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Economic aspects of an offshore wind farm located in Cantabria (North of Spain)

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ABSTRACT: This paper provides an overview of the main economic aspects of an offshore wind farm in the Cantabric region. The Net Present Value (NPV), the Internal Rate of Return (IRR) and the pay-back period are used to analyze the feasibility of the offshore wind farm. Furthermore, a sensitivity analysis is included to provide additional information. To calculate these factors, it is necessary to know the most relevant costs of the wind farm, such as the acquisition and installation of the wind turbines and the platforms, the electrical infrastructure and the operation and maintenance costs. Several locations have been studied. On the other hand, legal and environmental aspects, depth and distance from the coast have been applied. It helps to select the best region to install an offshore wind farm in Cantabria. These areas have been analyzed, studying the amount of energy that can be produced in each of them. In this study, a 5 MW offshore wind turbine and a semisubmersible floating platform are considered. Regarding to the electrical infrastructure, a dimensioning of the cabling system has been made. As it was predictable, the results obtained show that the feasibility of the offshore wind farm will have a heavy reliance on the electric tariff, because wind farm income only comes from the sale of energy.

1 INTRODUCTION

The current world energy situation is the result of the combination of diverse political, economic, technological, environmental and social trends.

Fossil fuels continue to represent most of the primary energy consumption worldwide. In 2016, oil accounted for 33.3% of primary energy consumption, coal 28.1% and natural gas 24.1% (British Petroleum 2017).

The agreements reached at the Convention on Climate Change developed in Paris in 2015 by 195 countries, establishes a global plan of action to limit the rise of the average temperature of the planet.

Therefore, a restructuring of current generation and energy consumption patterns is necessary, and renewable energies will play a fundamental role in it.

One of the renewable technologies that have achieved a greater development in recent years has been the marine wind energy.

In spite of being a recent technology, the use of the marine wind resource is already a reality, supported by the 4.149 offshore wind turbines that were connected to the electrical network at the end of 2017 in the different European countries.

The offshore wind farms installed so far have fixed platforms, but the use of floating platforms greatly increases the possibilities of the marine wind, because they can be used in locations that would be economically viable for fixed platforms.

There are three main types of offshore floating platforms: TLP platforms, semisubmersible platforms and SPAR platforms. This paper will be focused on offshore wind farms with semisubmersible floating platforms, which can operate with water depths greater than 50 meters.

The objective of this paper is to analyze the economic feasibility of an offshore wind farm with semisubmersible floating platforms located in the Cantabric region.

2 PROCEDURE

The procedure consists of several steps, which are shown in Figure 1.

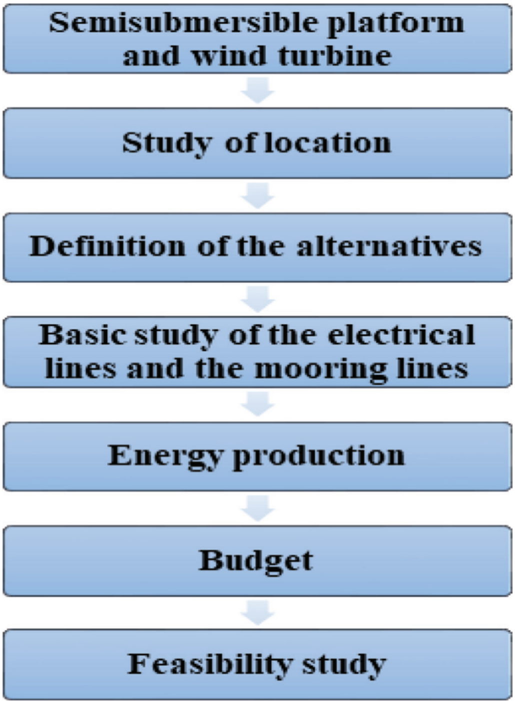

Figure 1. Procedure.

First of all, it is necessary to determine the semisubmersible platform and wind turbine model that will be considered to perform the study calculations.

Then, a study of the possible locations is carried out, considering legal, environmental, depth and distance from the coast restrictions.

Considering different locations and changing the number and the layout of the wind turbines several alternatives of study are defined.

Once the alternatives that will be analyzed have been defined, a basic study of the electrical lines and the mooring lines of the floating platforms is made.

Using all this data, a budget, which determines the initial investment required, is made for each of the alternatives.

It is also necessary to calculate the energy produced by each of the different alternatives, since that value will be used to determine the incomes.

Finally, the economic analysis of the aforementioned alternatives is carried out by calculating the Net Present Value and the payback period. In addition, a sensitivity analysis is made to determine which aspects of the project have a greater influence on the final result.

3 CASE STUDY

3.1 *Location*

The case study considered is the coast of Cantabria, a region located in the North of Spain.

3.2 *Offshore wind turbine*

The wind turbine selected is the G128-5.0MW Offshore of the Gamesa manufacturer, whose main characteristics are shown in Table 1 (Wind Turbine Models 2018).

3.3 *Offshore wind platform*

The semisubmersible floating platform was modelled by the "National Renewable Energy Laboratory" (NREL) in the report "Definition of the Semisubmersible Floating System for Phase II of OC4". Its main characteristics are shown in Table 2.

3.4 *Offshore wind resource*

To define the location of the wind farm, seven different zones are selected, all of them corresponding to geographic points included in the SIMAR

Figure 2. Location of Cantabria.

Table 1. Specifications of the wind turbine.

Parameter	Value
Rated power (MW)	5
Cut-in wind speed (m/s)	2
Cut-out wind speed (m/s)	27
Rated wind speed (m/s)	14
Rotor diameter (m)	128
Length of blades (m)	62.5
Tower height	80

Table 2. Specifications of the floating platform.

Parameter	Value
Depth of platform base below SWL (m)	20
Elevation of main column above SWL (m)	10
Elevation of offset columns above SWL (m)	12
Spacing between offset columns (m)	50
Diameter of main column (m)	6.5
Diameter of offset (upper) columns (m)	12
Diameter of base columns (m)	24
Diameter of pontoons and cross braces (m)	1.6
Platform mass (ton)	2527

node network (Ports of the State 2018). The seven locations chosen are analyzed to verify that they meet all the requirements for the installation of the wind farm.

3.5 *Environmental aspects*

To verify the environmental requirements, the "Estudio Estratégico Ambiental del litoral español para la instalación de parques eólicos marinos" is used (Secretaría General de Energía y Secretaría General del Mar 2009). Two of the seven locations chosen are located in allowed areas (green locations in Figure 3), while the other five are located in conditioned areas (yellow locations in Figure 3). None of them are located in the restricted areas (red locations in Figure 3), so it is not necessary to discard any location for environmental reasons.

3.6 *Bathymetry*

Bathymetry will be decisive to choose locations, because too large depths give rise to too high values in the lengths of moorings.

The Spanish coast is characterized by reaching great depths at distances relatively closed to the coastline.

Some of the points that have been chosen have depths near and even greater than 2000 metres (which is the limit of water depth exclusion criteria), so they should be discarded.

Those options that are outside the limits of the territorial sea will also be discarded.

3.7 *Locations selected*

As a final result of the study of location, it is concluded that of the seven locations analyzed, four are suitable for the installation of a wind farm with the sought characteristics. Therefore, these four locations will be taken into account to define the study alternatives.

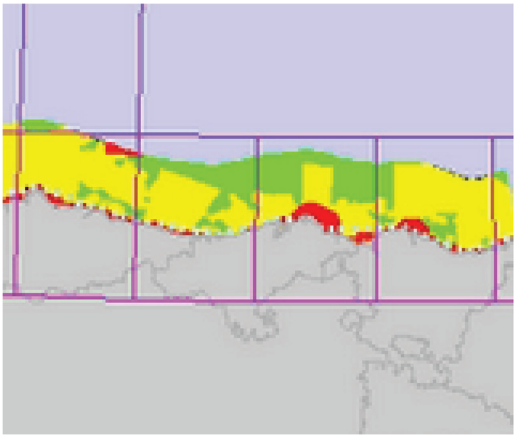

Figure 3. Restricted (red), conditioned (yellow) and allowed (green) areas (Secretaría General de Energía y de la Secretaría General del Mar 2009).

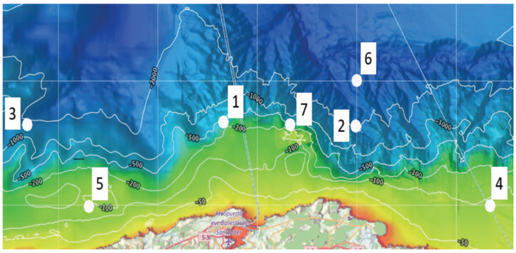

Figure 4. Bathymetry map.

Figure 5. Studied locations.

3.8 *Characteristics of the farm*

For each of the four locations considered, four possible wind farms, changing the number of turbines and their layout, are analyzed, which means that 16 alternatives are studied.

As far as the total power, three options are considered: 100 MW, 140 MW and 200 MW.

In the case of installing 100 MW, the possibility of distributing the 20 necessary wind turbines in 4 rows of 5 turbines or 5 rows of 4 is considered.

To define the distance between wind turbines, it is necessary to take into account the benefits of increasing the distance as well as the benefits of reducing it. The chosen distance will be 5 times the rotor diameter between the wind turbines which are in the same row and 8 times the row diameter between the wind turbines which are in different rows.

The wind turbine rows will be placed perpendicularly to the main direction of the wind (west direction).

Once the alternatives have been defined, a basic study of the electrical lines and the mooring lines is carried out.

Each platform will be moored by three catenary lines, distributed symmetrically around its central axis.

To dimension the mooring lines is necessary to take into account the wind loads on the wind turbine and on the platform and the waves loads on the platform.

4 RESULTS

4.1 *General results*

The length of each line is calculated using the free software "MK Catenary Calculations" (MK solutions 2018) based on the results obtained from the calculation of loads and on the depth data.

The offshore wind farm electrical system is divided in three parts:

The electrical installation and the transformation center of each wind turbine will not be analyzed in this study.

The internal wiring connects the wind turbines to each other and with the offshore substation.

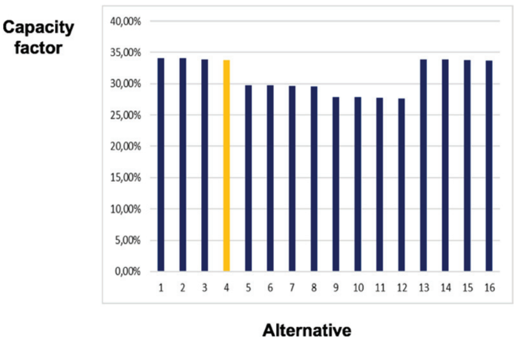

Figure 6. Capacity factor.

The evacuation line connects the offshore substation with the onshore substation.

It is necessary to calculate the cable section, which is required in each case in order to use its value to calculate the budget.

The next step is the energy production study. It consists in determining the amount of energy that can be extracted from the offshore wind farm.

The gross energy value will be calculated using the Weibull wind speed distribution, the wind turbine power curve and the number of wind turbines installed.

Net energy value will also depend on the wake effect losses, the no availability losses and the electrical losses.

The results show that the best capacity factor obtained with the defined alternatives is 34,1%.

Once the different aspects that define the offshore wind farm have been analyzed, and the study alternatives are established, the corresponding budget for each of these alternatives is calculated.

The results of the budget calculation show that the investment in wind turbines and platforms represents close to 75% of the total initial investment.

The evaluation of the economic feasibility of a project is based on the determination of the Cash Flow over its life cycle.

Once the Cash Flow values are known, two economic indicators, which determine the feasibility of the project, will be analyzed: The Net Present Value (NPV) in euro and the payback period in years.

In order to carry out the feasibility study, it is necessary to define a study scenario, which will contain the data related to the investment, the operation, the environment and the financing.

A total life cycle of 20 years will be considered, with a construction term of two years, paying 50% of the initial investment in each of them.

The value of O&M considered is 15 €/MWh (ECN 2016).

In this study, it will be considered a constant value for the electric tariff, 52.24 €/MWh, which is the average price of electricity in Spain in 2017 according to the annual report published by the OMIE (OMNI POLO ESPAÑOL 2017).

Currently, the Corporation tax in Spain is 25%.

The economic parameters considered are shown in Table 3.

Table 3. Economic parameters.

Parameter	Value
Number of years	20
Capital cost (%)	2.5
Electric tariff (€/MWh)	55.24

4.2 *Economic results*

The study of the economic feasibility shows that none of the alternatives that have been analyzed is profitable.

The payback period is higher than the total life-cycle of the project for all the alternatives studied. This is already an indication that it is not convenient to invest in the project. In addition, the Net Present Value (NPV) is negative in all cases, which also indicates that it is not advisable to invest in any of them.

A sensitivity analysis is used to measure how the feasibility of the project is affected when some of the variables that have been used changed.

Furthermore, it allows us to know what are the variables that most affect the economic results of the project.

The sensitivity analysis is performed for the alternative whose NPV is less unfavorable.

The output variable of the analysis is the NPV. The input variables are the initial investment, the operation and maintenance costs, the electric tariff and the energy production. For each of them, three values are defined: the minimum value, the most likely value and the maximum value.

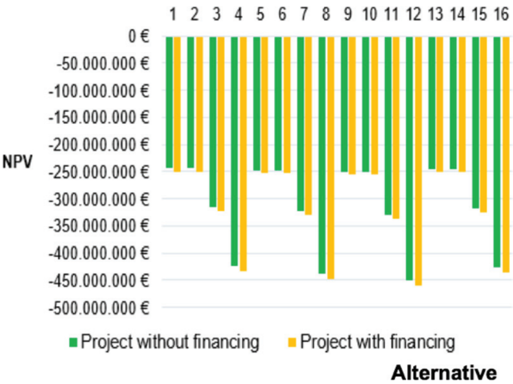

Figure 7. NPV results.

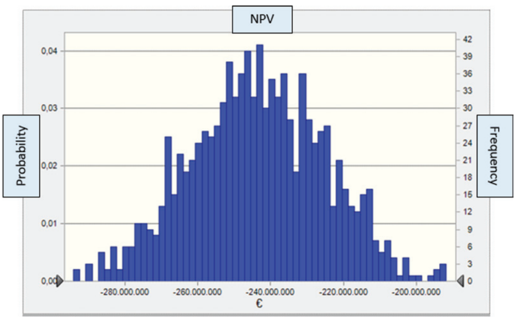

Figure 8. NPV frequency distribution.

Using the defined input variables and the software "Crystall Ball" (Oracle 2018), the NPV frequency distribution is calculated.

It can be seen that the NPV does not reach positive values in any case, so the probability that the project is profitable with the defined input variables is non-existent.

The results obtained show that the variables which have a greatest influence on the results of the Net Present Value are the electric tariff, the initial investment in wind turbines and platforms and the net energy production.

Due to the fact that with the current electric tariff the values of the economic feasibility are negative, it will be calculated the electric tariff that is necessary to make the Net Present Value equal to cero.

The electric tariff needed in each of the alternatives is shown in Figure 10.

In the best case, an increase of 60.23 € in the electric tariff is needed.

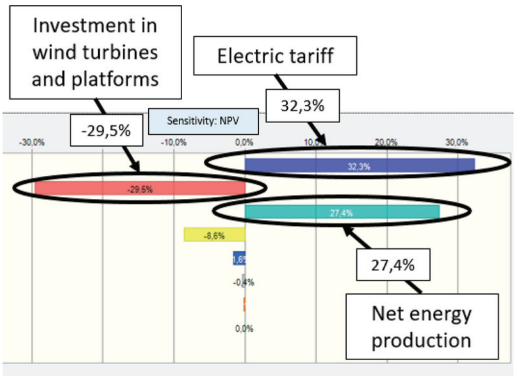

Figure 9. NPV sensitivity analysis.

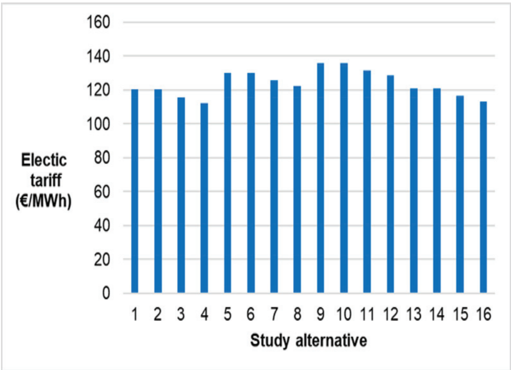

Figure 10. Electric tariff needed.

5 CONCLUSIONS

The results obtained show that the feasibility of the offshore wind farm will have a heavy reliance on the electric tariff, because wind farm income only comes from the sale of energy. However, the main aspect that should be improved is the total life-cycle costs, which should be reduced, especially the initial investment in platforms and wind turbines.

With the current conditions it is not advisable the material execution of a project with the studied characteristics. But as it is a recent technology, it is expected that the feasibility of these kind of projects will improve when the existing technology reach the necessary development.

ACKNOWLEDGEMENTS

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