbine. This style of vertical turbine uses a series of scoops to catch the passing wind and rotate its central shaft. A Savonius wind turbine is used in situations where reliability is essential since the design provides for a very consistent operation. Several models of recent turbine designs are based on the concepts first introduced with the Savonius wind turbine.

The other popular style of vertical wind turbine is based on lift and a good example of this is the Darrieus wind turbine design. Unlike the Savonius design that relies on blocking the wind to provide the energy for its rotation, the Darrieus wind turbine design uses the lift of the wind to provide rotation. Its blades are engineered to catch the upward thrust of a breeze and will spin in response to this lift.

The challenge with the Darrieus wind turbine design is that it is not a self starting turbine. This means that it can't generate enough power to start rotating on its own and needs to have a little help getting started. Most of these styles of turbine use a small motor to start this rotation and then the Darrieus wind turbine will spin on its own as long as a breeze is blowing.

Some of the newer versions combine the two designs and use a small Savonius wind turbine mounted on the shaft of a Darrieus wind turbine to provide the initial spin and then the lift takes over from there. The advantage that the Darrieus wind turbine has over other models is that its blades can spin faster than the wind that is passing. This gives it a very high rotation and is perfect for generating power as a result.

The hybrid turbine has the Darrieus rotor on the main device, and the Savonius rotor combined permanently to the same axis as a start-up device. In order to obtain good start-up characteristics regardless of the wind direction, the Savonius rotor is divided into two (upper and lower), with the two parts having an attachment angle separated by 90° [49].

3.3.4 Helical rotor wind turbine

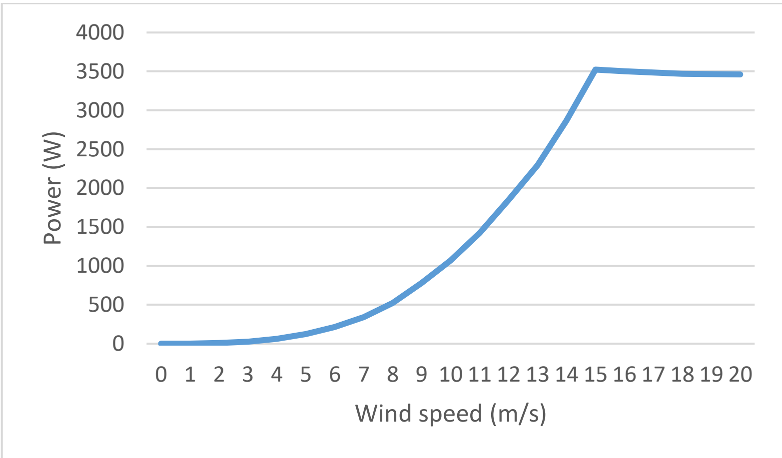
Based on the hybrid technology explained before the helical turbine also called Gorlov helical turbine in honour to one of the main developers (GHT) is a wind turbine evolved from the Darrieus turbine design by altering it to have helical blades/foils. The blades are arranged offset from one another, so that a part of the wind is diverted from the right and left openings to the scooped sides of the blades and can therefore act on the reverse side of one of the concave blades. The action is based both on aerodynamic lift as well as resistance induced tunnelling.

picture 11. Helical turbine in household

Source: Greendiary.com blog [50]

The helical rotor design is reputed to reduce or eliminate the torque ripple encountered in traditional two-blade Darrieus or eggbeater turbines. Because of its dramatic aesthetic appeal, the helical or Gorlov rotor has become the preferred wind turbine design by architects when adding architectural features to their buildings or development sites.

Graph 9. Operating curve Helical wind turbine



Source: Conclusion of Luis Perez Maroto

The helical wind turbine generally can be used in areas with higher wind speeds where bladed turbines would need to be shut down for safety reasons.

Regarding environmental impact this kind of wind turbine is bird safety. In recent years, manufacturers of utility scale horizontal axis bladed wind turbines have come under fire for killing birds especially in migratory paths [51].

In general, advantages of vertical turbine axis, are omni-directional. They do not need to turn and track the wind like conventional, horizontal axis wind turbines (HAWT). Therefore, once it is installed, it doesn't need to be managed. It simply begins generating as much power as able regardless of the direction of the wind. Though they are not as efficient as HAWTs, any inefficiency is cancelled out by the fact that VAWTs can harness more wind than HAWTs.

3.2 Results of market analysis

To conclude the research about the analysis of low power turbines is necessary to explain which factors have been kept in mind during the comparison of all the technologies.

There are two main aspects for studying the advantages and disadvantages of each technology: Technical and Economy factors which are going to be explained in the following paragraphs.

Technical factors include the analysis of the operating curve of each turbine and the specific features which are required for installing all the systems. Furthermore, it is also important to mention the part of the most proper kind of place which each technology is more effective.

Other technical aspects as air density properties or external factors to the engine are kept in mind but it cannot be proved during this project because it was not possible to try all different technologies in situ.

Regarding economy factors, there are two main points which make sense for the comparison of the low power wind technologies. The first one is the investment needed and the second the lifetime of the generators.

As it is known wind power as renewable energy has not big costs in maintenance and other types of operating cost which is an advantage for simplifying the study.

This project has used some useful ratios for comparing the hypothesis of installing each technology in the same place with the same conditions.

3.2.1 Technical study

The first analysis made has been the study of all operating curve for specific models of low power turbines. Each technology has associated a brand manufacturer of wind turbine which represents the model in the real life.

As it is mentioned before there are two kinds of turbine classification: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). It is important to consider the implicit comparison of each kind of classification.

Table 1. Comparison between HAWTs and VAWTs

Features	(HAWT) Horizontal Axis Wind Turbine	(VAWT) Vertical Axis Wind Turbine
Management after installation	yes	no
Wind direction dependence	yes	no
Efficiency	higher	lower
Device replacement	high	low
Resistance to fatigue	low	high
Installation place required	huge	small

The features showed in the table describe the main differences which should be explained for determining the importance of the axis position of the turbine.

Management after installation refers to how difficult is changing devices or components from the turbine in case it is needed to replace. For HAWT the components are mainly in the top of the mast, this situation makes more difficult to operate in the turbine because as consequence is needed safety materials which cover the maintenance worker during the operation. In the case of VAWT 90 % of replacing devices are in the ground (bottom of the mast) which makes it an easier maintenance procedure.

Regarding wind direction dependence is important to mention that al horizontal axis turbine technologies are necessary to redirect according to the wind flow of the location. In the case of VAWT this feature does not affect.

Efficiency of the engine is usually higher in HAWT due to the grade of development. Horizontal axis turbine technologies were discovered before VAWT which means that exist more research studies which support horizontal axis turbines.

Other features as Device replacement and installation place are depending on the location more than the type of technologies. Horizontal axis turbines need big areas in case of it is wanted to install more than one turbine for the same production system. This necessity is due to the shedding phenomena of the wind created when the flow cross through the turbine section. In the case of vertical axis turbines this feature is less intense and it allows to install the turbines closer.

The last feature but not less important is the resistance to fatigue. VAWT technologies are more resistant to the wind flow when it pushes the blades and the structure because the section of the turbine facing the wind is smaller than in HAWT technologies. It means that vertical axis turbines have higher survival wind speed.

Once analysed the comparison between the different classification of wind turbine technologies, it is going to explain the results obtained according to the operating curve of the models selected for each wind turbine.

The following table shows the behaviour of the turbine production depending on wind speed (meters per second)

Table 2. Wind speed features according to technologies

Wind Technology	Wind speed start (m/s)	Nominal speed (m/s)	Disconnection speed (m/s)
Windtronics	2,3	15,8	18,5
Micro turbine	4	17	20
Multiple rotor	3,129	15,65	22,35
Direct drive	2,570	14	20,5
Savonius	3	11	18
Helical	2.995	10	20

The results obtained from the different operating curves show that the first turbine which would start to generate electricity under the same location conditions for every engine is Windtronics technology model with a 2.3 m/s wind speed. Furthermore, is important to mention that all technologies studied for low power are able to start the engines by them self. In Daerrius technologies (there is not low power turbine model) would need help for starting to operate.

Regarding proper wind speed for reaching the nominal power of each kind of turbine model measured in this project is important to highlight that is helical turbine with 10 m/s. The results for nominal wind speed show that in general vertical axis wind turbine technologies reach the nominal power with lower wind speed.

The disconnection or survival wind speed which technology models can endure is directly related with the resistance to the fatigue which was explained before. The most resistant is the Savonius technology according to the chosen models.

The nominal wind speed of the turbines means that to reach the nominal power of the device is necessary the specific wind speed showed in the table below, it does not mean that the turbines must operate at the nominal power all the time, manufacturers keep in mind that turbines should work at 75% of its nominal power.

Other technical results obtained for the models of low power wind turbine is important to analyse the interval between the nominal and the survival speed. This specific study is made for that cases which the location has non- regular wind features, there are turbine technologies which do not accept high ranges of wind speed and as consequence the engine must be disconnected and stop generating.

Table 3. Wind speed range analysis

Wind Technology	Nominal speed (m/s)	Disconnection speed (m/s)	Range of wind speed
Windtronics	15,8	18,5	2,7
Micro turbine	17	20	3
Multiple rotor	15,65	22,35	6,7
Direct drive	14	20.5	6,5
Savonius	11	18	7
Helical	10	20	10

As it is shown in the table above, Windtronics model technology suffers more with irregular features having to disconnect the turbine with a difference of 3 m/s from the nominal wind speed.

On the other hand, is discovered that VAWT technologies have the biggest interval, reaching the double wind speed resistance of the HAWT technologies. It means that the range for vertical axis are better designed offering less surface to the wind flow.

To conclude the technical results, it is given a ratio which compares the power with the winds speed required for reaching the nominal value in watts.

Table 4. Nominal ratio technologies

Wind Technology	Nominal wind speed (m/s)	Nominal power (W)	Nominal ratio (W/m/s)
Windtronics	15,8	2200	140
Micro turbine	17	300	18
Multiple rotor	15,65	2000	127,8
Direct drive	14	400	28,57
Savonius	11	1500	136,36
Helical	10	1000	100

The important value of this ratio is to see how much power the technologies produce with 1 m/s of wind speed. The highest value is reached by Savonius technology which means that can arrange its nominal power with the lowest wind features.

3.2.2 Economy study

For the economy study has been taken original information from catalogues and questions to the manufacturers for determining which is the most approximate costs required for having the turbine model.

First, it was asked for the investment price for buying the turbine and install it in the simplest location (flat soil with no additional structures around the turbine and giving the opportunity of easy transportation to the location). The total investment required is shown in the next table:

Table 5. Wind turbine model investments

Wind Technology	Turbine cost (€)	Transportation and installation cost (€)	Investment (€)	Lifetime (years)
Windtronics	4200	500	4700	16-20
Micro turbine	520	150	670	20
Multiple rotor	2700	300	3000	16-20
Direct drive	1495	60	1555	20
Savonius	4400	100	4500	27
Helical	3000	500	3500	25

The previous table explains the approximation of the budget required for investing in the facility of the different wind technologies. It is important to assume that the budget would be according to standard conditions (locations with easy access and no obstacles). Furthermore, it is considered the lifetime data collected due to the importance in a possible investment comparison. The lifetime is an estimation average of years which the turbine should operate according to warranties and turbine complexity that manufacturers offer.

The difference of investment is related to the installed power of each turbine so it is necessary to compare the cost according to the output power which can produce.

Table 6. Installed power vs investment

Wind Technology	Installed power (W)	Investment (€)	Unit install price (€/W)
Windtronics	2200	4700	2,14
Micro turbine	300	670	2,23
Multiple rotor	2000	3000	1,5
Direct drive	400	1555	3,8
Savonius	1500	4500	3
Helical	1000	3500	3,5

When all models are compared under the same base, it can be observed that the most expensive investment would change for the direct drive technology, having a investment price of 3,8€ per watt installed.

To continue the analysis, it has been compared each technology for producing the same amount of output power under the same conditions, the low power system determined has been 2000 W of installed power:

Table 7. Levelized cost of electricity

Wind Technology	Installed power (W)	Investment (€)	Fix and variable costs (€)	LCOE (€/kWh)
Windtronics	2200	4700	470	0,113
Micro turbine	300	670	67	0,118
Multiple rotor	2000	3000	300	0,08
Direct drive	400	1555	156	0,2
Savonius	1500	4500	450	0,124
Helical	1000	3500	350	0,143

Making an approach about the computation of which would be the levelized cost of electricity for each technology, it is obtained that the most expensive one would be the direct drive turbine model due to its high investment in comparison with the installed power the manufacturer offers.

As it is known wind power turbines as other renewable device sources are characterized by the low costs in maintenance. Furthermore, low wind turbines do not require high operating cost as insurances, repairs or administration because the low power system is considered for feeding small households or buildings. That is why it is assumed that this kind of costs do not differ a lot for every kind of technology and only depends on the policy of the location where it is going to be installed.

4. Micro Wind Energy Technology Impact

One of the main problems about wind energy technologies until now is the ecology impact it offers when the wind facility is not properly installed.

Micro generation is being promoted as one of the promising ways for reducing greenhouse gas (GHG) emissions. Field trials of micro wind technologies suggest that many of the sites where the micro wind turbines are installed are generating less energy than predicted owing to insufficient wind resource.

Therefore, despite the claims that micro wind turbines can save significant GHG emissions compared to other grid electricity sources and fossil fuel options the actual performance data through field trials cast some doubt over these claims [52]. However, wind technology alternatives are not environmental free impact, after the lifetime the electronic waste produced by the turbine systems, suppose a big problem which is usually too expensive to solve.

Developed countries have two main solutions for managing their electronic waste. One is to recycle the mostly part of the useless products and the other is to buy services to other countries to remove the waste from their lands.

4.1 Life cycle environmental sustainability of micro wind turbine

Life Cycle Assessment (LCA) identifies, quantifies and evaluates the environmental impacts (inputs and outputs) of a product, service or activity, from cradle to grave. That is, the environmental impacts of all phases of the product's life are assessed, from the time materials are extracted through manufacture, transportation, storage, use, recovery, reuse and disposal [53].

The following are the main goals of the LCA study:

To estimate the life cycle environmental impacts of micro wind turbines for electricity provision in Europe homes.

To compare the environmental impacts of micro turbines among different wind technologies.

The functional unit is defined as generation of 1 Wh of electricity. The scope of the study for all three options considered is from “cradle to grave”. A 2 kW turbine is considered as the most common size of micro wind installations in this study. The operating life of the turbine is assumed at 20 years (not all wind technologies have the same lifetime but it can be considered as average of it).

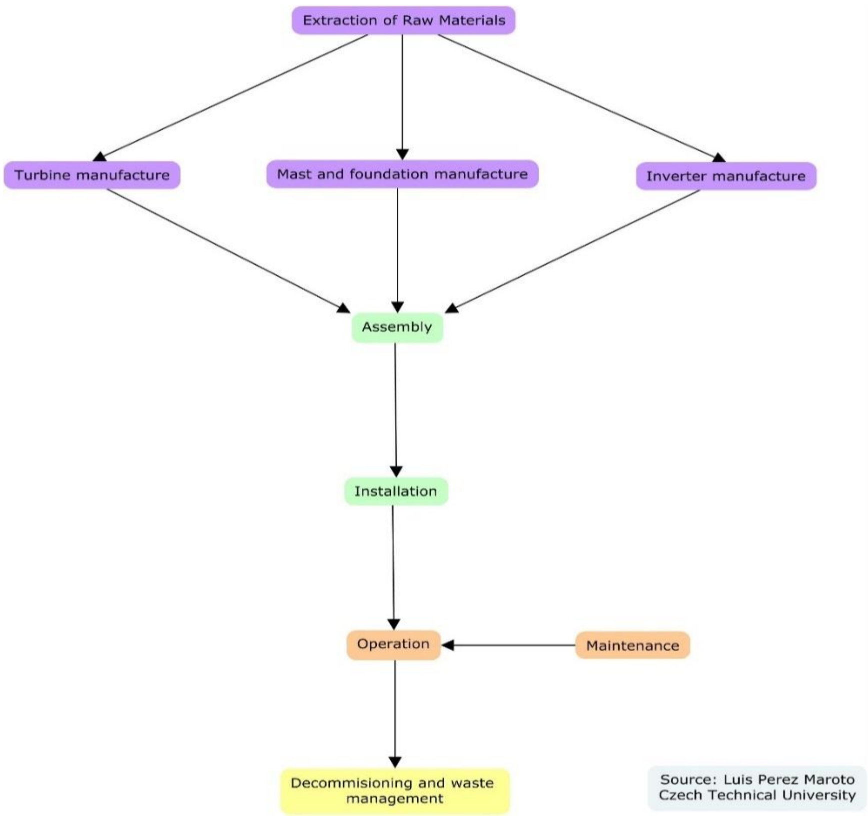
As it is known, micro wind turbines generate electricity by the rotation of turbine blades as wind passes over them. The low speed rotation of the input shaft connected to the rotor is converted to high-speed rotation by a gearbox. The high-speed shaft then drives the generator to produce electricity.

For the case of HAWT a yaw system is used to orientate the turbine towards the blowing wind.

An inverter is necessary to convert the DC electricity produced by the turbine to AC electricity suitable for use in dwellings.

In line with Europe trends is assumed to install the turbines at a location with an annual average wind speed of 5 m/s with no nearby obstructions, as the minimum requirements for a suitable location.

The analysis is based on the previous assumptions. Impact of low power wind turbines are based in the procedure of:



picture 12. Life cycle turbine scheme

There are 4 different parts which correspond different analysis for studying the environmental impact:

Manufacturing process (Purple colour) is according to the manufacture of the turbine and all the requirements needed for installing the device for being ready to use.

Transportation and assembling (Green colour) correspond to the part of the impact generating during the transportation and installation the turbine in the location.

Operation (Orange colour) is according to the use of the facility once It is working during all the lifetime.

Waste management (Yellow colour) cover all the procedures after the lifetime of the installation. There are some components which can be recyclable and others that must be discard.

Regarding the lifecycle steps, it is important to highlight that the advantages on the waste of materials for preventing the environmental impact, are mainly in manufacturing, decommissioning and waste management.

To continue with this chapter, it is going to mention how could be the impact created by Vortex technology and to research what would be the situation in this aspect in comparison with the other technologies.

4.2 Environmental impact of Vortex Wind Turbine

The impact produced by Vortex depends mainly on the size of the turbine (is directly proportional to the materials used for manufacturing) types of assembly area covered for the installation process.

The size of the vortex wind turbine model chosen for this study is around 3 meters high. It means that the materials used for manufacturing are according to the size of a cylindrical shape (it is not cylindrical at all but still valid for an approximation) [54].

The main advantage according to the assembly process as it is mentioned before is that there are not contacted parts which mean that the lubricants used are 80% less than the conventional low power turbines.

During the installation step, Vortex technology has no main differences according to the environmental impact. It is needed some workers, the same as for the other wind technologies. The simply Vortex facility makes that this process could spend at most only 2 days, once all components are in the location.

Along the operation activity does not require a lot of maintenance events during the lifetime. It means that the devices and turbine parts suffer less wastage due to the less contact parts.

Regarding the last part of the lifecycle, waste management, is important to mention that is direct connected to the management of raw materials used for the turbine manufacturing. In the following part of this chapter, is going to explain which raw materials predominate in the device and their management.

4.2.1 Vortex turbine building materials

Materials required for the vortex bladeless mast are mainly semi rigid fibreglass and carbon fibre which oscillates in the wind taking advantage of the vortex shedding effect.

Fibreglass is widely acknowledged as a material that has major advantages over more conventional rivals, such as wood, steel and aluminium. This material is stronger than sheet metal but it will not rust perfect for outside use or in locations near water, especially salt water. Fibreglass is also resistive to corrosive chemicals, and ready for events of fire when is made with special fire-retardant resins [55].

Main advantage of fibreglass, is less energy intensive in development and is used extensively for products which decrease carbon emissions in comparation with previous materials used in conventional wind turbines in the past.

Regarding carbon fibre, it is made of carbon crystals aligned in a long axis. These combination shaped crystals organize themselves in long flattened ribbons. This crystal alignment makes the ribbon strong in the long axis. In turn these ribbons align themselves within fibres. The fibre shape is the original shape of the material used to produce the Carbon Fibre. The most important factors determining the physical properties of this material are degree of carbonization and orientation of the layered carbon planes [56].

At the bottom of the mast a carbon fibre rod moves inside a linear alternator that generates the electricity with no moving parts in contact. Vortex has a small carbon footprint which is noiseless and It has low center of gravity that allows for small foundation dimensions, so more generators can be placed in an area, at twice the density of traditional turbines.

Table 8. Main materials used for Vortex Atlantis turbine model

Component	Material	Weight
Mast	Fibre glass	4.2 kg
	Carbon fibre	2.7 kg
	Resin reinforced	0.3 kg

Source: Vortex Bladeless company [58]

The foundation of the facility may vary according to the type of location. The turbine can be installed in terraces, gardens or roofs directly which means that the material used to fix the structure is different in each situation. Usually the structures are simply made with aluminium or iron material which avoid oxidation and work well in open spaces.

Regarding the manufacture, transportation of the turbine mast and usage of the device, it has been developed a simulation of the behaviour and impacts of the facility during all the life time.

The study assumes the raw materials required and analyses inside a big data base each component. Furthermore, OpenLCA simulates the flows and processes required to operate with the raw materials properly and gives the final results in percentage according to many factors.

The factors analysed in this study are: Human toxicity, Climate change and Ozone layer depletion.

Human toxicity releases to any chemical which, through its chemical action on life processes, can cause death, temporary incapacitation, or permanent harm to humans or animals. This includes all such chemicals, regardless of their origin or of their method of production, and regardless of whether they are produced in facilities, in munitions or elsewhere.

Climate change is the effect produced by emissions which contribute to change negatively the features in the environment.

Ozone layer depletion is the effect occurred when chemical activities destroy the ozone layer and create holes on it which allows to pass the most dangerous Sun rays.

Table 9. Cause- effect of Vortex turbine

Effect	Chemical component 1	Chemical component 2	Percentage of effect (%)
Human toxicity	Market glass fibre, polyamide	Market glass fibre, polyester resin	79.5
Climate change	Market glass fibre, polyamide	Market acrylonitrile	97.1
Ozone layer depletion	Market glass fibre, polyamide	Market acrylonitrile	86.2

Source: OpenLCA software [59]

The results showed above explain which are the most dangerous components which contribute to appear any of the effects explained before. The percentage refers to the sum quantity of the most affecting chemical components in comparison with all of them which are not represented in the table. As it is explained in the appendix, OpenLCA offers schematic data results in form of contribution tree which evaluate how affect the materials to each effect (Human toxicity, Climate Change and Ozone depletion layer) mentioned before.

As it can be observed in the table the most effective component according to the effects given, comes mainly from the glass fibre material during the manufacture of the turbine.

The second effective component is the acrylonitrile, component used for making the carbon fibre.

4.3 Biodiversity impact of Vortex Wind Technology

Wind power in general is unambiguously positive in terms of near zero emissions of GHG and other air pollutants and full renewability. However, wind power planners or developers must be concerned about the potential negative effects of wind turbines or associated infrastructures which affects mainly birds, bats, and other animals who can get confused about this kind of facilities.

On the other hand, ethical considerations underpin the concerns of many wind power stakeholders for generating and transporting electricity in ways that do not appreciably reduce the wild populations of animal species, thereby helping to maintaining healthy, viable natural ecosystems. natural habitats that may be affected by wind power facilities have significant scientific and sometimes also economic value. Some insectivorous bats are of major economic importance in consuming insects that are crop pests or nuisance species such as mosquitoes. In addition, some of the birds that are prone to collisions with wind turbines, such as eagles, storks, and other migratory species. It is important to focus on special interest for wildlife point of view where these species are concentrated. Furthermore, it may be important from an ecotourism standpoint according to economic terms.

To continue, some of the windy sites that appear attractive for wind power development are also of considerable biological interest because of concentrations of migratory birds, other wildlife, or rare plants such as on mountain ridgetops in the tropics. It means that is necessary to make a balance of the energy needs and the consequences they can do.

One of the best alternatives as solution regarding the previous paragraph is Vortex Wind Technology. The technology has not blades which cannot disturb bird migration ways in case this technology is installed in a committed space of Biosystems. Furthermore, the turbine size is smaller than the other turbine technologies which means that the impact potential is much lower in all aspects.

Regarding the operating activity of the turbine, as it is said, Vortex maintenance is easy to fix and a low frequent activity. It means that the surroundings of the facility can be easily invaded by wildlife in case it is wanted.

Wind turbines, like other tall structures, cast a shadow on the surrounding area when the sun is visible. For people who live close to the turbine, it may be annoying if the rotor blades cause a flickering (blinking) effect while the rotor is in motion.

Estimating the exact shape, place, and time of the shadow from a wind turbine requires computation, but professional wind software programs can do this very accurately, even in hilly terrain, and with house windows of any size, shape, location, and inclination facing in any direction. Shadow geometry varies by latitude, and the length of the shadow is much more a function of rotor diameter than of hub height [60].

Vortex technology reduces significantly the shaking shadows problem because the movement required is minimum.

The noise produced by the operation of wind facilities include “turbine hum” and “rotor swish” two types of common noise which are a big deal in this kind of industry. The first is emitted from the machinery in the nacelle of HAWT turbines. The second is produced by the friction between the wing blades and the wind. Noise levels from within an onshore wind farm are mostly in the range of 2 until 10 dBA. These are relatively low noise levels compared with other common sources such as ambient night time noise in the countryside but still important to reduce as much as possible if it is wanted to install a system in households.

Comparing the technology turbines with Vortex Turbine is important to highlight that the second one has few parts in contact which means that there is not noise produced by this issue. In VAWT technologies the structures are better optimized for avoiding noise because they do not have parts required to redirection facing the wind flow (less movement parts).

Summarising Vortex wind turbine model has the advantages of being a vertical axis and bladeless wind turbine.

There is a very small risk of a loose rotor blade being thrown because of severe mechanical failure. In cold climates, there is also a small rotor risk blades throwing off chunks of accumulated ice when they begin to rotate. Some wind turbine rotor blades (as with aircraft propellers) are equipped with heating elements to reduce ice formation.

For the case of Vortex technology, it could not be possible to find any freezing study but It would express better results against low temperatures because the turbine has not blades and few contact parts which are the most affected by this feature.

5. Scenario in Czech Republic and Spain

The common scenario about energy policy for Czech Republic and Spain is regulated by the standards of the European Union framework. This institution in most of the cases only provides the route of development for installations of self consumption and management of this according to a sustainable and economic way.

Along this chapter it is going summarize the current legislation which regulate and help to lead a sustainable development

5.1 European legislation

Directive 2009/28/CE, Defines binding targets for energy quotas of renewable energies of the Member States in the final consumption of energy. However, the Member States have full freedom regarding the contribution of different sectors (such as electricity, heat and transport) and the instruments support used to achieve the objectives. Member States also have the possibility to do use of flexibility mechanisms if they should or want to generate a part of the renewable energies needed in other EU countries. The process to get that target is subjecting close monitoring. In 2010, the Member States had to draw up national action plans on renewable energy, including their extension trajectories for each sector, technology, measures and instruments to promote renewable energies. On the other hand, they were defined half-yearly interim targets as milestones towards each national target by 2020.

The Member States must notify every two years of the differences between their current situation and the scenario expected. As result of freedom in terms of support instruments to promote the renewable energies, the EU Member States have a variety of support systems for renewable energy in general [61].

Regulation (EU) 2017/1369 lays down a framework that applies to energy related products placed on the market or put into service. It provides for the labelling of those products and the provision of standard product information regarding energy efficiency, the consumption of energy and of other resources by products during use and supplementary information concerning products, thereby enabling customers to choose more efficient products in order to reduce their energy consumption [62].

The regulation stablished supports indirectly the self consumption and allows it to interpret in different ways which are going to promote the use of low power facilities.

5.2 Czech legislation

Act No. 180/2005, of 31^{th} March 2005. This Act regulates, in accordance with the legislation of the European Communities, the method of promoting the production of electricity from renewable energy sources and from mining gas from closed mines, the performance of state administration, and the rights and obligations of natural and legal persons connected therewith.

Summarising this old Act is important to highlight that is focused on older plants, (Before 2013) they counted with high support and guaranties which create conditions for fulfilment of the indicative target for the share of electricity from renewable sources in the gross consumption of electricity in the Czech Republic amounting to 8 % in 2010, and for further increase of this share after 2010.

Act No. 165/2012, of 31^{th} January 2012. The promotion of electricity from renewable sources is defined regarding the predicted figures on energy for each type of renewable sources from 2013 to each single year until 2020, as specified in the National Action Plan.

Promotion of electricity is carried out by means of green bonuses for electricity or by purchase prices. The right to choose the electricity promotion in the form of purchase prices has only the producer of electricity from renewable energy sources in electricity production plants with an installed capacity of up to 100 kW inclusive. In other cases, including electricity produced in the electricity production plants with the installed capacity up to 100 kW together from renewable and non-renewable sources, the producer of electricity from renewable sources has the right only for electricity promotion in the form of green bonuses for electricity.

The Green bonus for electricity is set in CZK/MWh and is provided in an annual or hourly mode.

The decision about selection of compulsorily purchaser, the supplier of the last instance for the relevant defined territory is the compulsorily purchaser. The Ministry informs about the choice of the mandatory purchaser by away allowing remote access. This method is a kind of feed in tariffs system.

The market operator is entitled for reimbursement of the costs associated with promotion of electricity. Costs are reimbursed to the market operator by the regional distribution system operator, and the transmission system operator from the funds forming component of the price for electricity transmission and the price for distribution of electricity to cover the costs associated with promotion of electricity, and further the subsidies from the state budget.

Price Decision Establishing the Support of Renewable Energy Sources No. 3/2017 of 26th September 2017. Settled by Energy Regulatory Office. The scope and amount of the promotion of electricity from renewable sources shall be defined by the Office hereunder in the price decision.

This law is made according to the previous article 165/2012 for determining the bases of the promotion of renewable energy sources.

Decree 296/2015, of 9th of November 2015. focused on the technical and economic parameters for the fixing of purchase prices for the production of electricity and on the determination of the lifetime of electricity generators from renewable energy sources

This Decree is related to technical and economic parameters Decree on Technical and Economic Parameters for the Determination of Feed-in Tariffs for electricity generation and establishing the Life Cycle of installations Producing Power from Renewable Energy Sources.

For the case of wind power plants is necessary to fix some terms for evaluating the conditions:

- Useful life of the power plant: 20 years.

- Efficiency required for primary energy use. According to the average of annual wind speed at the construction site of the wind power plant at the height of the rotor axis of the proposed power plant is at least 6 m / s.

- Specific investment costs and annual utilization of installed capacity which does not affect to small wind facilities. It is focused on power plants only.

Operational Program Enterprise and Innovation for Competitiveness (OP PIK) 2014 to 2020 is a document prepared by the Managing Authority of the OP EIC, Ministry of Industry and Trade, in collaboration with partners, which sets objectives and priorities for the effective use of the European Regional Development Fund in order to achieve a competitive and sustainable economy based on knowledge and innovation. The OP EIC shall be implemented under the Investment for growth and jobs goal of the EU cohesion policy.

The Operational Programme sets out a strategy based on which it will contribute to the Union Strategy for smart, sustainable and inclusive growth (Europe 2020 Strategy), and which is in conformity with the provisions of the General Regulation and the ERDF Regulation and with the contents of the Partnership Agreement for the Programming Period 2014–2020.

The strategy of the OP EIC is based on two intersecting pillars. The first pillar consists in common ideas and goals embodied in the Europe 2020 Strategy and the second one is represented by the priorities and needs of the Czech Republic identified in national and European strategic documents [63].

Summarising, there are three types of electricity promotion from renewable energy sources: Green Bonuses, Feed in Tariffs and Subsides in the investment costs. All of them are available for the promotion of the renewable energy and heat production in different ways. The paragraphs explained before are only according to the law which affects wind production.

5.3 Spanish legislation

Royal Decree 900/2015, of 9th October, regulating administrative, technical and economic types of electricity supply and generation with self-consumption.

The regulations of the Decree apply to any renewable generation facility that produces electricity for self consumption and is connected to the national grid. Installations that are not connected to the grid are not regulated by this Royal Decree.

Type 1: Supply with self-consumption. This type of self-consumption model applies to facilities no larger than 100 kW. The electricity is only generated for self-consumption. Surplus of the electricity can be exported to the grid but it is not remunerated with economic compensation. Only one type of the Third-Party Access Contract (TPA).

Type 2: Generation with self-consumption. This refers to a consumer in a single facility or supply point which is associated to one or several production facilities connected within its grid, or which share connection infrastructure with it or is connected to it. The surplus of the generated electricity can be exported to the grid and is remunerated with the economic compensation.

Consumers covered by any self-consumption modality will be subjected to distribution and transport grid access fees charges to ensure technical and economic sustainability of the grid. These charges are divided into fixed and variable charges. Following exceptions are exempted from paying fees:

Consumers covered by the Type 1 self-consumption model with an installation equal or less than 10 kW. Those customers are exempted from transitory variable charges.

Cogeneration facilities that are registered with Electricity Production Facilities Administrative Register with the requirements set by Royal Decree 661/2007. Those installations are exempted from payment charges until 31st of December 2019.

The failure to register as a self-consumer or noncompliance with the rules will be subjected to the financial penalty between EUR 6.000.001 and EUR 60.000.000.

Royal Decree 110/2015, of 20th February, photovoltaic panels and low power wind turbines are considered for the first time as electrical and electronic category devices and the correct management of their waste is available when they reach the end of their useful life.

Royal Decree 413/2014, of 6th June, framed within the general law of the electricity sector, whose most remarkable aspect is the reform of the incentive system received by renewable energy installations, so that only those that have not exceeded the useful life established by law (20 years for the wind, 30 for photovoltaics and 25 for the rest) will continue to receive premiums. It also establishes the rights and obligations of electricity production facilities from renewable energy sources, cogeneration and waste and regulates their participation in the electricity market.

Law 24/2013, of 26th December, inside the article 14.7 explains a competitive procedure for the establishment of a specific remuneration regime for the promotion of the production of energy from renewable energy sources. Furthermore, it establishes a specific remuneration regime for photovoltaic and wind installations in non-peninsular territories to promote its expansion, since in these territories the cost of conventional generation is higher than with renewable sources.

Royal Decree Law 9/2013, of 12th July, approves a new legal and economic regime for existing electric power production facilities from renewable energy sources, cogeneration and waste.

Royal Decree Law 2/2013, of 1st February, eliminates the option of a market price plus premium, determining the remuneration according to tariff of all the facilities of the special regime.

Royal Decree law 1/2012, of 27th January, stablish procedures for the assignment of remuneration and eliminates economic incentives for new installations whose production of electricity come from cogeneration, renewable energy sources or waste are suspended.

Law 2/2011, 4th March, includes under its leading principles the promotion of clean energies, reduction of emissions and reduction of waste, as well as savings and energy efficiency. It also prolongs the term of receipt of premium compensation in the case of photovoltaic plants [64].

5.4 Scenario analysis for self-consumption facilities

The field about self consumption facilities in general is mainly applied in photovoltaics because it is the kind of technology most developed available. According to this affirmation, in Czech Republic and Spain exist two different interpretation of low power energy facilities meaning.

In the following chapter, it is going to explain which is the situation in both countries and then there will be a comparation for deciding which one is more suitable for installing self consumption facilities under the given conditions.

5.4.1 Spanish Scenario

Regarding the field of low wind power facilities, it is evident that the development has not been the same as power wind plants due to the lack of regulatory framework which helps to grow it faster.

Historically, micro wind turbines have been always included inside the group of the power wind farms because the administrative requirements are mostly the same. As consequence of it, micro wind technologies were affected avoiding the promotion of small wind facilities.

Given the raising growth of renewable energy capacity in Spain, as well as the innovative design of the Spanish support system and measures for the integration of systems, Spain has always been at the forefront of the countries that support the renewable energy. However, this situation changed radically after 2007

In 2007, supporting electricity production from renewable energy sources was based on a system in which the operators of the central banks could choose between a regulated tariff or a regulated premium, of the wholesale price of wholesale electricity, so that total revenue per MWh were limited by a lower and upper limit.

Nowadays, and according to European directives as 2009/28/CE Spain has the target of produce at least 20% of the energy from renewable sources. Keeping in mind the important role of the self consumption facilities in households, IDAE in cooperation with municipalities and regional institutions promote to develop new energy systems specially for those places where is more expensive to supply electricity.

The first step is to organize a National system where all low power facilities are registered in transparent and objective ways. Regulations which lead this type of registration demand that for some buildings whose size is considered bigger enough have to be supply at least with any renewable source (Mainly photovoltaic and wind sources).

Spanish action plan for facing the challenge of 20% renewable production in 2020 is based on the following rules:

Specific regulatory treatment for grid connection once there is a self consumption facility existing as it is mentioned in the Spanish legislation subsection.

Supporting regulations for implementing small production facilities.

Standardization of technical procedures which affect to the installation. It is pretended to guarantee the quality of the equipment.

Promote professional workers for installing the facilities properly. In Spain until 2010 it was not needed to have any certificate to build and install wind facilities. Currently it is required to have a special certificate which allows to do according to the RD 249/2010 [66].

Regarding economy retributive aspects Spain, there are not incentives for promoting the self consumption. As it is written before, the Royal Decree 900/2015 which eliminates at the same time all the other Decrees which can affect it, allows to install energy systems for consumption but there is not compensation in case the surplus of energy is delivered to the grid.

Green bonus and feed in tariffs systems for clean energy production in self consumption facilities have been deleted, so it is not possible to remunerate economically producing energy.

5.4.2 Czech Scenario

Since of the beginning of this century Czech Republic has been promoted renewable sources according to the demand and conditions of the country. This activity is being proposed for reaching the target 2020, where the European countries signed that among all countries must have a mean of 20% of final consumption from renewable sources. For Czech Republic, the target is 13,5% which almost reached in 2015 and meant that mostly subsidiary activity stopped by the Government for promoting other society aspects.

In the Czech Republic, the energy market is subject to immense regulation. There is a regulated access to the transmission system, to the distribution systems, to the authorizations given by Ministry of Industry and Trade (MPO), for the construction of power plants and to the construction and running of utilities necessary for transferring electricity. The regulation is provided via several main channels (The Government and the Parliament which owns the legislation, the Energy Regulatory Office of the Czech Republic in charge of production control and the Czech Transmission System Operator that works on the transfer network) [67].

The Energy Regulatory Office competences are mainly price control, supporting the use of renewable and secondary energy sources, support for heat and power generation, consumers protection, granting licensing permissions and market administration, support for a fair competition in the energy industries, cooperation with the Office for the Protection of Competition and supervision of the energy market.

The CEPS (Czech Transmission System Operator), with its license under the Energy Act granted by the Energy Regulatory Office, is responsible for the electricity transmission operating through the ownership unbundling. The CEPS was established in 1998, when the General Meeting of CEZ separated the Transmission system division from the CEZ activities and formed this brand new institution. The CEPS has an exclusive license for a long distance transmission of electricity at high voltage. It implements a supervisory control of the transmission system on the Czech territory in real time and is also responsible for the stability of the power and frequency, voltage control and reactive power. The CEPS is allowed to trade the energy on its own account to ensure stability parameters and required power reserves. Hand in hand with the extension of an unpredictable energy production from renewables (especially solar systems and wind power plants), the CEPS processes and tests a plan of defence against the spread of the system failures transmission and a recovery plan for the electrification system after system disorder [68].

5.5 Technical analysis

Regarding the computed analysis of wind potential, energy outputs and economy feasibility, it has been based in most similar features when it is wanted to compare both countries (Czech Republic and Spain). In the following paragraph it is going to describe the base features taken for making this particular analysis.

- The location chosen of the key study for both countries are the capitals, Madrid for Spain and Prague for Czech Republic.
- The wind data has been obtained from public anemometric towers which have been provided from different sources.
- The aim of this study is to compare both cities, Prague and Madrid. On the other hand, it is not searched through the countries the most suitable location for installing the turbines.
- Wind energy data has been collected from historical data for computing the probability of different wind speeds.

The economy analysis of the hypothetical installation has been performed from the same point of view for being objective as possible in the results shown. Furthermore, It has been kept in mind the scenarios described before for each country.

To continue with the study, it is going to explain which conditions have been taken for both countries and which are not kept in mind because of lack of information.

Spanish wind source is “Wind Atlas” developed by IDAE (Instituto de Diversificación y Ahorro de la Energía) which offers free data related to the land of Spain and Portugal. This data comes from a big historical source collected since 1978 and provides different wind speed data at different high.

The data from Spain used for this specific study come from the description of the following location:

Table 10. Spanish features location

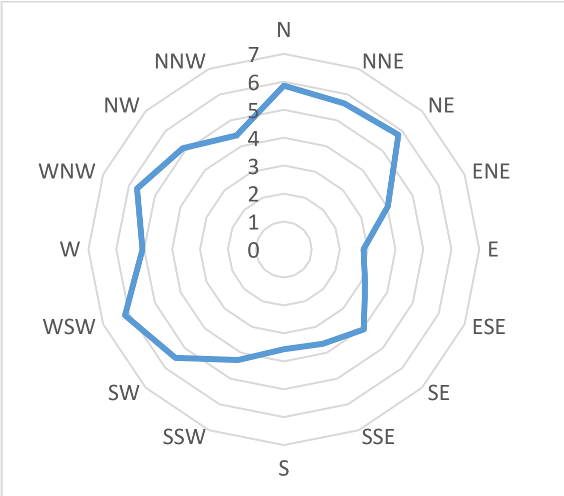
UTM coordinates	Place	City	Country	Tower high
443445, 4483265	Ciudad Universitaria	Madrid	Spain	80 meters

Source: IDAE [69]

The anemometric tower is on a building which is placed in the top of a hill. It means that the obstacles that could affect to the data collected by this device are not significant. There is not higher obstacles than 60 meters in 1 kilometre around it.

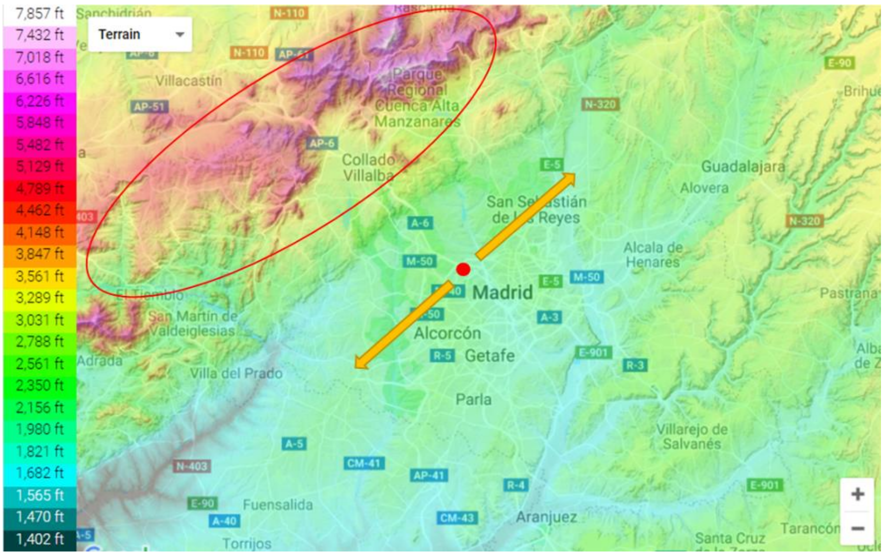
Ciudad Universitaria is a district of Madrid located 664 meters over the Mediterranean Sea, so the absolute data collected is being at 744 meters. The predominant directions of the wind are North- East and South- West with average wind speed around 6 to 6.5 m/s.

Graph 10. Wind Rose of Ciudad Universitaria



Source: IDAE [70]

The table shown above indicate that the best conditions of wind speed are in the directions explained before. It is due to the mountain range which exist in the western part of the Madrid region (Guadarrama Mountain range). This altitude causes a wind predominance in the parallel directions to the mountains.



picture 13. Elevation study of Madrid

Source: Topographic-map.com [71]

The picture shows the different elevation in Madrid Region. This analysis works obtaining two results:

- The first one tells the explanation about the predominance direction of the wind along the years. In this case as was described before, the wind direction is directly affected by the mountain range which exist in the northern- West part of the map. It means that the obstacle works as a physical barrier which partially avoid the wind coming from North – West direction.

- The second target of the elevation study is to show which would be the most suitable place to install wind turbines. Usually the higher elevation means the best wind conditions. This study does not incur on the searching of the best location but it could be observed that the most probably place with best conditions would be the proper mountain range.

Regarding the code of colours shown in the picture, it is referred to the high in feet of each elevation, one feet is around 0.3 meters and the data is given as absolute height.

Once the it has been analysed the direction and its predominance is important to focus in the wind speed of this resource. Madrid city is not one of the best places in Spain to install wind turbines but the aim of this key study as it is mentioned before is to compare in which city (Madrid or Prague) both capital of countries is more profitable to install this kind of devices.

Regarding the wind speed analysis, is important to highlight that the study is based in a statistic method which determines the probability of wind speed for each wind direction for one year.

Madrid wind speed predominance is up to 11 meters per second (around 90% of the measures are under this wind speed). There are few cases according to wind speed higher than 12 m/s which means that the wind conditions could not be not acceptable for Vortex turbines. The explanation remarked is because there is lack of information (outliers) for this location in the data source (IDAE), so it is decided to compute the values only with known data.

Table 11. Wind speed feature averages I

Direction	Frequency (%)	Wind speed (m/s)
N	5,64	5,863
NNE	11,67	5,661
NE	20,16	5,802
ENE	8,71	4,025
E	3,62	2,848
ESE	3,44	3,151
SE	3,3	4,05
SSE	3,38	3,656
S	3,72	3,57
SSW	5,22	4,282
SW	8,34	5,489
WSW	8,62	6,156
W	4,12	5,06
WNW	3,83	5,686
NW	3,31	5,121
NNW	2,95	4,414

Source: IDAE [72]

For computing the probability of the wind speed for each direction it has been developed a continuous probability distribution called Weibull distribution. This statistical tool works with parameters called “shape factor” K and “scale factor” C.

The Weibull shape parameter, K, is also known as the Weibull slope. This is because the value of K is equal to the slope of the line in a probability plot. Different values of the shape parameter can have marked effects on the behaviour of the distribution. In fact, some values of the shape parameter will cause the distribution equations to reduce to those of other distributions.

A change in the scale parameter, C, has the same effect on the distribution as a change of the abscissa scale. Increasing the value of C while holding K constant has the effect of stretching out the curve in the plot. Since the area under a curve is a constant value of one, the "peak" of the curve will also decrease with the increase of C.

Once the probability of wind speed is calculated for the location chosen, it is necessary to observe the operating curve of the Vortex wind turbine for determining aa estimation of the energy output which would generate.

Regarding the Spanish wind resource, the results obtained from this part of the key study are:

Table 12. Estimated yearly energy generated at each wind speed I

Wind speed (m/s)	Power (w)	Probability (%)	Power produced (W)	Yearly power produced (Wh/year)
3	3	0,151	0,451	3954,967603
4	8	0,131	1,051	9206,382321
5	20	0,106	2,119	18570,77849
6	33	0,082	2,702	23670,81751
7	52	0,062	3,251	28478,84451
8	76	0,048	3,650	31975,42725
9	100	0,034	3,428	30029,26523
10	105	0,021	2,204	19314,03296
11	109	0,054	5,531	48451,11867

Source: IDAE [73]

The table showed above, explains the relationship between the wind speed and the output obtained for the turbine. As can be observed, the probability of having high wind speed decrease with the raising output power. It can be assumed that having nominal output (100 W) in Madrid location is not probabilistic high.

To conclude with the Spanish study, the following table is going to show the summarise results under the conditions given: Location Ciudad Universitaria (Madrid), 80 m high from the relative high of the city and the wind features explained before.

Table 13. Summary of output power for one wind turbine I

Maximum yearly work **(hours per year)**	**5567,59**
Estimated total output year (kWh/year)	213,65

The results showed from the analysis of the location in Madrid determine that the electricity output for one vortex wind turbine is around 200 kWh per year which means that the wind conditions studied would not be the best.

Regarding Czech wind analysis, the source chosen for obtaining the wind data is from Ústav Fyziky Atmosféry (Institute of Atmospheric Physics) which offers the database related to the land of Czech Republic. This data comes from a big historical source collected and behaviour models that provides different wind speed data at different high.

The data from Czech country used for this specific study come from the description of the following location:

Table 14. Czech features location

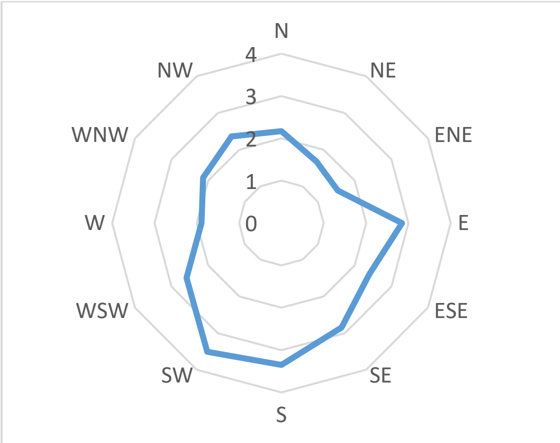
UTM coordinates	Place	City	Country	Tower high
392004, 1547954	Faculty of Electrical Engineering (CVUT), Dejvice	Prague	Czech Republic	10 m

Source: Ustaf Fyziky Atmosfery [74]

The obstacles that could affect to the data collected by this device are not significant because there is not higher obstacles than 60 meters in 1 kilometer around it.

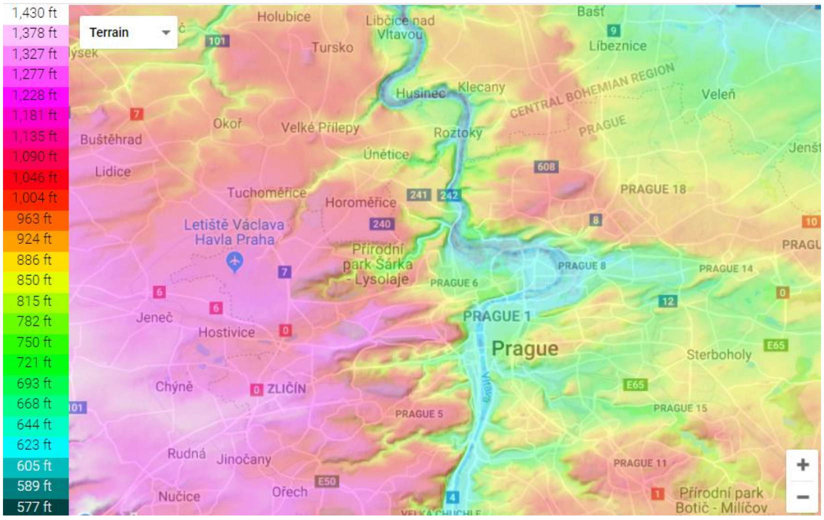
Dejvice where is located the Faculty chosen as model, is a district of Prague 234 meters over the Mediterranean Sea, so the absolute data collected is being at 244 meters. The predominant directions of the wind are South- West with average wind speed around 3.3 to 3.5 m/s.

Graph 11. Wind Rose of Dejvice



Source: Ustaf Fyziky Atmosfery [75]

In the following picture it is going to show the different height levels of the location under the study. It is possible to observe that there is not special elevations which could affect to the wind directions like a mountain range or other huge obstacles.



picture 14. Elevation study of Prague

Source: Topographic-map.com [76]

Regarding Prague wind speed is important to highlight the low values collected for the location selected, it is well known that the profitability of the turbines is directly connected to the wind speed averages. When estimations about the mean wind speed should be higher than 5 m/s for conventional wind turbines, Dejvice shows an average of 2.7 m/s according to the Czech data base Ustaf Fyziky Atmosfery.

Table 15. Wind speed average II

Direction	Frecuency (%)	Wind speed (m/s)
N	10,6	2,17
NE	5	1,67
ENE	3,8	1,54
E	8,4	2,85
ESE	9,3	2,4
SE	9,7	2,85
S	11	3,35
SW	12,1	3,51
WSW	7,6	2,59
W	6,4	1,89
WNW	6,8	2,14
NW	9,3	2,36

Source: Ustaf Fyziky Atmosfery [77]

Once the probability of wind speed is computed for the location chosen, it is necessary to observe the operating curve of the Vortex wind turbine for determining aa estimation of the energy output which would generate.

Regarding Czech wind resource, the results obtained from this part of the key study are:

Table 16. Estimated yearly energy generated at each wind speed II

Wind speed (m/s)	Power (w)	Probability (%)	Power produced (W)	Yearly power produced (Wh/year)
3	3	0,156	0,468	4100,029791
4	8	0,077	0,620	5435,893315
5	20	0,035	0,719	6300,180913
6	33	0,016	0,540	4738,16157
7	52	0,007	0,379	3321,301773
8	76	0,003	0,244	2138,804476
9	100	0,001	0,143	1257,415063
10	105	0,001	0,068	600,073242
11	109	0,001	0,057	502,9049525

Source: Ustaf Fyziky Atmosfery [78]

The table showed above, explains the relationship between the wind speed and the output obtained for the turbine. As can be observed, the probability of having high wind speed decrease with the raising output power. It can be assumed that having nominal output (100 W) in Prague location is not probabilistically high.

To conclude with the Czech study, the following table is going to show the summarize results under the conditions given: Location Dejvice (Prague), 10 m high from the relative high of the city and the wind features explained before.

Table 17. Summary of output power for one wind turbine II

Maximum yearly work **(hours/year)**	**2615,05**
Annual output (kWh/year)	28,394

The results obtained for Prague determine that the electricity output for one vortex wind turbine is around 30 kWh per year which means that the wind conditions studied would not be the best. At the end of the chapter is expected to show which kind of premises would be the most profitable according to the wind potential and other technical aspects.

The results analyzed show that the hypothetical facility in Madrid would work the 25% of time during the year at its nominal power while in Prague only the 3,5% of the yearly time would be operating as its nominal power.

To conclude the potential wind analysis which compares Prague and Madrid is important to highlight that both locations would be discarded in a real situation due to the poor wind speed values. Madrid would a better location from the wind potential point of view but still not suitable for installing a facility of Vortex wind turbines.

5.6 Economy analysis

Since it is known that the wind conditions for the locations chosen, Prague and Madrid, it has been decided to make an economy study from the profitability point of view. It means that the aim of this subchapter is to explain which would be the minimum conditions of the wind potential for the installation of the Vortex turbine is profitable.

The analysis of the economical part has been developed thank to a software called SW EFEKT developed by the department of Economics and Management from Czech Technical University. This software covered all needed aspects required for the study and provided many extra information in addition to the main results.

The file contains macros which simplify the understanding of the study for obtaining the minimum price per kWh, payback period, IRR and sensitivity analysis of the economy project. The main advantage of this tool was the time savings for trying different scenarios; Best wind features, optimal wind features, minimum wind features for being profitable and other conditions about different number of Vortex turbines installed or different lifetime.

5.6.1 Assumptions

As it is mentioned before, the target of this part of the study is to determine the break even point of the investment. For that reason, it is necessary to fix all other parameters according to assumptions and size calculations of the theorical wind facility.

The first assumption is referred to the investment. Potential investors would assume three different kinds of investment costs for the facility: the turbine device, the batteries and other components which cover; Regulator, wire connections, inverter and other control systems.

Regarding the lifetime, the project would stay 35 years. The reason of choosing this number, is because It does not make any sense to maintain or extend projects of low power more than this period. It is important to highlight that Vortex turbine test simulations showed that the lifetime could be until 96 years being optimistic but as it is well known reaching this life period is not possible. The lifetime value has been simulated by Vortex Bladeless Company and the conditions are unknown for this project, so this value is only additional data provided but not used for computations.

To continue with the assumptions given, operating costs are divided into three main parts which covers all the aspects required for this study: Maintenance, Insurance and overhead costs.

Taxes of Spain are in the rate of 21% for this kind of projects and the discounted rate is around 8 % [79]. Price of electricity is 0.1155 €/kWh taken on April 2018.

Depreciations are according to each electronic device. For the Vortex turbine it has been decided all the lifetime because it is the same application that for the other conventional micro wind turbines and photovoltaic modules, for batteries has been taken 5 years of the 8 years if lifetime. However, for the other devices it has been taken the depreciation of 10 years of 20 considered as lifetime.

To conclude this part, it is important to highlight that the project has been studied from the investment of one Vortex wind turbine of 100 W, for simplifying calculations and analyses the procedure generally as possible which means that keeps out of the scope the assumption of having more turbines in the facility.

5.6.2 Economy results

Keeping in mind the assumptions explained before is possible to generate an hypothetical project whose target would be to determine which is the best option to install this technology.

The possible scenarios according to the facility feasibility would be: Connected to the grid with combined installation with PV panels; connected to the grid without other type of supply; grid-off facility (isolated system).

The first scenario covers the possibility of selling the energy produced by the facility. Grid-on facility must be able to be competitive for the electricity market prices. It means that the minimum price for selling the electricity should be lower than the prices offered by other suppliers.

Regarding the combined PV and Vortex facility, where the energy resources are much bigger (it is taken energy combined from the Sun and wind) which means that the operating hours and generation per year are higher than simple Vortex installation. This scenario should be more profitable than the first one because the addition of technologies increase the power density in the facility.

The last scenario is according to grid-off option when the facility delivers energy to an isolated system on premises where is not possible to connect the customer to the grid for supplying electricity.

Once explained the scenarios, and keeping in mind the assumptions given, the results obtained from this theorical study conclude in the explanation of the most suitable scenario for this technology.

Table 18. Grid- on Scenario

Operating hours (h/year)	Min. price available (€/kWh)	Market price (€/kWh)
2700	0.2513	0.1155
3100	0.2188	0.1155
5900	0.1153	0.1155

The results showed in the table above represents the calculations for facility locations which would have a determined number of operating time at its nominal power. As can be seen, the first two theorical locations which have 2700 and 3100 yearly working hours, the minimum price obtained for the investment of one Vortex turbine is more than the double than the electricity market which means that the installation would not be able to sell its energy.

For finding an optimal facility whose selling price was close to the break even point, would be necessary to operate 5900 hours. It is concluded that it is not possible to find any location with these features so it is possible to confirm that is not profitable to install this facility in a connected grid- on system.

Regarding the mixed scenario it is kept in mind one photovoltaic module of 100 W combined with one turbine of 100 W of Vortex technology. However, the results of this scenario are still not good enough for the market competition, the minimum price obtained for 3100 operating yearly hours (sum of PV and wind turbine) is around 0.17 €/kWh. It can be observed that there exist a better situation and even if the size of the facility grows (increase the number of PV panels and turbines) would be possible to reach a competitive price for selling the electricity at the market price. The combined facility has 2 main advantages: Using two different resources at the same time (wind and Sun) and the investment of the photovoltaic panels which would be cheaper than the turbines due to the grade of trading they have.

Table 19. Study comparison of minimum prices

Grid On	Vortex Facility Price	Combined Facility Price	Electricity Market Price
Minimum Price (€/kWh)	0.219	0.183	0.115

To conclude, it is important to highlight that this kind of technologies are available for mostly locations in the world which means that is also possible for that places where there is not possible to install a grid system. Vortex and other wind technologies and photovoltaic facilities are the most suitable sources to generate off-grid electricity. For this scenario is necessary to make a particular study and determine the premise resources.

6. Conclusions

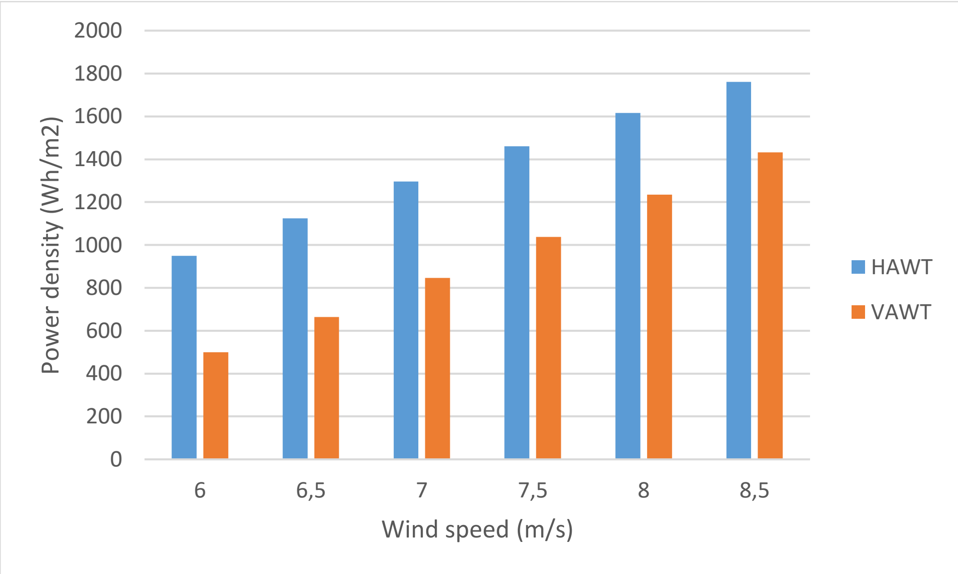
In this master thesis, it has been analysed the situation of the new developing kind of wind turbine Vortex bladeless. It has been explained how the turbine works, which technology base it uses and the size and physical features which would be advantageous for the current low power wind turbine market.

There are currently two kind of wind turbines in the market, Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines. The first type is more developed due to its history. HAW technology is the most manufactured for wind turbines, the types available are conventional turbines, multirotor and many other technologies that have been improved for many years.

It has been realized that in HAWT, the turbine has to be faced always against the wind and it meant that the structure required shows problems of maintenance and operation. It is one of the biggest disadvantages for this kind of technologies and impacts in the LCOE stud increasing those costs.

Regarding maintenance problems, VAW technologies started to be developed according to the impossibility of improved the design of horizontal axis wind turbines and the results so far, about the power density of both kinds of turbines can be seen in the next graph.

Graph 12. Power density of Horizontal and Vertical technologies



Source: Wind works. Paul Gipe [80]

As it is shown VAWT offer less power density but according to the raising wind speed, the power of both technologies trend to be the same. That is why researchers are developing vertical axis turbines as solution of problems which HAWT presents.

It is chosen the graph of Mr. Gipe to show the current situation about HAWT and VAWT because in this project is checked that the different technology groups are being developing at the same time and the conclusion is to confirm that HAWT presents more maintenance problems but are technically more developed. However, vertical axis turbines show many advantages specially from the environmental point of view.

The specific comparison of Vortex with HAWT is that this new technology is a type of turbine which require lower operating costs than horizontal axis turbines. It is not necessary to face the Vortex to the wind direction which makes the control devices simpler or even not necessary.

On the other hand, Vortex does not show as much power output as horizontal axis wind technologies have which limit the production and makes it less competitive in the trading markets. Conventional low power turbine models have at least 300 W peak output while Vortex has only 100 W.

According to the economy analysis computed in this project for the market comparison, it is concluded that Vortex technology has an LCOE higher than other turbines but it is necessary to keep in mind that there only exist prototypes of Vortex turbines. This situation could reduce the LCOE for this turbine in the future.

To continue with the comparative analysis of VAWT, it is important to highlight that Vortex Technology presents factors which would be interesting to show. Usually VAWT offer better benefits due to the low operating costs. For the case of Vortex are even lower than the vertical axis technologies. Furthermore, the lifetime of this new technology would be much higher if the simulations with the prototypes are not mistaken, which means that the benefits offered, make Vortex more competitive turbine inside the VAWT market.

Regarding the size and weight of the turbine it is important to highlight that for the case of Vortex technology, the turbine shows good features for being installed in roofts and special foundations were there exist limits of volume or mass.

OpenLCA software results showed that Vortex turbine materials represented a lower environmental impact when it is compared with other turbine models which are in the current market, this is due to the use of less assembling components in the manufacturing process.

OpenLCA software consists on a data collector system which measures and evaluates the percentages of materials that could affect in different stages of the environment. For the particular analysis given it has only been taken the results for Human toxicity, ozone depletion layer and climate change.

Human toxicity results show mainly which are the products and materials which could affect more in case of there exist direct human exposition during continuous periods of time.

Regarding the ozone layer depletion outcomes, it can be observed the percentage and components which contribute more to the ozone depletion. Furthermore, the complement of climate change results showed, explain the most aggressive material emissions which raise the climate change process.

The conclusion of this part is that the most dangerous materials of the Vortex turbine manufacturing come from the Glass fibre mainly. This is because the complex processes needed to create this fibre and put into the mast of the turbine according to the expectations of flexibility, temperature and strength. All the graph explanations about this concept are included in the appendix as extra information according to the calculations obtained.

Moving to the environmental impact, it is realized that the material amount used for this technology is lower than many others which means that wastes after the lifetime would be significantly lower. Furthermore, according to the noise topic, this study has collected all the information found about levels of noise and it is determined that Vortex has the advantage of being one of the turbines which produce less noise and it would not have restrictions in the installation of it.

Finally, concerning to the feasibility analysis of the location case study, it has been obtained a lot of results and conclusions which could be interesting discussions for other projects.

The part of the comparison analysis between Spain and Czech Republic showed interesting results about the different situation in each country. The wind potential study for the main cities Prague and Madrid allows concluding that none of those places are suitable for the installation of Vortex Wind Turbines but for the case of Madrid the wind conditions for technical analysis are almost 10 times better than for the Prague. However, the final decision for determining in which place this facility should work better, could change due to other many factors, for instance, the renewables promotion of each country, the different electricity prices, investment and loans offered for each country.

The economic part of this Master Thesis aims to determine the optimal wind conditions of the location for making a theorical Vortex installation project profitable. For this reason, in this project it was decided to analyse 3 possible scenarios in which the facility could be installed.

The first one was Grid-On scenario whose target was to determine the investment study in case of all the outcome were sold to the market.

The second scenario was the proposal of installing a combined facility among PV panels and Vortex Turbines. The results obtained of this case, were better than for the first one but still not profitable for grid on connections. This proposal has not been computed accurately because depending on the location, the photovoltaic modules could producer more or less electricity, so it would be necessary to make an individual study for each situation.

The last scenario mentioned was about the possibility of installing the turbines in isolated places (Grid-Off) which there is not availability to connect it to the grid. For this case, it could be created many other sub scenarios which would be discussed in economic terms. So, in this study it is only mentioned that the Vortex Wind Turbine would be only profitable in Grid-Off places under other conditions of the location.

The results obtained from this analysis are interesting because It has found out that it could be better option if many turbines for the same facility were installed due to different installation sizing. The minimum number of turbines would be 6 according to the assumptions explained in the case study and standard conditions of the premise.

The summary of the investment study given in this project is:

Table 20. Investment analysis

Investment (€)	Discount rate (%)	IRR (%)	Payback period (years)
3000	7,96	8,5	22

Source: SW EFEKT from CTU [81]

The study of the Cash Flow analysis was made for a lifetime of 35 years and assuming that the investment does not required any external financial form as loans or other borrowing systems.

The approach of the investment study determined the size of the facility, namely, as it was explained, researching in catalogues for electrical devices there are many possibilities to obtain more accurate prices when the specifications required are clearer. The study takes in mind the battery, inverter and other devices for a basic facility in households.

Finally, is important to remark that developing ways for Vortex technology is not stopped and currently there are many possibilities to improve the turbines and make it competitive even in Grid-On scenarios. It is checked that there is not suitable location to introduce a Vortex facility from the economy point of view but it presents better results for combined facilities (PV and Vortex).

Optimal economy analysis showed that the price per unit of energy for combined facilities is around 20% less than for a complete Vortex installation.

As it is explained, this project is focused on Europe but there are many regions all over the World where Vortex could operate as Grid- off or combined system. The computations given in this study demonstrate which would be the most suitable conditions installing the facility.

7. References

7.1 Web references

[1] "United Nations Framework Convention on Climate Change". 2014. Web address http://unfccc.int/kyoto_protocol/items/2830.php

[2] "AEE". Asociación empresarial eólica. 2011. Web address http://www.aeeolica.org

[3] "IDAE" Instituto de diversificación y ahorro de la energía. 2016. Web address http://www.idae.es

[4] "Bloomberg new energy finance". 2016. Web address https://about.bnef.com/blog/vestas-reclaims-top-spot-annual-ranking-wind-turbine-makers/

[5] "IDAE" Instituto de diversificación y ahorro de la energía. 2016. Web address http://www.idae.es

[6] "Ten of the biggest and the best manufacturers". Wind power monthly. 2015. Web Address https://www.windpowermonthly.com/article/1352888/ten-biggest-best-manufacturers

[7] "Small wind turbines work at low wind speeds" CBS Interactive Inc. C/net application. Web address https://www.cnet.com/news/small-wind-turbine-works-at-low-wind-speeds/

[8] "Vortex Bladeless wind generator". Vortex Bladeless Company. 2015. Web address https://www.youtube.com/watch?v=2_5K4kmnsL4

[12] "Basics of the alternator". Prueba de ruta Blog. 2010. Web address https://www.pruebaderuta.com/alternador-partes-y-principales-fallas.php

[14] "Vortex Offshore". Vortex U.S. 2017. Web address http://www.vortexfdc.com/

[15] "Low power systems connected to the grid". Wikipedia. 2014. Web address https://en.wikipedia.org/wiki/Grid-connected_photovoltaic_power_system

[16] "Creating Community, One Neighbourhood at a Time" The cohousing association of the United States. 2017. Web address http://www.cohousing.org/what_is_cohousing

[17] "Installing and maintaining a small wind energy system" Energy.gov United States. 2017. https://energy.gov/energysaver/installing-and-maintaining-small-wind-electric-system

[18] "Low power systems connected to the grid". Energy.gov United States. 2017. Web address https://en.wikipedia.org/wiki/Grid-connected_photovoltaic_power_system

[19] “Horizontal shaft analysis on wind collector devices”. American wind energy association. 2017. Web https://www.awea.org/faq/vawt.html

[20] “Urban wind generation”. Strathclyde Glasgow. 2017. Web address http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/Urban%20wind.htm

[21] “Windtronics Low Speed Wind Turbines” Solaripedia database. 2017. Web address http://www.solaripedia.com/13/366/windtronics_low_speed_wind_turbines.html

[22] “Gearless Blade Tip Power System” Energy efficient choices blog. 2017. Web address http://www.energyefficientchoices.com/wind-turbine-power-energy/blade-tip-wind-turbine.php

[24] “5 Top wind turbines for low wind speeds”. Green Home Gnome. 2014. Web address https://www.greenhomegnome.com/wind-turbines-low-wind-speeds/

[27] “Optiwind Accelerating Wind Turbine Taps New Energy Fields”. Inhabitat blog. 2009. Web address https://inhabitat.com/optiwind-accelerating-wind-turbine-taps-new-fields/

[28] “Optiwind Amazing New Compact Wind Acceleration Turbines”. 3Rings Blogger. 2012. Web address http://media.designerpages.com/3rings/2012/04/optiwinds-amazing-new-compact-wind-acceleration-turbines/

[29] “Factory direct sales”. Selsam. 2017. Web address http://www.dualrotor.com/

[30] “Factory direct sales”. Selsam. 2017. Web address http://www.dualrotor.com/

[31] “Operating curve California SuperTwinTM” Selsam. 2017. Web address www.dualrotor.com

[32] “Eclectic energy D400 wind generator”. Energy on the hook. 2017. Web address https://www.energyonthehook.com/Eclectic-Energy-D400-Wind-Generator-p/ecld400.htm

[34] “Direct Drive Wind Turbine Market to increase at Steady Growth Rate”. Offshore wind industry blog. Web address http://www.offshorewindindustry.com/news/direct-drive-wind-turbine-market-to-increase

[36] “Eclectic energy StealthGen D400 wind generator power output curve”. Renweable energies. Web address www.renugen.co.uk

[37] “Small Wind Turbine LE-300 Wren at a Glance”. Ecopen Ltd. 2017. Web address http://miniwindsystems.com/small-wind-turbine-e-300-wren/

[38] “Wind turbine set 2 kW model” Voltec Energy Co. 2017. Web address http://voltecenergy.co.uk/wind-turbines/434-micro-wind-turbine-m300-12v-or-24v-with-6-x-blades-charge-controller.html

[39] “Micro wind catalogue” Enair. 2018. Web address https://www.enair.es

[40] “LE 300-wind turbine model” EcoPower shop. 2018. Web Address https://www.ecopowershop.com/le-300-wind-turbine

[41] “LE 300-wind turbine standard” Leading edge power. 2017. Web address

[42] “Vertical-axis wind turbines potential sources of cheaper electricity in urban and suburban areas, researchers discover” Frances Bloomfield. 2017. Web address https://www.naturalnews.com/2017-08-15-vertical-axis-wind-turbines-harvest-turbulent-wind-more-efficiently.html

[43] “Savonius-Rotor”. Egerdach. Youtube license. 2010. Web address https://www.youtube.com/watch?v=ZWxa44m2WKY

[47] “Daerrius wind turbine”. Wikipedia. 2013. Web address https://en.wikipedia.org/wiki/Darrieus_wind_turbine

[48] “Explora turbina de vento” Pinterest. 2017. Web addrerss https://www.pinterest.com/pin/463800461607035054/

[49] “Wind turbine constructions following the Savonius and Darrieus concepts” Abc-Wind Energy. 2018. Web address http://abc-windenergy.de/windturbines/savonius-darrieus.html

[50] “10 most unusual wind turbine desings” Greendiary.com. 2014. Web address https://greendiary.com/10-unusual-wind-turbine-designs.html

[51] “Construction of a helical vertical axis wind turbine for electricity supply” Taylor and Francis online. 2015. Web address https://www.tandfonline.com/doi/full/10.1080/16864360.2015.1077069

[53] “Life-cycle assesstment” Wikipedia. 2018. Web address https://en.wikipedia.org/wiki/Life-cycle_assessment

[55] “Perhaps we are getting closer to fibreglass recycling”. Sara Black. 2017. Web address https://www.compositesworld.com/blog/post/perhaps-were-getting-closer-to-fiberglass-recycling

[56] “Carbon fibre characteristics”. Christine Demerchant. 2018. Web address https://www.christinedemerchant.com/carboncharacteristics.html

[59] “Ecoinvent” OpenLCA software. 2018. Web address https://nexus.openlca.org/databases

[63] “Legal sources on renewable energy: Czech Republic”. Res Legal Europe. 2018. Web address http://www.res-legal.eu/search-by-country/czech-republic/tools-list/c/czech-republic/s/res-e/t/promotion/sum/120/lpid/119/

[64] “Legal sources on renewable energy: Czech Republic”. Res Legal Europe. 2018. Web address http://www.res-legal.eu/search-by-country/czech-republic/tools-list/c/czech-republic/s/res-e/t/promotion/sum/120/lpid/119/

[65] “Boletín Oficial del Estado”. Spanish State. 2018. Web address http://www.boe.es/boe/dias/2018/04/19/index.php?lang=fr

[68]” Electro-Energy Sector in Czech Republic: Present Situation, Opportunities and Threats”. 4liberty newspaper. 2015. Web address http://4liberty.eu/electro-energy-sector-in-czech-republic-present-situation-opportunities-and-threats/

[69] “Atlas de Viento”. Instituto de Diversificación y Ahorro de la Energía. 2018. Web address http://atlaseolico.idae.es/meteosim/

[70] “Atlas de Viento”. Instituto de Diversificación y Ahorro de la Energía. 2018. Web address http://atlaseolico.idae.es/meteosim/

[71] “Topography of Madrid”. Topographic map.com data collector. 2018. Web address http://en-gb.topographic-map.com/places/Madrid-5421985/

[72] “Atlas de Viento”. Instituto de Diversificación y Ahorro de la Energía. 2018. Web address http://atlaseolico.idae.es/meteosim/

[73] “Atlas de Viento”. Instituto de Diversificación y Ahorro de la Energía. 2018. Web address http://atlaseolico.idae.es/meteosim/

[74] “Wind data source” Ustav Fiziky Atmosfery.2018. Web address http://vitr.ufa.cas.cz/male-vte/

[75] “Wind data source” Ustav Fiziky Atmosfery.2018. Web address http://vitr.ufa.cas.cz/male-vte/

[76] “Topography of Prague”. Topographic map.com data collector. 2018. Web address http://en-gb.topographic-map.com/places/

[77] “Wind data source” Ustav Fiziky Atmosfery.2018. Web address http://vitr.ufa.cas.cz/male-vte/

[78] “Wind data source” Ustav Fiziky Atmosfery.2018. Web address http://vitr.ufa.cas.cz/male-vte/

7.2 Book references

[11] “Electricidad y magnetismo”. Francisco Gascón Latasa in collaboration with ETSI Minas Technical University of Madrid. 2010.

[60] “Greening the wind” George C. Ledec, Kennan W. Rapp, and Robert G. Aiello. 2011.

[81] “Vortex Bladeless case study” Developed by Department of Economy, Management and Humanities of the Czech Technical University in Prague.

7.3 PDF references

[9] “Vortex general information”. Vortex Bladeless Company. 2017. Portable document file

[10] “Vortex sheding phenome”. Vortex Bladeless Company. 2017. Portable document file

[13] “Why Vortex Bladeless”. Vortex Bladeless Company. 2017. Portable document file

[23] “WindTronics a wind turbine like no other”. WindTronics Company. 2010. International catalogue

[25] “WindTronics a wind turbine like no other”. WindTronics Company. 2010. International catalogue

[26] “WindTronics a wind turbine like no other”. WindTronics Company. 2010. International catalogue

[33] “D400 support and regulator manual”. Eclectic Energy Company. 2016. Use manual

[35] “Micro wind turbines in the UK domestic sector”. Energy and buildings paper. 2008. A.D.Peacock, Jenkins Ahadzi, Berry Turan. 2014

[44] “Numerical investigation of conventional and modified Savonius wind turbines”. Konrad Kacprzak, Grzegorz Liskiewicz and Krzysztof Sobczak. 2013. Portable document file.

[45] “A double-step Savonius rotor for local production of electricity: a design study” J.L.Menet. 2004. Portable document file.

[46] “Design of a Savonius Wind Turbine” D. Babalas, E. Bafounis, I. Divanis, E. Psomas, A. Simadopoulos. 2015. Academic project.

[52] “Environmental impacts of micro wind turbines and their potential to contribute to UK climate change targets” Benjamin Greening, Adisa Azapagic. 2013. Research paper.

[54] “Vortex Tacoma: Datasheet and user guide” David J. Yañez. Summary paper.

[57] “Guía tecnología de fabricación de vidrio” Entorno Foundation. Guide paper point 3.3, Fabricación de vidrio

[58] “Vortex general information”. Vortex Bladeless Company. 2017. Portable document file

[61] “Energy infrastructure priorities for 2020 and beyond” European Commission. Eur-Lex. 2009. Directive.

[62] “Setting a framework for energy labelling and repealing Directive 2010/30/EU” European Parliament. Eur-Lex. 2017. Regulation.

[66] “Guía sobre tecnología mini eólica” Fenercom. 2012. Official guide.

[67] “Analysis of The Wind Energy Potential of The Czech Republic with Respect to its Integration into The Power System” Jaroslava Orságová, Petr Toman, Jiří Ptáček, Petr Modlitba. 2016. Research paper.

[79] “Renewable energy discount rate survey results”. Grant Thornton. 2017. Official Guide.

[80] “Worldwide Capital and fixed assets” EYcom. 2016. Official guide.

APPENDIX

Circulation and potential Vorticity

The attachment of this project is dedicated to who would know more about how work the tools used for the different calculations and explanations provided.

This first chapter is about the wind potential explanation which Vortex technology is based.

Generally, vorticity is a measure of the local spin of a fluid element given by

$$\bar{w} = \nabla\, x\ \bar{v}$$

So, if the flow is two dimensional the vorticity will be a vector in the direction perpendicular to the flow.

Divergence is the divergence of the velocity field given by

$$D = \nabla * \bar{v}$$

Circulation around a loop is the integral of the tangential velocity around the loop

$$\tau = \oint \bar{v}\ \overline{dl}$$

Once understood this basic meaning of fields theory, it is possible to explain the Kelvin circulation Theorem. This theorem provides a constraint on the rate of change of circulation. Consider the circulation around a closed loop C. Consider the loop to be made up of fluid elements such that the time rate of change of the circulation around the loop is the material derivative of the circulation around the loop given by

$$\frac{d\tau}{dt} = \oint (-2\bar{\Omega}\, x\ \bar{v})\ \overline{dl} - \oint \frac{\nabla \mathrm{p}}{\rho}\ \overline{dl} + \oint F_f\ \ \overline{dl}$$

Where F_f is the frictional force per unit mass.

The Coriolis term ($\oint(-2\bar{\Omega}\, x\ \bar{v})\ \overline{dl}$): Consider the circulation around the curve C in a divergent flow. The Coriolis force acting on the flow field acts to induce a circulation around the curve C.

The baroclinic term ($-\oint \frac{\nabla \mathrm{p}}{\rho}\ \overline{dl}$): From this this term will be zero if the surfaces of constant pressure are also surfaces of constant density. A fluid is Barotropic if the density depends only on pressure. This implies that temperature does not vary on a pressure surface. In a barotropic fluid temperature does not vary on a pressure surface and therefore through thermal wind the geostrophic wind does not vary with height.

The friction term ($\oint F_f\ \ \overline{dl}$) Consider friction to be a linear drag on the velocity with some timescale $F_f = -\frac{\bar{v}}{\tau}$

In other words there will be a trade off between the relative and planetary vorticities. As the curve moves to higher latitude the area normal to the Earth's rotation axis will increase and so the circulation associated with the planetary vorticity increases

Kelvins circulation theorem provides us with a constraint on the circulation around a material curve but it doesn't tell us what's happening to the circulation at a localised point. Another important equation is the vorticity equation which gives the rate of change of vorticity of a fluid element. Consider the momentum equation in the inertial reference frame in geometric height coordinates.

$$\frac{dv}{dt} = -\frac{\nabla \mathrm{p}}{\rho} + F_f - \nabla \phi$$

and noting that the divergence of the vorticity is zero, this gives

$$\frac{d\overline{w}}{dt} = (\overline{w} * \nabla) * \overline{v} - \overline{w} * (\nabla * \overline{v}) + \frac{\nabla \rho \; x \; \nabla \mathrm{p}}{\rho^2} + \nabla \,\mathrm{x}\, \overline{F_f}$$

This is the vorticity equation which gives the time rate of change of a fluid element moving with the flow. So, vorticity can be altered by the baroclinicity (third term) and friction (fourth term) just like for circulation. However, for vorticity there are two additional terms on the right hand side. These represent vortex stretching ($\overline{w} * (\nabla * \overline{v})$) and vortex tilting ($(\overline{w} * \nabla) * \overline{v}$) and will be now be discussed in more detail.

So far it has derived Kelvin's circulation theorem which demonstrated that in the absence of friction or baroclinicity the absolute circulation is conserved. This provides us with a constraint on the circulation around a closed curve but it's non-local. It does not tell us what is happening to an individual fluid element. We would need to know how the material curve C evolves. The vorticity equation tells us how the vorticity of a localised point may change but there is not constraint.

What it really needs to describe the flow is a scalar field that is related to the velocities that is materially conserved. The theory of Potential Vorticity due to Ertel (1942) provides us with such a quantity. It provides us with a quantity that is related to vorticity that is materially conserved. The theorem really combines the vorticity equation and Kelvins circulation theorem.

Potential vorticity conservation is the foundation of our theories of atmospheric dynamics. It allows for the prediction of the time evolution of flows that are in near geostrophic balance and allows us to understand the propagation and generation of different types of atmospheric waves. In each of these systems potential vorticity takes on a slightly different form but the concept is the same. It is a materially conserved tracer that is related to both the velocities and the stratification. We can therefore assume it is advected by the mean flow. Therefore, if the potential vorticity at a point in time is known, and the velocity field is also known then it can work out how the potential vorticity field will evolve allowing us to calculate the potential vorticity at a point a later time from which an inversion can give use the new velocity field.

OpenLCA analysis

OpenLCA is the open source software for Life Cycle Assessment (LCA) and Sustainability Assessment, developed since 2006 by GreenDelta2. As open source it provides the software without license costs.

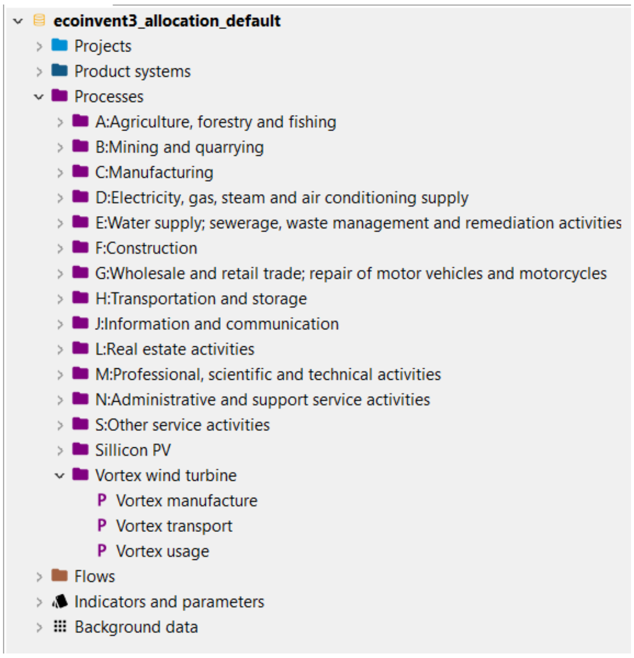
This text focuses on the 1.7 version of OpenLCA and explains basic modelling and environmental impact assessment. This includes step by step instructions for modelling flows, processes, products systems and projects in order to quantify environmental impacts of product systems and projects.

The flows are all products, material or energy inputs and outputs of processes in the product system under study. A flow is defined by the name, flow type, and reference flow property.

picture 15. OpenLCA flow features

It has been created different flows according to the needs of each stage of the Vortex process: Manufacture, transport and usage. All of them together define the complete analysis of the production and life time of the photovoltaic panel.

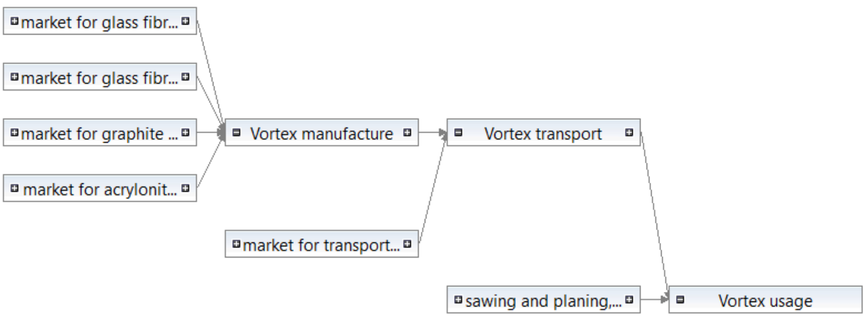
Regarding the processes are sets of interacting activities that transform inputs into outputs. Every process is defined by an output flow as a quantitative reference with the flow type “product flow”, which is either selected or created when creating a project.



picture 16. OpenLCA process features

The processes are the part in which it is distributed each material needed for the application of each Vortex turbine stage.

After defining the previous steps, it precedes to create the product system which contains all processes under study. The product system can consist of one process only or a network of multiple processes and is defined by the reference process.



picture 17. OpenLCA product scheme

In OpenLCA the impacts can be calculate for a product system. The reference process of the product system is used to calculate the impacts for all connected upstream processes of the product system. Furthermore, product systems can be created automatically or manually. The model graph visualizes the product system created and can be modified easily.