UNIVERSITAT DE BARCELONA

Feasibility analysis of repowering a wind farm in Catalonia

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INDEX

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

ρ	Air density
z	Altitude of the wind speed measure
$\langle v^3 \rangle$	Average of the cube of the wind speed
$\langle P \rangle$	Average power
CF	Capacity factor
$CAPEX$	Capital expenditures
k_t	Correction factor
$EBIT$	Earnings Before Interests and Taxes
$EBITDA$	Earnings Before Interests, Taxes, Depreciation and Amortization
EBT	Earnings Before Taxes
η	Efficiency ratio
E	Energy output of the wind farm
FCF	Free cash flow
$NOPAT$	Net Operating Profit After Taxes
NPV	Net Present Value
$OPEX$	Operational expenditures
$p(v)$	Weibull distribution
c	Weibull distribution’s scale parameter
k	Weibull distribution’s shape parameter
$P(v)$	Wind turbine’s power curve
v	Wind speed
$\langle P_d \rangle$	Wind’s power available

ABSTRACT

This study aims to analyze the economic viability of repowering a 20 years old wind farm located in the Province of Tarragona, in Catalonia/Spain (Les Colladetes Wind Farm).

A model to calculate the electricity produced by the wind observed is developed using four scenarios, each one considering the substitution of the 660 kW existent turbines for one with the nominal power varying from 2,000 kW, to 2,500 kW, to 3,300 kW, to 5,000 kW.

The number of new turbines are estimated in compliance with the recommended spacing distances for wind turbines and the regulation that allows up to a 40% increase of the actual installed power without needing new permits.

A project finance model is developed to calculate the net present value of each scenario, taking as inputs the total energy produced by each type of turbine, their estimated capital cost and other relevant parameters. The best scenario is given by the alternative that provides the highest financial return.

Results show that for three scenarios the repowering of the wind farm is highly profitable. In the best case (scenario with the 3,300 kW turbine), the investment of €36.3 million is payed back in 5.24 years and gives a net return (NPV) of €42.1 million.

1 - INTRODUCTION

Over the last years the world has been experiencing a growing concern about the emissions of greenhouse gases (GHG) to the atmosphere as well as their impact on the increase of the global temperature. Around 25% of the emissions of GHG are related to energy generation, especially from burning fossil fuels (1).

Globally, the power generation is historically dependent on the fossil resources. Since the beginning of the 90's, the electricity sector has been reliant on fossil (coal-fired, gas-fired, diesel) thermal power plants. Including nuclear power plants, they consistently accounted for more than 50% of the world's installed capacity.

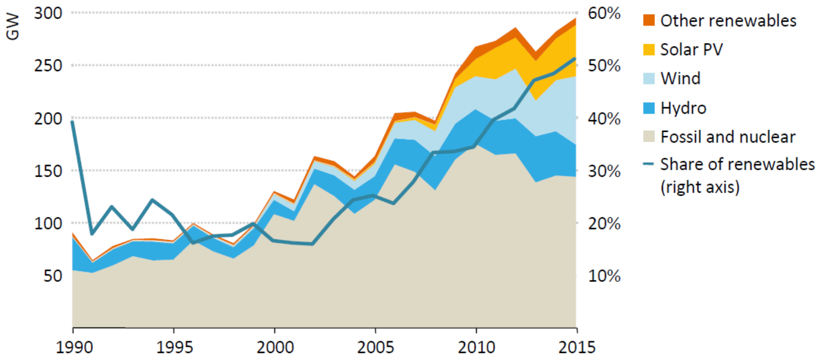

Figure 1: World renewables-based power capacity additions by type (2)

To reduce the amount of GHG coming from the power sector, most countries have created public incentives and have been encouraging the transition of the actual electricity matrix to a decarbonized one. In this context, the renewable resources have been playing an important role to (i) meet the growing global energy demand while (ii) reducing the carbon intensity of the energy sector.

As it is seen in the Figure 1, up to the 2000's, the only renewable source with relevant installed capacity was hydraulic energy, which since then gave room to the called "new renewables" – solar and wind.

Due to a series of factors, including technology development, cost reduction and oriented public policies, wind energy has been presenting some of the highest increases in investments and installed capacity. Between 2012 and 2016, the installed capacity had grown by 15% per year on average. This trend of growth is reflected by the forecasts of the future energy generation, where wind energy is found to increase the installed capacity from the actual 486 GW to 3,000 GW in 2050 (3).

In Spain, the electricity mix have a relatively low GHG emissions factor. Approximately 53% of the matrix has near zero direct emission (32% of renewables and 21% of nuclear) and 32% is composed by a low emission fossil resource – the natural gas. Amid this context, wind energy has a high penetration in the electricity generation, accounting for 18% of the total power generated in Spain in 2015.

The establishment of a stable regulatory framework with adequate remuneration contributed decisively to the promotion of wind generation in Spain (4). From 2004 to 2013, the Spanish production from wind energy resources have increase from 15,744 to 54,334 GWh per year (5). In 2015, the wind energy accounted for 18% of the electricity energy produced in the country.

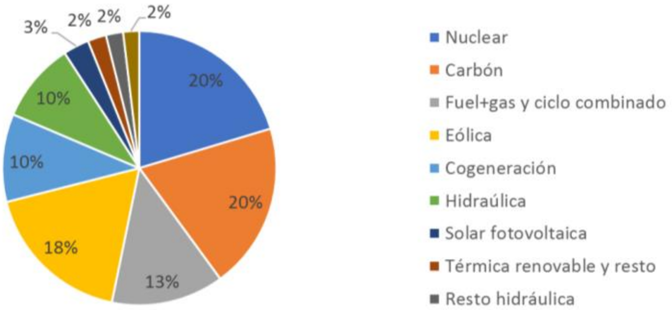

Figure 2: Electricity mix in Spain in 2015 (Percentage of energy produced) (6)

Due to this high increase in the wind energy production, Spain became a top-ranking producer in the world. At the end of 2015, the top five countries in total installed wind power capacity were China (148 GW), the United States (74 GW), Germany (45 GW), India (25 GW) and Spain (23 GW). Nearly 64 GW of capacity was added worldwide in 2015, with the top additions in China (33 GW), the United States (8.6 GW), Germany (4.9 GW), Brazil (2.7 GW) and India (2.3 GW). The global capacity growth rate in 2014 was 14% (7).

Together with that, Spain has taken much of its existent wind potential. However, some of the wind farms built are getting closer to the end of their lifetime and the possibility of repowering them makes even more sense. In addition, the efficiency gap of the technologies applied and the current technologies increasingly contribute for the economic viability of the repowering project.

Repowering the current wind farms is becoming an attractive alternative in Spain due to three main reasons:

(i) The wind generators technology had experienced a significant increase of efficiency over the last decade[1];

(ii) Approximately 50% of the wind capacity in Spain have 10 years or more (8);

(iii) Once they were built firstly, most of these old wind farms are located at some of the country's best locations regarding to the energy potential.

This study aims to evaluate the economic feasibility of repowering a given wind farm in Spain in light of the wind technology advances presented over the last years. The wind farm chosen is located in the Province of Tarragona, in Catalonia. This location was chosen because of its high wind potential[2].

In the next chapters, it will be presented the theoretical foundation to develop such analysis. The chapter 2 aims to present the physics basis of wind generation. The chapter 3, to the technical aspects of a wind farm repowering. In the chapter 4, it will be presented the specific information of the wind farm under analysis. The chapter 5 is dedicated to present the methodology of the wind generation model and the economic model developed for this study and the chapter 6 to present the results of these models.

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[1] An assessment prepared for the USA's scope found that the average capacity factor of wind farms increased from 25% to more than 40% for the projects launched in 1998-1999 and 2014 (9).

[2] See Figure 18.

2 - THE WIND RESOURCE

The wind energy utilization is achieved by transforming the kinetic energy contained in the winds into rotational mechanical energy of the turbine blades and subsequently converting into electric energy.

To quantify the energy contained in the winds, the wind resource is characterized by a Weibull distribution estimated by registers of wind speed samples over long periods (at least one year). This makes possible to express mathematically the average behavior of the wind in that location and to predict it with a reasonable degree of confidence.

A Weibull distribution is completely defined with two parameters: the shape parameter, k, and the scale parameter, c. Its expression is represented by the equation 1, as function of the wind speed, v.

$$p(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \qquad 1$$

In practice, the Weibull distribution parameters can be calculated by the application of the Minimum Squares Method on a historical series of the wind speed in a location, typically at 10 m. The parameters k and c of the Weibull distribution are given by the method explained in the Annex II.

It is interesting to situate the rotor as high as possible as the wind speed increases with the height. Moreover, at higher altitudes the wind becomes more uniform so that the difference in velocity between the upper and lower ends of the rotor and the blades is reduced by the less difference in stress on the rotating plane of the rotor.

On the other hand, the height of the tower presents the limitations due to a greater structural resistance and a higher cost of investment and installation. Therefore, the height of the tower in practice is obtained through a balance between the use of energy and the higher costs represented by a tower of greater height.

To calculate the Weibull distribution at different heights, it is necessary to make some adjustments in the Weibull distribution obtained for 10 m height. The method relies in adjust the parameters k and c (calculated for 10 m) based on the relation of the altitudes. The equations are:

$$k' = k\left(\frac{1-0.088\, ln\left(\frac{z}{10}\right)}{1-0.088\, ln\left(\frac{z\prime}{10}\right)}\right) \qquad 2$$

$$c' = c\left(\frac{z'}{z}\right)^{\beta} \qquad 3$$

Where k' and c' are the Weibull's parameters at height z'. The parameter β is given by the equation 4.

$$\beta = \frac{0.37 - 0.088 \ln c}{1 - 0.088\, ln\left(\frac{z}{10}\right)} \qquad 4$$

Once the Weibull distribution was calculated at the height of the turbines' hubs, it is possible to calculate the available power from the wind at that height.

$$\frac{\langle P_d \rangle}{A} = \frac{1}{2}\, \rho\, \langle v^3 \rangle \qquad 5$$

There is a physical limit of the maximum power that can be extracted from the wind, independent of the design of a wind turbine. It is known as Betz's law. As a result, it states that the efficiency limit of any turbine is 59.3%. The turbine efficiency is given by the equation 6.

$$\eta = \frac{\langle P \rangle}{\langle P_d \rangle} \qquad 6$$

To calculate the energy produced by a wind turbine, it is necessary to have the power curve provided by the manufacturer. The power curve correlates the power output of the turbine as a function of the wind speed. For a given wind distribution, the average power output of a wind turbine is:

$$\langle P \rangle = \sum_{v=1}^{25} p(v) * P(v) \qquad 7$$

Another important parameter to compare the performance of wind turbines is the capacity factor (CF). It relates the actual average power provided by the turbine with the nominal power informed by the supplier.

$$CF = \frac{\langle P \rangle}{P_N} \qquad 8$$

To have an idea of the order of magnitude, for the USA, the capacity factor of the wind farms built in 2014 ranged from 29% to 50% (9).

The total energy output of the wind farm is calculated considering the average power of the wind turbines during the period analyzed and the total correction factor (k_t). This parameter takes into account several factors that act reducing the final energy output. The most important correction factors are:

(i) Aerodynamic factor: the loss of aerodynamics by the blades by dirt, rain, ice, snow, etc.;

(ii) Interference factor: interference of obstacles and other wind turbines. The recommended spacing between wind turbines is ten times the rotor diameter in the wind direction and five times in the perpendicular direction (10);

(iii) Availability factor: time that the wind turbine is not operational due to maintenance or repairs;

(iv) Interconnection factor: losses in the lines and equipment of the interconnection with the grid;

(v) Utilization factor: time that the wind farm is disconnected from the grid due to low energy demand or high wind speeds.

So, considering all these factors, the energy output of the wind farm produced in a period T is:

$$E = k_t * \langle P \rangle * T \qquad 9$$

Today, most of the wind turbines deployed are 3-bladed. As will be presented in the chapter 4 and 5, the wind farm that will be studied have this kind of wind turbines and the turbines that will replace the actual ones also are of this type. Further details about the characteristics and advantages of 3-bladed wind turbines are placed in the Annex III.

In the chapter 3 it will be discussed the particularities of the repowering projects.

3 - WIND FARMS REPOWERING

The installed capacity of wind energy has been growing by an average of 21% per year over the last decade (11). As the wind energy capacity is expanded throughout the world, the sites with the best wind potential come to disappear in some locations. With the technological development of the wind turbines, the use of the greatest wind potentials more efficiently may become an alternative economically even more attractive.

With the development of the wind technology, the efficiency of the new turbines is much higher. Their start-up speed is lower (winds of 2.5 m/s) when compared with older turbines (with start-up wind speed of 5 m/s) and the higher hubs make possible to exploit stronger winds. For this reason, repowering a wind farm leads to a noticeable increase in the energy production, although the number of generators installed is reduced (12).

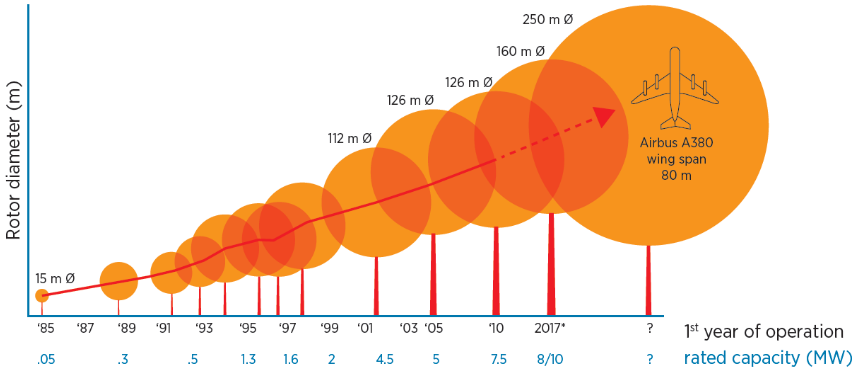

Figure 3: Growth in capacity and rotor diameter of wind turbines (7)

The result is an increasing trend of repowering the existing wind farms. As a reference, the annual repowering demand in the USA may increase from near zero in 2017 to 2.5 GW in 2030 (13).

According to the current Spanish regulation about repowering, the *Real Decreto* 661/2007, the wind farms launched up to 2001 are subject to be repowered with a limit of 2,000 MW of additional power beyond the current installed capacity. Also, if the repowering does not exceed 40% of the current installed capacity, it is not required a new request for access to the system operator (14).

In addition to the possibility of having more energy production, the repowering of wind farm comes with other advantages (12). Below, there are listed some:

(i) Lower environmental impact: quieter equipment and, as the new turbines work at lower speeds, their appearance is more calming and cause less avian mortality;

(ii) Better land use: more productive with fewer machines;

(iii) Less difficult to integrate into the grid;

(iv) The maintenance costs for air generators with over ten years of service increase by 25%. Replacing machines after ten years, once initial costs have been recovered, makes it possible to have newer and more advanced equipment for a significant number of years;

However, it also comes with some disadvantages, especially in Spain (12). Below, there are listed some:

(i) Excessive regulation (national and regional);

(ii) Conflicts of competition between administrations;

(iii) Problems relating to network access;

(iv) Deadlines for authorization takes too long;

(v) Lack of certainty as to the remuneration framework applicable and it leads to difficulty to obtain finance.

The investment costs of repowering are likely to be lower than those of new greenfield projects because it takes advantage of some of the existing infrastructure. According to a recent report from the International Renewable Energy Agency (IRENA) (7), the wind turbine accounts for 64% to 84% of the capital cost for a typical onshore wind power system. The grid connection and constructions in the site (foundations, roadways, etc.) take 13% to 24%. The remaining share is due to land rent, electric installations, control systems and consulting services[3]. The Table 1 summarizes this estimation.

Table 1: Wind farm's capital cost breakdown (7)

Cost share	**%**
Wind turbine	64-84
Grid connection	9-14
Construction	4-10
Other capital	4-10

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[3] Sources consulted: (2), (7), (9), (13), (29).

In a repowering project, by definition, the applicable cost are essentially the turbines and a percentage of some other costs. This can be a consultancy, electric installation replacement and other minor services. Depending on the new turbines and the energy production capacity, a grid connection upgrade may be necessary, as well as some construction works (like foundations reinforcement).

Finally, the decision of repower a wind farm may go through the analysis of the risks intrinsically related to the kind of project. These risks can be divided into four categories, representing the stages of the project development: planning, construction, operational and decommissioning. The Table 2 shows a list with some important risks to consider by development stage of a wind farm.

Table 2: Description of stage-specific risks (4)

Planning	Construction	Operational	Decommissioning
• Expensive site feasibility studies which may result in the project being rejected • Important that these studies are conducted properly in order to successfully pursue further investments • Many wait-and-see investors who do not invest due to risk of losing development costs and due to little benchmark data	• Bad weather may increase downtime and shorten construction time windows • Improvement of infrastructure and supply chain is needed to mitigate construction risk • Competition may create bottlenecks of supply	• Energy production is affected by technological performance via downtime and turbine breakdowns • Uncertain related to operation of large wind turbines which is still a very immature market • Interconnection between production risk and financial risk	• Lack of experience with this stage exhibits uncertainty with regard to environmental impacts such as seabed damage and bird migration • Little experience with the process and costs of decommissioning • Political risk in potential change in decommissioning responsibility

So, in addition to the financial results that this work aims to analyze, the developer must take into consideration a several set of uncertainties that may affect the project's viability and its return.

In the next chapter, it will be presented the wind farm that will be studied for the repowering.

4 - CASE STUDY: LES COLLADETES WIND FARM

In the last chapter, it was presented how the repowering of old wind farms may represent a relevant alternative in the investment decision of new installed capacity. The bottom-line of this concept is to take advantage of the infrastructure already built to deploy more efficient machines.

The case of Spain has some aggravating factors regarding to the update of its existing wind farms. First, Spain is a forerunner country in the wind technology development, having its first gigawatt of installed capacity around two decades ago (8), which implies that the much of the technology in-place today is outdated. Second, comparatively to other important countries in the wind market[4], Spain has a limited area, which also limits much of its potential area to dedicate to the use of wind energy.

For these reasons, it is important to analyze whether or not is economically attractive to make a significant investment in new equipment to make better use of the wind potential.

4.1 - Actual situation

The case study chosen to be object of the analysis of this work is the wind farm Les Colladetes, located in the southern region of Barcelona (Spain), in the province of Tarragona, city of El Perelló. It has 54 turbines that add up to 35.64 MW. It is owned and operated by the company Enervent. It started its operations in 1999, first with 36 turbines (23.76 MW) and then, in 2000, with the remaining 18 turbines (11.88 MW). The Table 3 presents a summary of the main characteristics of Les Colladetes Wind Farm.

Table 3: Les Colladetes Wind Farm characteristics (15)

Characteristic	Value	Unit
Total power	35.64	MW
Number of turbines	54	Units
Turbine manufacturer	Gamesa	
Turbine model	G47/660	

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[4] For example, China, USA, Brazil, India.

As the Table 3 also shows, the wind farm is equipped with the turbine G47/660 from Gamesa. The Table 4 shows the main characteristics of this turbine model and the Figure 4 shows the power curve.

Table 4: Actual turbine characteristics (16)

Characteristic	Value	Unit
Nominal power	660	kW
Rotor diameter	47	M
Rotor area	1735	m^2
Height	45	m
Rated wind speed	16.0	m/s
Cut-in wind speed	4.5	m/s
Cut-out wind speed	25.0	m/s

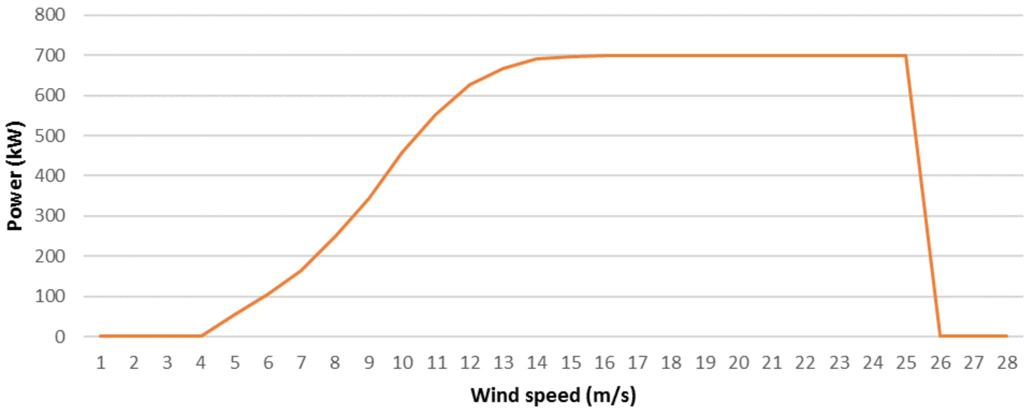

Figure 4: Actual turbine's power curve (16)

Regarding to the wind in the site, the region where the wind farm is placed has one of the best wind potentials of Spain, with more than 500 W/m^2 (17). The wind data for this site was obtained from the historical series of the automatic meteorological station of El Perelló[5].

Other important information about the wind farm is how the turbines are laid out in the site and the distance between them. This will make possible to estimate the number of new more powerful turbines that can be installed in the same area, also having in mind to take advantage of the existing foundations[6].

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[5] Further details are included in the chapter 5.

[6] One important consideration of this analysis is that the existing foundations can be reused and they can support the new equipment load.

The Figure 5 shows how the 54 turbines are placed in the site. This figure also shows how it was separated the turbines into seven groups: G1 with 6 turbines; G2 with 6 turbines; G3 with 12 turbines; G4 with 2 turbines; G5 with 10 turbines; G6 with 8 turbines; and G7 with 10 turbines.

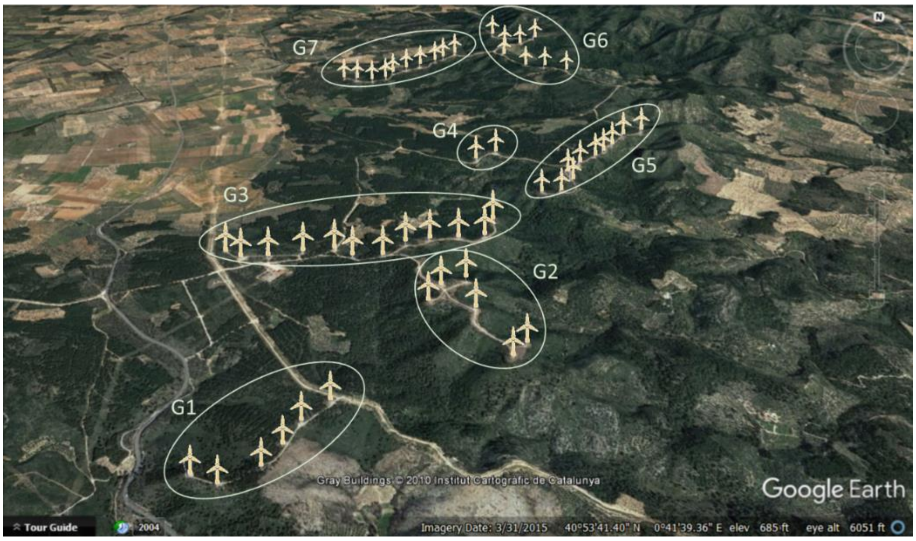

Figure 5: Les Colladetes layout (18)

Using the measuring tool of the software Google Earth it is possible to obtain an estimation of the distance of the turbines from each other. The measure done with this tool find the average distance of 100 m.

The data available does not inform the wind direction. Although this information is highly important to the operation of the wind farm, for the feasibility study it will be considered (i) that the generators can adjust their positioning according to the wind direction and (ii) that the wind direction does not have any effect in the energy production.

4.2 - Repowering plan

This section aims to explain the repowering options to be analyzed for the Les Colladetes Wind Farm. Fundamentally, it is what are the turbine models considered and, based on that, how many new turbines can be deployed to replace the old turbines.

The wind turbine model is an essential factor to calculate the final energy production of the wind farm. There are a huge number of different manufacturers and models of wind turbines in the market, and there is no determined process to define the best one that suites to the wind profile of the wind farm in question.

The Figure 6 shows the top ten world's largest manufacturers of wind turbines. They represent together more than three quarters of the global market share. At first is Vestas, followed by GE Energy, Goldwind and Gamesa.

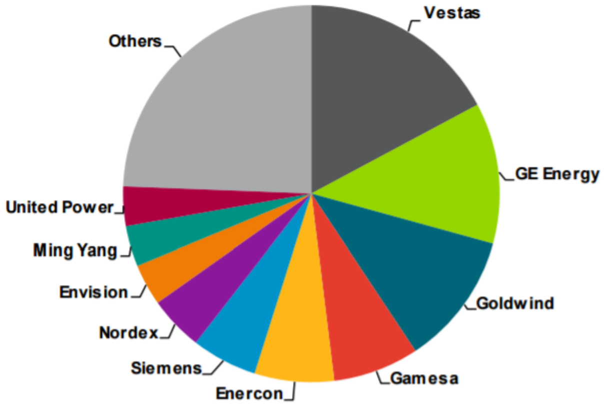

Figure 6: Largest wind turbine suppliers by market share in 2016 (19)

As the Les Colladetes Wind Farm was built with Gamesa's equipment and this manufacturer is a leading player in this market, it seems natural to keep the same brand in the repowering project, just changing the turbine model. In addition, in Spain Gamesa is the supplier with the largest market share of wind turbines, with more than half of the total installed capacity.

Today, Gamesa provides four different turbine models, varying the nominal power: 2,000 kW, 2,500 kW, 3,300 kW, 5,000 kW. Each of them has a variety of possible blades' sizes (indicated by rotor diameter) and tower's heights. The Table 5 presents the main characteristics of these models.

Table 5: Gamesa's wind turbine models (16)

Characteristic	G114/2000	G126/2500	G132/3300	G132/5000
Nominal power	2000 kW	2500 kW	3300 kW	5000 kW
Rotor diameter	114 m	126 m	132 m	132 m
Rotor area	10,207 m^2	12,469 m^2	13,685 m^2	13,685 m^2
Height (min-max)	80 m – 125 m	84 m – 129 m	84 m – 134 m	95 m – 140 m
Rated wind speed	12.5 m/s	10.0 m/s	11.0 m/s	13.5 m/s
Cut-in wind speed	2.5 m/s	2.0 m/s	2.0 m/s	2.0 m/s
Cut-out wind speed	25.0 m/s	25.0 m/s	25.0 m/s	27.0 m/s

In this study, each scenario will have one different type of turbines available. To limit the number of scenarios considered, the rotor diameter will be taken as the as higher possible for each model (the size shown in the Table 5).

To calculate the energy generated by the wind farm, another essential information is the power curve of the turbine. The Figure 7 presents how much power each turbine provides in function of wind speed.

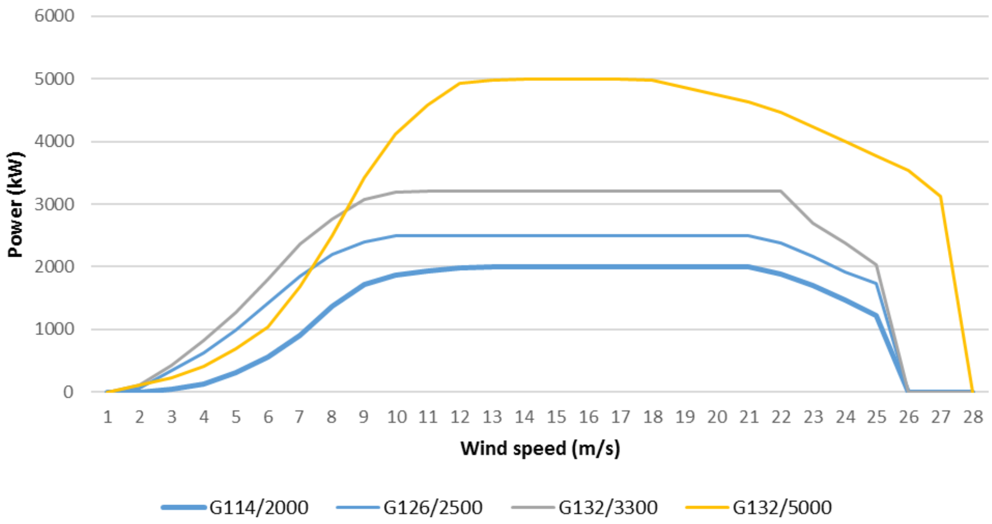

Figure 7: Power curve of the replacement turbines (16)

Finally, it lasts to define the height of the hubs of each type of turbine and the number of turbines that can be deployed in each case. The first will be explained in the section 5.1.2. The second needs information about the recommended spacing between adjacent wind turbines.

As presented in the chapter 2, this parameter must be equal to the distance equivalent to five times the rotor diameter. Considering the layout of the Figure 5, the average distance between the existing turbines is 100 m [7].

So, having presented the main aspects of the wind farm in question, the next step is to explain the methodology used to calculate the energy produced by it and the economic model to analyze the viability of the repowering scenarios.

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[7] The number of turbines for each scenario, calculated based on the recommended distance, will be presented in the chapter 5, Table 7.

5 - METHODOLOGY

After the brief theoretical foundation presented in the chapters above about the wind energy, the wind power generation and the wind farm case, now it will be detailed the methodology used to calculate the viability of repowering a wind farm.

The method developed is based on two main parts. The first is aimed to calculate the energy produced by the wind farm using the local historic wind series and the characteristics of the respective installation in-place and in each scenario considered. It is the wind model.

The second part is aimed to calculate the net present value (parameter used to measure the economic viability of the investment) of each scenario considered, taking as input the output of the wind model (electricity power produced) and also considering some economic and financial assumptions that will be detailed in the next sections.

In summary, the methodology follows the scheme presented in the Figure 8.

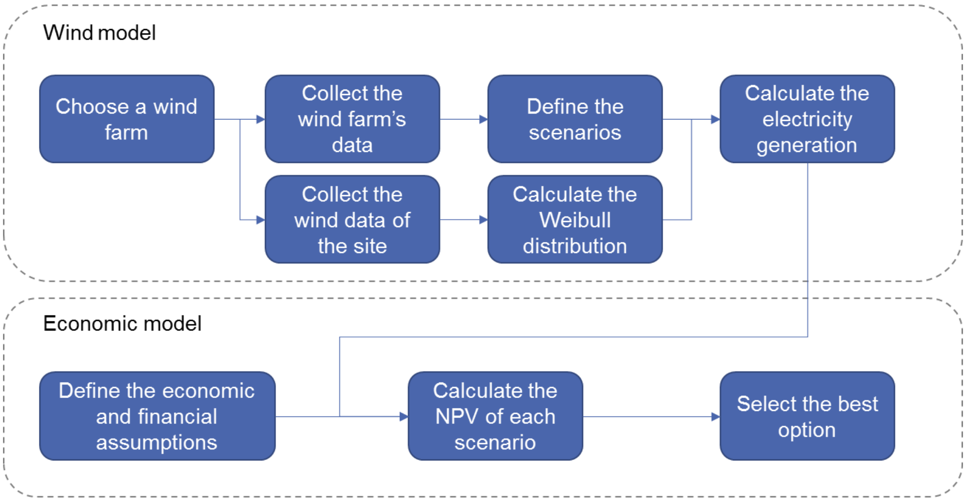

Figure 8: Study's methodology

Throughout the next sections, it will be presented the details of each step done to calculate the repowering viability.

5.1 - Wind model

The wind model workflow starts with the definition of the wind farm and then goes to the data collection. The wind farm definition (Les Colladetes Wind Farm) as well as its general information was presented in chapter 4. Then, the next step is the analysis of the wind data.

5.1.1 - Statistical wind data distribution

As presented in chapter 4, the focus of this study is the wind farm Les Colladetes, located in the city El Perelló, Province of Tarragona, Autonomous Community of Catalonia.

The statistical wind data was collected from the meteorology agency of Catalonia, Meteocat. The available data is from the automatic meteorological station of El Perelló, the closest station to the wind farm, at 10 meters height, each 30 minutes, for the period ranging from February 5th, 1998 to April 30th, 2017. The total number of entries is 334,464, representing 6,968 days or approximately 19 years.

With the wind data in hands, the next step is to group all the wind measures into intervals of wind speed. Each interval was considered with 1 m/s range. For reasons of representativeness, the statistical wind data distribution was calculated for wind speeds with up to 20 m/s, which represents 99% of the data sample. Then, it was calculated the class frequencies, relative frequencies and cumulative frequencies for each interval.

Table 6: Wind speed data distribution (20)

Interval	**Class frequency**	**Relative frequency**	**Cumulative freq.**
m/s	# days (n_i)	$f_i=n_i/N$	F_i
0 < v < 1	36,858	0.111	0.111
1 < v < 2	43,493	0.132	0.243
2 < v < 3	46,281	0.140	0.383
3 < v < 4	46,246	0.140	0.523
4 < v < 5	38,951	0.118	0.641
5 < v < 6	29,200	0.088	0.729
6 < v < 7	21,996	0.067	0.795
7 < v < 8	17,290	0.052	0.848
8 < v < 9	13,418	0.041	0.888
9 < v < 10	10,245	0.031	0.919
10 < v < 11	7,634	0.023	0.942
11 < v < 12	5,715	0.017	0.959
12 < v < 13	4,108	0.012	0.972
13 < v < 14	3,035	0.009	0.981
14 < v < 15	2,147	0.006	0.988
15 < v < 16	1,613	0.005	0.992
16 < v < 17	1,019	0.003	0.996
17 < v < 18	739	0.002	0.998
18 < v < 19	473	0.001	0.999
19 < v < 20	262	0.001	1.000
Total	**N = 330,723**	**1.000**	

After obtaining the wind distribution from the statistical data, the next step is to calculate the Weibull distribution associated to these data.

5.1.2 - Weibull distribution

As presented in the chapter 2, a wind distribution can be properly modeled by a Weibull distribution. This distribution is dependent on two main parameters, k (shape parameter) and c (scale parameter).

The definition of the distribution – which means find these two parameters – is performed by the Least Squares method described in the Annex II, including the summary table of the intermediate steps to find the parameters k and c. As a result of the application of this method, the values of these parameters are the following:

- Shape parameter: $k = 1.35$
- Scale parameter: $c = 5.01\, m/s$

As a comparative analysis, the Figure 9 shows the frequency distribution of the statistical data and the Weibull distribution.

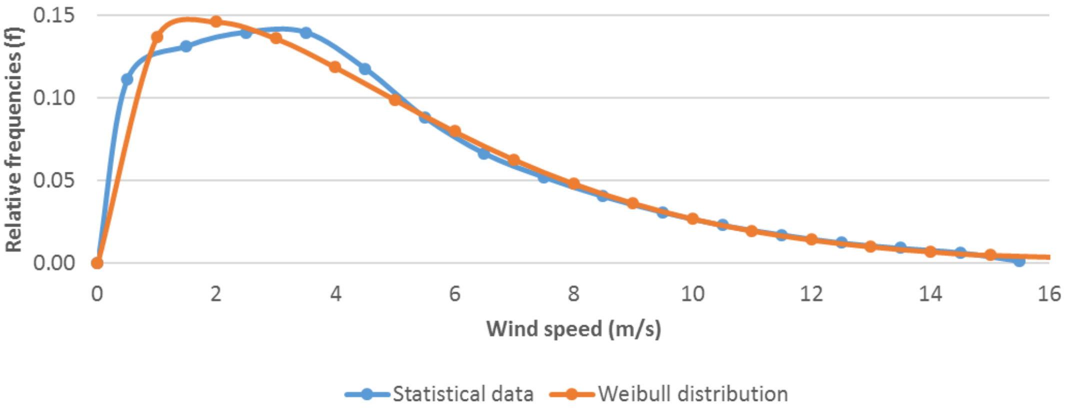

Figure 9: Statistical and Weibull distributions

Finally, to calculate the energy produced by a wind turbine, it is necessary to know the wind distribution at the hub's height. As presented in the chapter 2, the variation of the Weibull distribution with the height is calculated by the equations 2, 3 and 4.

Beforehand, it is needed to know what heights will be used for the wind turbines. As the Table 5 shows, the possible heights for the wind turbines considered range from 80 m to 140 m, besides the 47 m of the existent equipment.

Performing the analysis of the variation of Weibull distributions with this range of heights, it is found that from 125 m to 140 m there is no relevant shift in the distribution that justifies increasing the tower's height. This result is supported by the Figure 10.

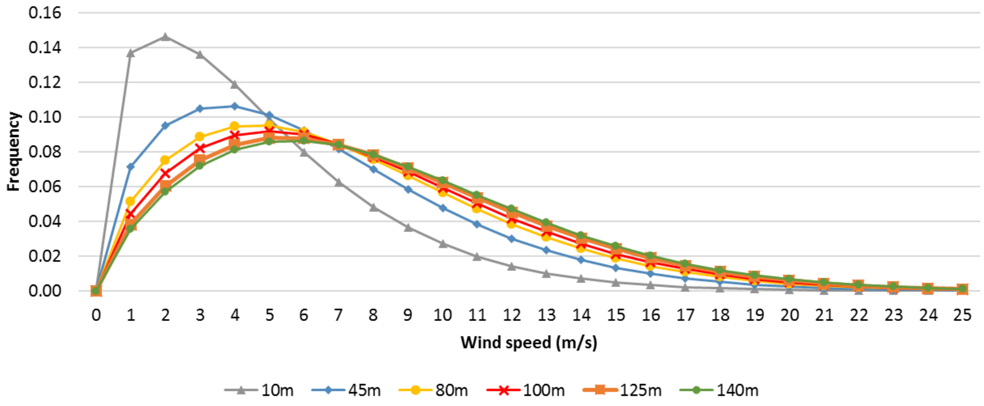

Figure 10: Weibull distributions variation with the height

Then, in order to use the wind potential as much as possible, taking into account the economic costs associated, the height of the wind turbines will be considered the higher as possible up to 125 m.

It is important to notice that the calculation of the wind potential resulting from this analysis (540 W/m^2) gives similar values to the wind potential map provided by the Spanish Energy Agency, presented in the Annex I, Figure 18.

The next step of the model is to define the power and size of the wind turbines.

5.1.3 - Scenarios definition

This section is aimed to present the method used to define the scenarios considered in this work. In this case, the scenarios definition is intrinsically related with the wind turbines specification.

As showed in the chapter 2, the Les Colladetes Wind Farm is equipped with turbines from the manufacturer Gamesa, a renowned company of the wind turbine industry. This work will consider each scenario with the four different models of the wind turbines available from Gamesa, which are: the 2,000 kW model (scenario A), the 2,500 kW (scenario B), the 3,300 kW (scenario C) and the 5,000 kW (scenario D). In each case, as default, it was considered the maximum diameter possible. The power curves of the turbines are presented in the Figure 7.

To conclude the definition of each scenario, in addition to the type of turbine considered, it is necessary to define the number of turbines that replaces the old ones. This number is calculated by the recommended lateral spacing between the turbines, which is around five times the diameter of the rotor – as mentioned in the chapter 2.

By the aerial view of the wind farm – as presented in the chapter 4 –, the turbines were gathered into 7 groups and it was considered that these groups do not interfere on each other.

Applying these restrictions, by the diameter of the turbine in each scenario it is calculated the recommended distance between them. With the average distance of the existing turbines it is found how many turbines of each model can be installed to replace the existing 54.

Table 7: Number of wind turbines by scenario

Group	Actual	A	B / C / D	D’
Group 1	6	2	1	1
Group 2	6	2	1	1
Group 3	12	3	2	1
Group 4	2	1	1	1
Group 5	10	2	2	2
Group 6	8	2	2	2
Group 7	10	2	2	2
Total	**54**	**14**	**11**	**10**

In the case of the scenario D, the installation of 11 turbines of 5,000 kW will give 54% more installed power in the wind farm than before. As mentioned in the chapter 3, the regulation just allows repower a wind farm while maintaining the permits with up to 40% more installed capacity. To comply with the regulation, scenario D will be considered with 10 turbines (D’ in the Table 7).

5.1.4 - Energy produced

The last step – or the output – of the wind model is the calculus of the energy produced by the wind farm in each case defined.

To calculate the average power of the wind turbine in a year, it is taken the power curve of the turbines (shown in the Figure 7) and the wind distribution at the hub’s height of each turbine (shown in the Figure 10), and the it is applied the method presented in the chapter 2.

To calculate the annual energy produced in each scenario, it is considered the average power obtained, the number of hours in a year ($T = 8{,}760\ h$) and the correction factor (k_t) equal to 0.98.

It is also calculated the capacity factor (CF) and the efficiency ratio (η), defined in the chapter 2. In the Table 8 it is presented a summary of the main parameters obtained for each scenario.

Table 8: Energy produced by scenario

Scenario	**Turbine**	**Number**	**Total Power**	**ΔP**	**Annual Energy**	**CF**	**η**
	kW		MW		GWh		
Actual	660	54	35.6	-	87	28%	27%
A	2000	14	28.0	-21%	128	52%	15%
B	2500	11	27.5	-23%	155	64%	19%
C	3300	11	36.3	2%	197	62%	22%
D	5000	10	50.0	40%	206	47%	25%

The Table 8 also provides some key conclusions:

(i) The increase of the installed power (ΔP) of all scenarios are within the Spanish regulation *Real Decreto* 661/2007, that allows repowering up to 40% power increase without new permits;

(ii) The higher the turbine nominal power, the higher the annual energy produced;

(iii) The turbine with 2,500 kW has the higher capacity factor;

(iv) The actual turbine has the higher efficiency ratio.

Also, it is important to notice that the capacity factors found are very high. Even more when compared to the average of the industry: for example, in 2014 in the USA the best wind farms had capacity factors of almost 50%. The reasons to achieve more than 60% may lie in some technology improvement in the last 3 years and the placement of the wind farm in a region with great winds.

The next step of the methodology is to calculate the economic viability of these scenarios taking as input the energy produced in each one.

5.2 - Economic model

The aim of this section is to detail the method used to evaluate the alternatives in discussion to replace the existing equipment. The method chosen uses as a parameter of decision the net present value (NPV) of the free cash flow (FCF) of the investment.

This method is largely used in projects viability analysis. In this work, it will be used a simplification of the method, due to the low availability of detailed data. So, it was applied a version of the method that has a lower level of details but allows to find results with a good degree of accuracy. The method is composed by twelve entries, which are described below, as well as their estimation method:

1) Income increase: the income is the total revenue of the wind farm. Each scenario will consider the income increase relative to the actual scenario;

$$Income = energy\,produced * electricity\,price \qquad 10$$

2) Operational costs increase: is the total cost to maintain the wind farm operating. It is also called OPEX. Because it is not known the values of each service, it is estimated by the following equation. Like the income, it will be considered the operational costs increase relative to the actual scenario;

$$Operational\,costs = average\,cost\,per\,energy\,produced * energy\,produced \qquad 11$$

3) EBITDA: Earnings Before Interests, Taxes, Depreciation and Amortization;

$$EBITDA = Income - Operational\,costs \qquad 12$$

4) Depreciation: is an accounting method of allocating the cost of a tangible asset over its useful life. It is usually considered as a linear depreciation;

$$Depreciation = \frac{CAPEX}{Project's\,lifetime} \qquad 13$$

5) EBIT: Earnings Before Interests and Taxes;

$$EBIT = EBITDA - Depreciation \qquad 14$$

6) Interests: is the charge over the amount of remaining debt in the year;

$$Interests = Interest\,rate * Remaining\,debt \qquad 15$$

7) EBT: Earnings Before Taxes;

$$EBT = EBIT - Interests \qquad 16$$

8) Taxes: is the fee collected from individuals or corporations that is enforced by a government entity;

$$Taxes = tax\,rate * EBT \qquad 17$$

9) NOPAT: Net Operating Profit After Taxes;

$$NOPAT = EBT - Taxes \qquad 18$$

10) CAPEX: is the expenditure in fixed assets. It is equivalent to the total cost of the repowering investment. Because it is not known the values of the equipment (turbine) and services (consultancy), it was estimated by the equation 19;

$$CAPEX = average\ cost\ per\ capacity * installed\ capacity \qquad 19$$

11) Amortization: is the paying off of the debt with a fixed repayment schedule in regular installments over a period of time.

$$Amortization = \frac{Debt}{Loan\ period} \qquad 20$$

12) Free cash flow (FCF): is a measure of a company's financial performance. It represents the cash that a company is able to generate after spending the money required to maintain or expand its asset base;

$$FCF = NOPAT - CAPEX - Amortization \qquad 21$$

After calculating the free cash flow for each year in the project’s lifetime, the valuation of the viability of the project is obtained by summing the free cash flow of each year discounted by the weighted average cost of capital[8] (WACC). This is the NPV of the project, represented by the equation 22:

$$NPV = \sum_{i=0}^{N} \frac{FCF_i}{(1+WACC)^i} \qquad 22$$

Notes:

(i) If the NPV>0, the investment is considered attractive;

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[8] More details about the WACC in the section 5.2.4 - Financial parameters.

(ii) If the NPV of a project A is greater than the NPV of a project B, the project A is considered more attractive than the project B;

(iii) If in a certain point of time the NPV=0, this period is called payback time;

(iv) In the case of a more detailed study, considering a bottom-up cost structure, for example, some other details could be added to the free cash flow calculation, like variations of the working capital. In this study, these variations will be considered negligible.

The Table 9 represents a summary of the process describe above.

Table 9: Cash flow calculation (21)

#	**Entry**	**Calculation**	**Year 0**	**Year 1**	**…**	**Year N**
1	Income					
2	Operational costs					
3	EBITDA	(1) – (2)				
4	Depreciation					
5	EBIT	(3) – (4)				
6	Interests					
7	EBT	(5) – (6)				
8	Taxes					
9	NOPAT	(7) – (8) + (4)				
10	CAPEX					
11	Amortization					
12	Free cash flow	(9) – (10) – (11)				

In the next sections, it will be presented the main parameters assumed in the methodology to calculate the economic viability of the repowering options of Les Colladetes Wind Farm. These parameters are divided into five groups:

(i) Income parameters: price of electricity and price increase;

(ii) Capital expenditures (CAPEX): cost of installation of a wind farm and percentage of the costs applied to a repowering project;

(iii) Operational expenditures (OPEX): costs of operation and maintenance of a wind farm;

(iv) Financial parameters: share of equity and loan in the total capital, cost of capital, loan period and loan interest;

(v) Other parameters: Spanish tax rate and project lifetime.

In the following sections, it is detailed how it was calculated each of the parameters mentioned or the value assumed for them.

5.2.1 - Income parameters

The price of the electricity has an important impact in the valuation of the alternatives for the project. According to the Spanish law, the price of the electricity produced from wind resources is subject to a special regime. The price is regulated by the *Real Decreto-Ley* 2/2013, which charges a fixed tariff of 81.25 €/MWh, independently from the market price of the electricity. Comparative to other countries, Spain has a regulated price to wind energy lower than most of European members, as shown in the Figure 11 (22).

This price is substantially higher than the market price verified for the average period of 2015, 50 €/MWh, and 2016, 40 €/MWh (23).

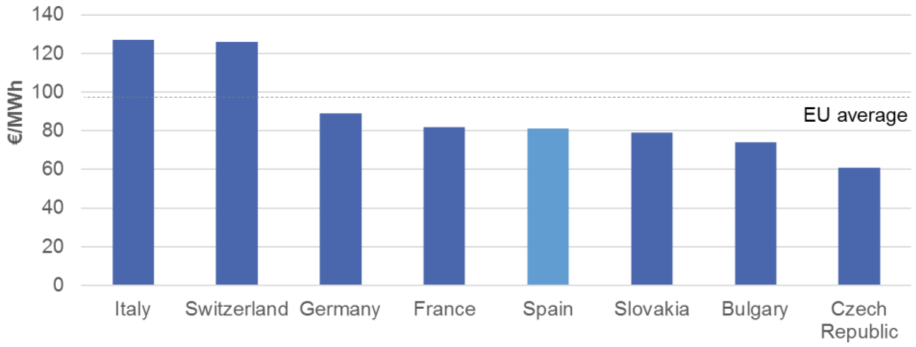

Figure 11: Regulated price of wind energy in the EU (22)

Another important factor to a project's income evaluation is the prices' inflation. For the regulated tariff, according to the same normative, the prices adjustment is indexed by the IPC (Consumption Prices Index, translated from Spanish). The average value of this index in Spain over the period of 1997 to 2017 (the same timeframe of the project's life) is approximately 2% per year (24).

5.2.2 - Capital expenditures

The capital expenditures, also called CAPEX, is the total investment in fixed assets, which means: acquisition of the wind turbines with all its parts (tower, hub, blades, generator, gearbox, etc.), contracting of the civil works, construction of the electrical infrastructure, acquisition/lending of the land, among others.

Because the values of these items are not easily available, especially the wind turbines' prices – which corresponds to around 75% of the investment –, most studies estimate the CAPEX of wind farms by the average "costs per installed capacity"[9]. According to the references consulted, one approximate estimation of this parameter, which will be considered in this work, is 1,250 €/kW.

However, this value refers the total investment for a new wind farm. As it was showed in the chapter 3, some of the existing installations in a wind farm can be reused for the repowering, like the grid connection, the tower's foundations, the electric installations and the roadways. The other items that need to be replaced for repowering – essentially the turbines – account for around 80% of the total investment.

5.2.3 - Operational expenditures

The operational expenditures, also called OPEX, are the costs necessary to maintain the operation of the wind farm. In general terms, it is the cost of operations and maintenance.

The estimation of the OPEX value is usually provided as a "cost per unit of energy produced". For a Spanish wind farm, an average value found in the references consulted is 10 €/MWh (9).

Like the electricity prices, it will also be considered that the OPEX is adjusted annually by the IPC, or 2% per year.

5.2.4 - Financial parameters

For the financial modeling, some parameters were assumed to have conservative values, most of them found in the references consulted:

(i) 80% of the investment needed will be financed (loan) (7);

(ii) The applicable interest is 2.75% per year (25);

(iii) The loan period is 12 years (25);

(iv) The cost of capital is 10% (25).

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[9] (29), (25), (7), (9), (13).

To calculate the discount rate of the cash flow, it is used the weighted average cost of capital (WACC). It represents the effective cost of capital of the project considering its financial structure. By the values indicated, the WACC[10] is 4.20%.

5.2.5 - Other parameters

To complete the list of parameters used to the financial model, first there is the project lifetime. According to the own manufacturer of the turbines considered, Gamesa, the exploitation period is “at least” 20 years. To be conservative, the project lifetime will be considered 20 years (26).

Finally, the last parameter used in the financial model is the tax, which is 30% (25).

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[10] WACC is the weighted average of the loan interest and the cost of capital, considering their shares in the total capital.

6 - RESULTS

Along the last chapters, it was described the methodology used to calculate the output energy of repowering alternatives for a given wind farm in Catalonia, as well as the economic viability of those alternatives and the theoretical foundation that supports that method developed. In this chapter, it will be presented the results obtained from the application of the methodology.

The net present value (NPV) and the payback time of the investment were calculated taking the energy produced in each scenario and calculating their respective cash flows. The cash flows given by the model are presented in the Figure 12 (scenario A), Figure 13 (scenario B), Figure 14 (scenario C) and Figure 15 (scenario D).

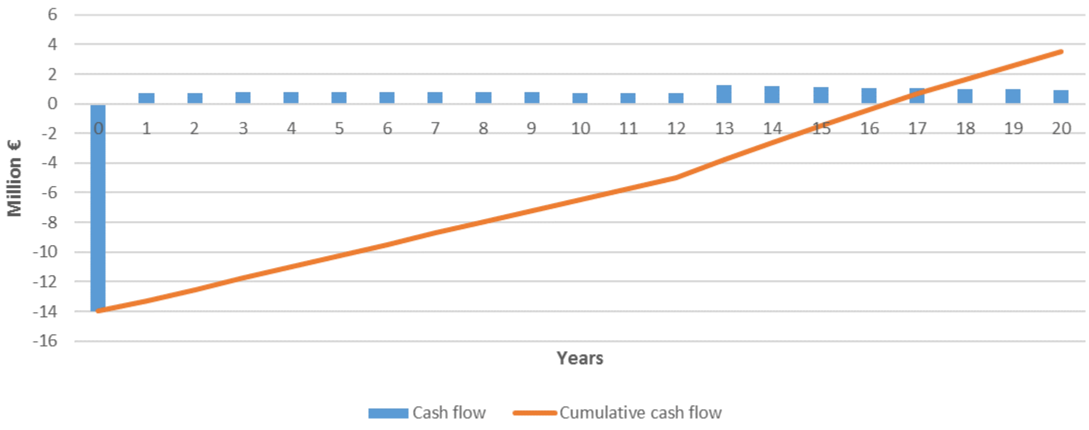

Figure 12: Cash flow of scenario A

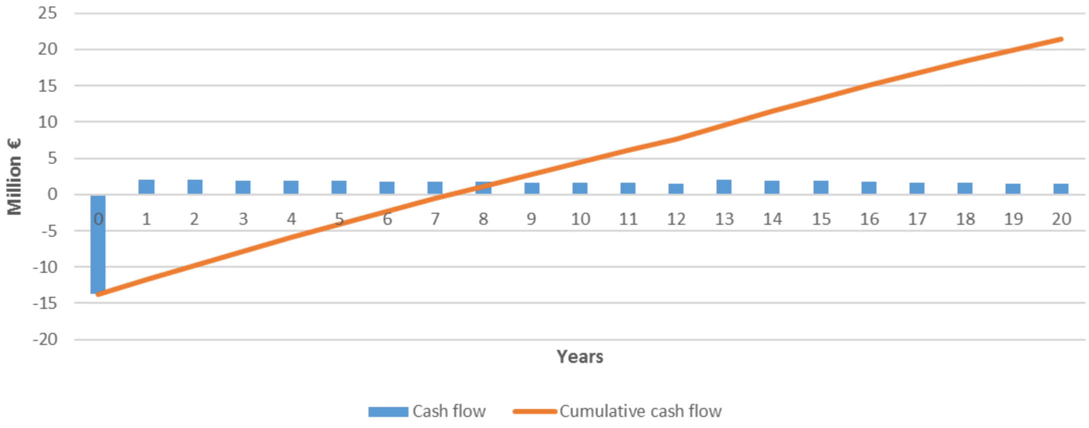

Figure 13: Cash flow of scenario B

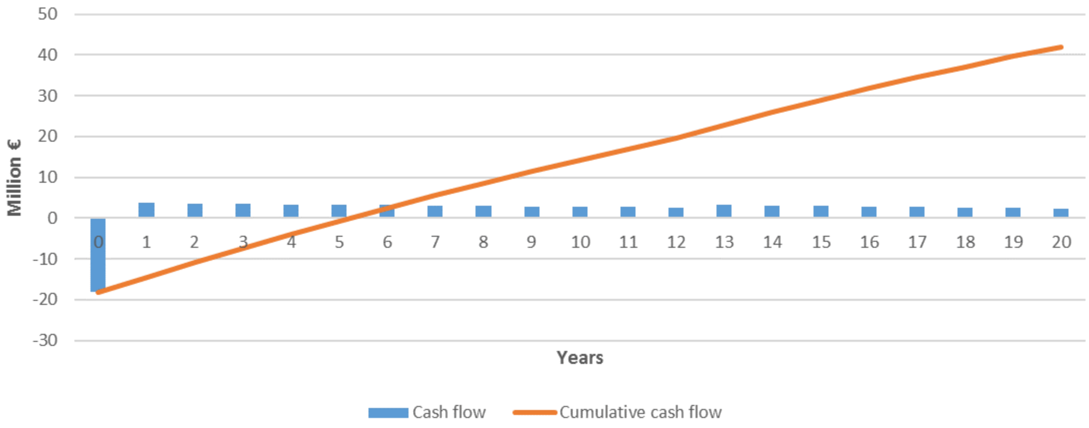

Figure 14: Cash flow of scenario C

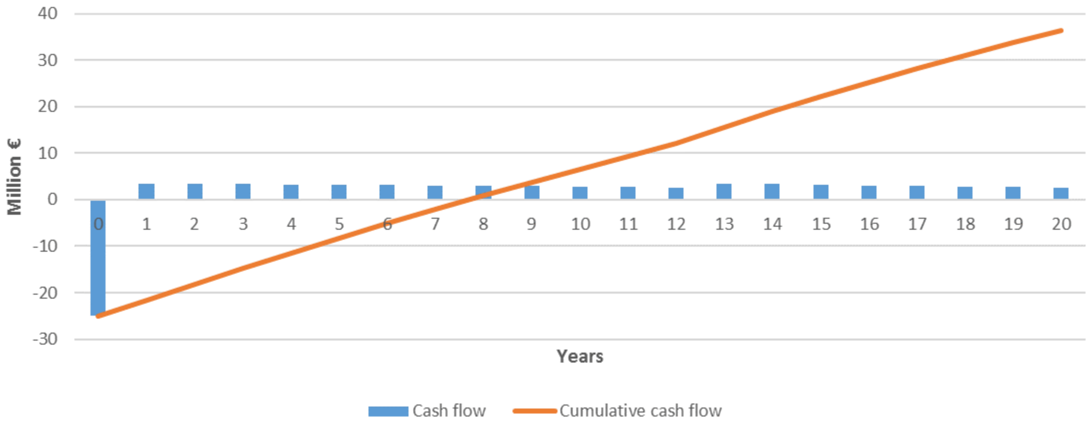

Figure 15: Cash flow of scenario D

As a result, it was obtained the NPVs and the payback times of each scenario. The results are summarized in the Table 8.

Table 10: Summary of the results by scenario

Scenario	Turbine	Total Power	Annual Energy	CAPEX	NPV	Payback
	kW	MW	GWh	Million €	Million €	Years
Actual	660	35.6	89	0	0	0
A	2000	28.0	128	28.0	3.5	16.37
B	2500	27.5	155	27.5	21.4	7.30
C	3300	36.3	197	36.3	42.1	5.24
D	5000	50.0	206	50.0	36.4	7.69

The results show that the best option is the scenario C – which considers turbines of 3,300 kW –, by the NPV and the payback criteria. It shows that the NPV of the investment is €42.1 million and the initial investment is recovered in approximately 5 years and 3 months.

Despite the better attractiveness of the scenario C, scenarios B (turbines of 2,500 kW) and D (turbines of 5,000 kW) also present great returns (€21.4 million and €36.4 million, respectively) combined with acceptable payback times (both with less than 8 years).

Only the scenario A does not show attractive characteristics for the investment, presenting a low return on investment (25%)[11] and a long payback (more than 16 years).

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[11] Reminding that the project's lifetime is 20 years.

7 - FINAL COMMENTS

As could be seen, the energy potential from wind resources have been largely exploited over the last decades throughout the world. One of the reasons is the technology development, which made the economics of wind energy to be improved significantly. With the use of the best wind potentials and the ageing of some of the wind farms located in these regions, repowering the wind farms have become one attractive alternative to increase the financial return of these plants.

This work studied four scenarios to repower a wind farm in Catalonia (Spain) with almost 20 years old. The results found show that there are attractive alternatives to repower this wind farm, taking advantage of the wind potential of the site and the infrastructure in place. Using only 20% of the actual number of wind turbines, but replacing them by others with 3,300 kW that sum approximately the same installed capacity, the energy output of the wind farm is increased from 87 GWh to 197 GWh, or 126% plus. The investment required is estimated to be around €36.3 million, being recovered in 5.24 years.

Besides some uncertainties, like the price of the turbines or historical data of the wind in the site, some acceptable proxies were assumed to develop the model. Given the magnitude of the results found, it seems that a further analysis could be developed to refine the numbers and increase the accuracy of the result.

However, this model suggests that for wind farms (i) with turbines outdated and (ii) located in sites with good wind potential the repowering should be an alternative to be analyzed carefully.

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RESUMEN

Este estudio pretende analizar la viabilidad económica de la repotenciación de un parque eólico con 20 años ubicado en la provincia de Tarragona, en Cataluña, España (Parque eólico de Les Colladetes).

Se desarrolló un modelo para calcular la energía eléctrica producida utilizando cuatro escenarios, cada uno teniendo en cuenta la sustitución de los aerogeneradores existentes con la potencia nominal de 660 kW por otros de 2.000 kW, 2.500 kW, 3.300 kW y 5.000 kW.

El número de nuevos generadores eólicos a instalarse fue estimado teniendo en cuenta el espaciamiento recomendado para las torres y el cumplimiento de la regulación española que permite hasta un 40% de aumento de la potencia instalada sin la necesidad de nuevos permisos.

Se desarrolló un modelo económico del proyecto para calcular el valor actual neto de cada escenario, tomando como entradas la energía total producida por cada tipo de aerogenerador, su costo de capital estimado y otros parámetros relevantes. La mejor situación es dada por la alternativa que ofrece el más alto retorno financiero.

Los resultados muestran que, para tres de los escenarios, la repotenciación del parque eólico es altamente rentable. En el mejor caso (situación con el aerogenerador de 3.300 kW), la inversión de € 36,3 millones se recupera en 5,24 años y además ofrece un rendimiento neto (NPV) de € 42,1 millones.

ANNEX I: LES COLLADETES WIND FARM DETAILS

Figure 16: Les Colladetes Wind Farm situation (27)

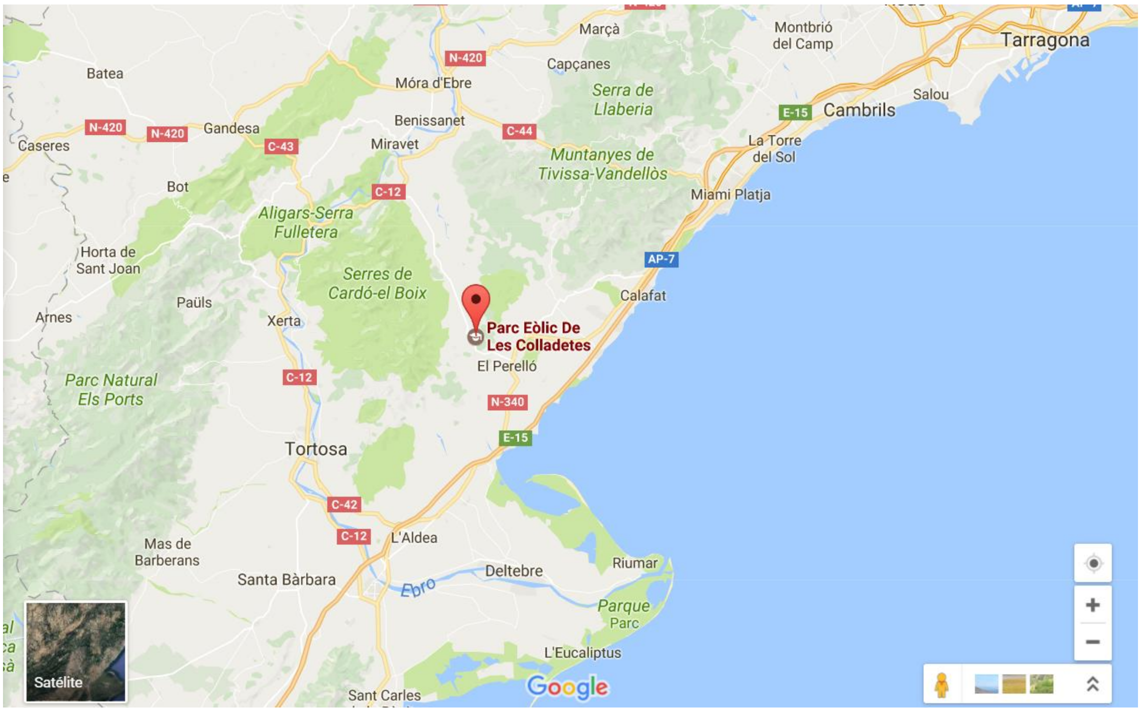


Figure 17: Les Colladetes Wind Farm location (28)

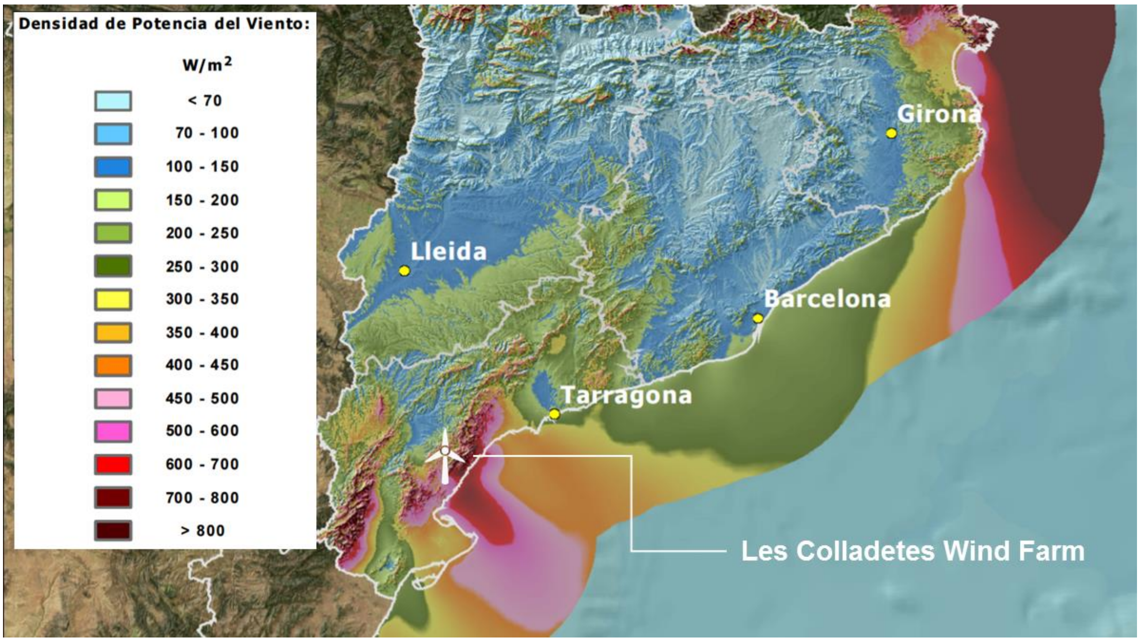


Figure 18: Wind potential in the region of Les Colladetes Wind Farm (17)

ANNEX II: WEIBULL DISTRIBUTION CALCULATION

The calculation of the Weibull distribution based on statistical data obtained from real wind measures is performed by the following steps:

(i) Calculate the classes frequencies of each wind speed interval as in Table 6;

(ii) Calculate the parameters x and y as in Table 11;

Table 11: Weibull distribution calculation (20)

Interval	**Class freq.**	**Relative freq.**	**Cumulative relat. freq.**	**yi**	**xi**	**Products**			
(m/s)	ni (dias)	fi=ni/N	Fi	ln(-ln(1-Fi))	ln(vi)	fi xi	fi xi 2	fi yi	fi xi yi
0 < v < 1	36,858	0.111	0.111	-2.136	0.000	0.000	0.000	-0.238	0.000
1 < v < 2	43,493	0.132	0.243	-1.279	0.693	0.091	0.063	-0.168	-0.117
2 < v < 3	46,281	0.140	0.383	-0.728	1.099	0.154	0.169	-0.102	-0.112
3 < v < 4	46,246	0.140	0.523	-0.302	1.386	0.194	0.269	-0.042	-0.058
4 < v < 5	38,951	0.118	0.641	0.023	1.609	0.190	0.305	0.003	0.004
5 < v < 6	29,200	0.088	0.729	0.266	1.792	0.158	0.283	0.023	0.042
6 < v < 7	21,996	0.067	0.795	0.461	1.946	0.129	0.252	0.031	0.060
7 < v < 8	17,290	0.052	0.848	0.632	2.079	0.109	0.226	0.033	0.069
8 < v < 9	13,418	0.041	0.888	0.784	2.197	0.089	0.196	0.032	0.070
9 < v < 10	10,245	0.031	0.919	0.922	2.303	0.071	0.164	0.029	0.066
10 < v < 11	7,634	0.023	0.942	1.048	2.398	0.055	0.133	0.024	0.058
11 < v < 12	5,715	0.017	0.959	1.165	2.485	0.043	0.107	0.020	0.050
12 < v < 13	4,108	0.012	0.972	1.273	2.565	0.032	0.082	0.016	0.041
13 < v < 14	3,035	0.009	0.981	1.378	2.639	0.024	0.064	0.013	0.033
14 < v < 15	2,147	0.006	0.988	1.479	2.708	0.018	0.048	0.010	0.026
15 < v < 16	1,613	0.005	0.992	1.587	2.773	0.014	0.037	0.008	0.021
16 < v < 17	1,019	0.003	0.996	1.689	2.833	0.009	0.025	0.005	0.015
17 < v < 18	739	0.002	0.998	1.810	2.890	0.006	0.019	0.004	0.012
18 < v < 19	473	0.001	0.999	1.966	2.944	0.004	0.012	0.003	0.008
19 < v < 20	262	0.001	1.000						
Total	**330,723**	**1.000**				**1.390**	**2.453**	**-0.298**	**0.288**

(iii) Calculate the parameters A and B as in the equations below;

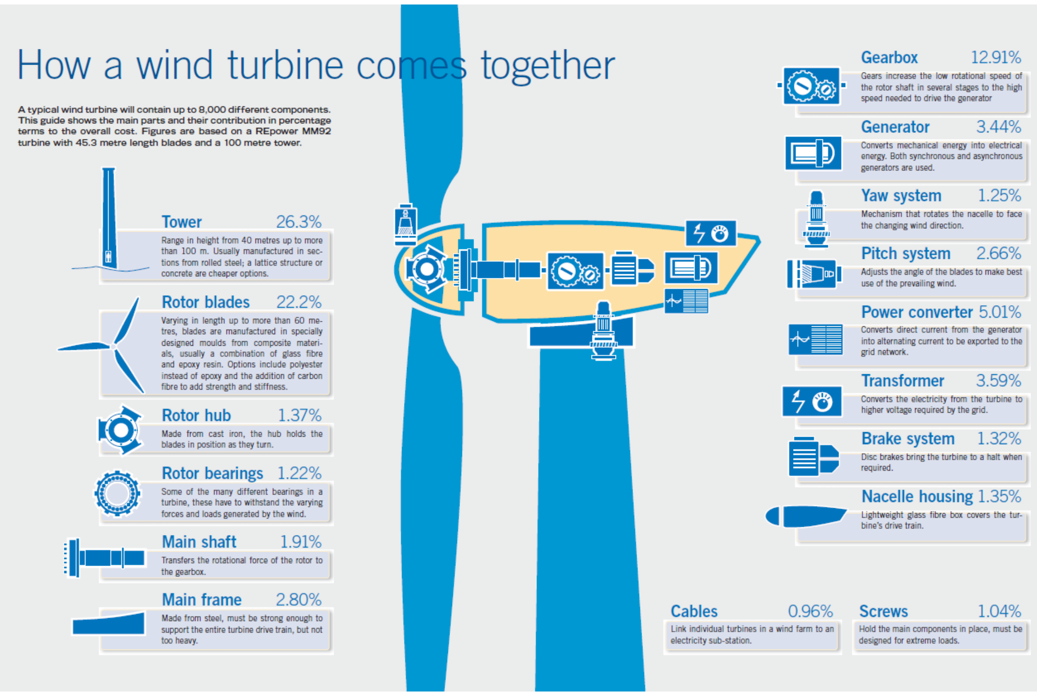
$$A = \frac{\sum f_i x_i y_i - \left(\sum f_i x_i\right)\left(\sum f_i y_i\right)}{\sum f_i x_i^2 - \left(\sum f_i x_i\right)^2} \quad ; \quad B = \sum f_i y_i - A \sum f_i x_i$$

(iv) Calculate the Weibull's parameters k and c as in the equations below;

$$k = A \quad ; \quad c = e^{-\left(\frac{B}{A}\right)}$$

ANNEX III: WIND TURBINES

Modern wind turbines with three-blade rotors are the most common worldwide. Due to the configuration of the most advantageous efforts, this type of turbine does not require additional expensive components such as joints and shock absorbers of the shaft. The noise level is relatively low and the rotor develops a smooth rotation movement, positive aspects for public acceptance of wind energy. In the Figure 19 it is presented the main components of a wind turbine.



How a wind turbine comes together

A typical wind turbine will contain up to 8,000 different components. This guide shows the main parts and their contribution in percentage terms to the overall cost. Figures are based on a REpower MM92 turbine with 45.3 metre length blades and a 100 metre tower.

Tower 26.3%
Range in height from 40 metres up to more than 100 m. Usually manufactured in sections from rolled steel; a lattice structure or concrete are cheaper options.

Rotor blades 22.2%
Varying in length up to more than 60 metres, blades are manufactured in specially designed moulds from composite materials, usually a combination of glass fibre and epoxy resin. Options include polyester instead of epoxy and the addition of carbon fibre to add strength and stiffness.

Rotor hub 1.37%
Made from cast iron, the hub holds the blades in position as they turn.

Rotor bearings 1.22%
Some of the many different bearings in a turbine, these have to withstand the varying forces and loads generated by the wind.

Main shaft 1.91%
Transfers the rotational force of the rotor to the gearbox.

Main frame 2.80%
Made from steel, must be strong enough to support the entire turbine drive train, but not too heavy.

Gearbox 12.91%
Gears increase the low rotational speed of the rotor shaft in several stages to the high speed needed to drive the generator

Generator 3.44%
Converts mechanical energy into electrical energy. Both synchronous and asynchronous generators are used.

Yaw system 1.25%
Mechanism that rotates the nacelle to face the changing wind direction.

Pitch system 2.66%
Adjusts the angle of the blades to make best use of the prevailing wind.

Power converter 5.01%
Converts direct current from the generator into alternating current to be exported to the grid network.

Transformer 3.59%
Converts the electricity from the turbine to higher voltage required by the grid.

Brake system 1.32%
Disc brakes bring the turbine to a halt when required.

Nacelle housing 1.35%
Lightweight glass fibre box covers the turbine's drive train.

Cables 0.96%
Link individual turbines in a wind farm to an electricity sub-station.

Screws 1.04%
Hold the main components in place, must be designed for extreme loads.

Figure 19: Scheme of a typical wind turbine

The wind energy industry found the most efficient technology in wind turbines with horizontal blades with three blades, and consequently it spread throughout the world, completely dominating the market, so that all others fell into disuse.

In this sense, the inventions of the last few years have practically happened in the gradual increase of the size and power of the three-bladed horizontal axis aerogenerators, being this a tendency for the next steps of the wind sector in the world.

The turbines with 3 blades have a better distribution of weight and, therefore, are dynamically more stable. This, in turn, reduces the mechanical forces in the other components of the turbine, especially in the tower. In addition, 3-bladed turbines have less noise due to lower rotational speed compared to 1 or 2-bladed turbines for the same level of energy generated.

ANNEX IV: TABLES OF RESULTS

Table 12: Cash flow of scenario A

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Income	0	3,272	3,337	3,404	3,472	3,542	3,613	3,685	3,759	3,834	3,910	3,989	4,068	4,150	4,233	4,317	4,404	4,492	4,582	4,673	4,767
Operational costs	0	-403	-411	-419	-427	-436	-445	-454	-463	-472	-481	-491	-501	-511	-521	-531	-542	-553	-564	-575	-587
EBITDA	0	2,869	2,927	2,985	3,045	3,106	3,168	3,231	3,296	3,362	3,429	3,498	3,568	3,639	3,712	3,786	3,862	3,939	4,018	4,098	4,180
Depreciation	0	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700	-700
EBIT	0	2,169	2,227	2,285	2,345	2,406	2,468	2,531	2,596	2,662	2,729	2,798	2,868	2,939	3,012	3,086	3,162	3,239	3,318	3,398	3,480
Interests	0	-385	-353	-321	-289	-257	-225	-193	-160	-128	-96	-64	-32	0	0	0	0	0	0	0	0
EBT	0	1,784	1,874	1,964	2,056	2,149	2,243	2,339	2,436	2,534	2,633	2,734	2,836	2,939	3,012	3,086	3,162	3,239	3,318	3,398	3,480
Taxes	0	-535	-562	-589	-617	-645	-673	-702	-731	-760	-790	-820	-851	-882	-904	-926	-949	-972	-995	-1,019	-1,044
NOPAT	0	1,249	1,312	1,375	1,439	1,504	1,570	1,637	1,705	1,773	1,843	1,913	1,985	2,057	2,108	2,160	2,213	2,267	2,322	2,379	2,436
CAPEX	-14,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amortization	0	-1,167	-1,167	-1,167	-1,167	-1,167	-1,167	-1,167	-1,167	-1,167	-1,167	-1,167	-1,167	0	0	0	0	0	0	0	0
Free cash flow	-14,000	782	845	908	973	1,038	1,104	1,171	1,238	1,307	1,376	1,447	1,518	2,757	2,808	2,860	2,913	2,967	3,022	3,079	3,136
Disc. cash flow	-14,000	735	747	755	760	762	762	759	755	749	742	733	723	1,235	1,182	1,132	1,084	1,038	994	952	911
Cum. cash flow	-14,000	-13,265	-12,518	-11,763	-11,003	-10,242	-9,480	-8,720	-7,965	-7,216	-6,474	-5,741	-5,018	-3,783	-2,601	-1,469	-385	653	1,646	2,598	3,509

Table 13: Cash flow of scenario B

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Income	0	5,464	5,574	5,685	5,799	5,915	6,033	6,154	6,277	6,402	6,530	6,661	6,794	6,930	7,069	7,210	7,354	7,501	7,651	7,804	7,960
Operational costs	0	-673	-686	-700	-714	-728	-743	-757	-773	-788	-804	-820	-836	-853	-870	-887	-905	-923	-942	-961	-980
EBITDA	0	4,792	4,888	4,985	5,085	5,187	5,291	5,396	5,504	5,614	5,727	5,841	5,958	6,077	6,199	6,323	6,449	6,578	6,710	6,844	6,981
Depreciation	0	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688	-688
EBIT	0	4,104	4,200	4,298	4,398	4,499	4,603	4,709	4,817	4,927	5,039	5,154	5,270	5,390	5,511	5,635	5,762	5,891	6,022	6,156	6,293
Interests	0	-378	-347	-315	-284	-252	-221	-189	-158	-126	-95	-63	-32	0	0	0	0	0	0	0	0
EBT	0	3,726	3,854	3,983	4,114	4,247	4,382	4,520	4,659	4,801	4,945	5,091	5,239	5,390	5,511	5,635	5,762	5,891	6,022	6,156	6,293
Taxes	0	-1,118	-1,156	-1,195	-1,234	-1,274	-1,315	-1,356	-1,398	-1,440	-1,483	-1,527	-1,572	-1,617	-1,653	-1,691	-1,728	-1,767	-1,807	-1,847	-1,888
NOPAT	0	2,608	2,697	2,788	2,880	2,973	3,068	3,164	3,261	3,361	3,461	3,563	3,667	3,773	3,858	3,945	4,033	4,123	4,216	4,309	4,405
CAPEX	-13,750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amortization	0	-1,146	-1,146	-1,146	-1,146	-1,146	-1,146	-1,146	-1,146	-1,146	-1,146	-1,146	-1,146	0	0	0	0	0	0	0	0
Free cash flow	-13,750	2,150	2,239	2,330	2,421	2,515	2,609	2,706	2,803	2,902	3,003	3,105	3,209	4,460	4,545	4,632	4,721	4,811	4,903	4,997	5,093
Disc. cash flow	-13,750	2,021	1,979	1,935	1,891	1,846	1,801	1,755	1,710	1,664	1,619	1,573	1,529	1,997	1,913	1,833	1,756	1,683	1,612	1,544	1,480
Cum. cash flow	-13,750	-11,729	-9,750	-7,815	-5,924	-4,077	-2,276	-521	1,189	2,853	4,471	6,045	7,573	9,571	11,484	13,317	15,073	16,756	18,368	19,912	21,392

Table 14: Cash flow of scenario C

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Income	0	8,947	9,125	9,308	9,494	9,684	9,878	10,075	10,277	10,482	10,692	10,906	11,124	11,346	11,573	11,805	12,041	12,282	12,527	12,778	13,033
Operational costs	0	-1,101	-1,123	-1,146	-1,169	-1,192	-1,216	-1,240	-1,265	-1,290	-1,316	-1,342	-1,369	-1,396	-1,424	-1,453	-1,482	-1,512	-1,542	-1,573	-1,604
EBITDA	0	7,845	8,002	8,162	8,326	8,492	8,662	8,835	9,012	9,192	9,376	9,564	9,755	9,950	10,149	10,352	10,559	10,770	10,985	11,205	11,429
Depreciation	0	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908	-908
EBIT	0	6,938	7,095	7,255	7,418	7,585	7,754	7,928	8,104	8,285	8,469	8,656	8,847	9,042	9,241	9,444	9,651	9,863	10,078	10,298	10,522
Interests	0	-499	-458	-416	-374	-333	-291	-250	-208	-166	-125	-83	-42	0	0	0	0	0	0	0	0
EBT	0	6,439	6,637	6,839	7,044	7,252	7,463	7,678	7,896	8,118	8,344	8,573	8,806	9,042	9,241	9,444	9,651	9,863	10,078	10,298	10,522
Taxes	0	-1,932	-1,991	-2,052	-2,113	-2,176	-2,239	-2,303	-2,369	-2,435	-2,503	-2,572	-2,642	-2,713	-2,772	-2,833	-2,895	-2,959	-3,023	-3,089	-3,157
NOPAT	0	4,507	4,646	4,787	4,931	5,076	5,224	5,375	5,528	5,683	5,841	6,001	6,164	6,330	6,469	6,611	6,756	6,904	7,055	7,208	7,365
CAPEX	-18,150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amortization	0	-1,513	-1,513	-1,513	-1,513	-1,513	-1,513	-1,513	-1,513	-1,513	-1,513	-1,513	-1,513	0	0	0	0	0	0	0	0
Free cash flow	-18,150	3,902	4,041	4,182	4,326	4,471	4,619	4,770	4,923	5,078	5,236	5,396	5,559	7,237	7,376	7,519	7,663	7,811	7,962	8,116	8,273
Disc. cash flow	-18,150	3,668	3,571	3,475	3,378	3,283	3,188	3,095	3,002	2,912	2,822	2,734	2,648	3,241	3,105	2,975	2,851	2,732	2,618	2,508	2,404
Cum. cash flow	-18,150	-14,482	-10,910	-7,436	-4,058	-775	2,413	5,508	8,510	11,422	14,244	16,978	19,626	22,867	25,972	28,948	31,799	34,530	37,148	39,656	42,060

Table 15: Cash flow of scenario D

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Income	0	9,623	9,816	10,012	10,212	10,416	10,625	10,837	11,054	11,275	11,501	11,731	11,965	12,205	12,449	12,698	12,952	13,211	13,475	13,744	14,019
Operational costs	0	-1,184	-1,208	-1,232	-1,257	-1,282	-1,308	-1,334	-1,360	-1,388	-1,415	-1,444	-1,473	-1,502	-1,532	-1,563	-1,594	-1,626	-1,658	-1,692	-1,725
EBITDA	0	8,439	8,608	8,780	8,955	9,134	9,317	9,503	9,694	9,887	10,085	10,287	10,493	10,702	10,916	11,135	11,357	11,585	11,816	12,053	12,294
Depreciation	0	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250	-1,250
EBIT	0	7,189	7,358	7,530	7,705	7,884	8,067	8,253	8,444	8,637	8,835	9,037	9,243	9,452	9,666	9,885	10,107	10,335	10,566	10,803	11,044
Interests	0	-688	-630	-573	-516	-458	-401	-344	-286	-229	-172	-115	-57	0	0	0	0	0	0	0	0
EBT	0	6,501	6,727	6,957	7,190	7,426	7,666	7,910	8,157	8,408	8,663	8,922	9,185	9,452	9,666	9,885	10,107	10,335	10,566	10,803	11,044
Taxes	0	-1,950	-2,018	-2,087	-2,157	-2,228	-2,300	-2,373	-2,447	-2,522	-2,599	-2,677	-2,756	-2,836	-2,900	-2,965	-3,032	-3,100	-3,170	-3,241	-3,313
NOPAT	0	4,551	4,709	4,870	5,033	5,198	5,366	5,537	5,710	5,886	6,064	6,246	6,430	6,617	6,767	6,919	7,075	7,234	7,396	7,562	7,731
CAPEX	-25,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amortization	0	-2,083	-2,083	-2,083	-2,083	-2,083	-2,083	-2,083	-2,083	-2,083	-2,083	-2,083	-2,083	0	0	0	0	0	0	0	0
Free cash flow	-25,000	3,718	3,876	4,036	4,199	4,365	4,533	4,703	4,877	5,052	5,231	5,412	5,596	7,867	8,017	8,169	8,325	8,484	8,646	8,812	8,981
Disc. cash flow	-25,000	3,495	3,425	3,353	3,280	3,205	3,129	3,052	2,974	2,897	2,820	2,742	2,666	3,523	3,375	3,233	3,097	2,967	2,843	2,723	2,609
Cum. cash flow	-25,000	-21,505	-18,080	-14,727	-11,447	-8,242	-5,114	-2,062	912	3,809	6,629	9,371	12,037	15,560	18,934	22,167	25,265	28,232	31,074	33,798	36,407