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OFFSHORE WIND POWER PRODUCTION

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Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

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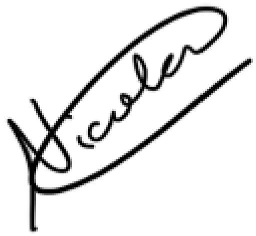

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I would like to thank my family for their unconditional support, patience, and constant encouragement throughout the entire process of this project. Without them, this project would not have been possible.

I would also like to thank Dr. Fernando de Cuadra García for answering all the questions I had about how a Final Degree Project works.

OFFSHORE WIND POWER PRODUCTION

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Entidad colaboradora: ICAI – Universidad Pontificia Comillas

ABSTRACT

Este proyecto presenta un estudio del diseño y la viabilidad de un parque eólico marino de 160 MW en el Golfo de Rosas (Girona, España). El proyecto describe la metodología para la selección del emplazamiento, las características técnicas y el análisis ambiental y económico de futuros parques eólicos marinos en España. Los resultados confirman la viabilidad técnica, ambiental y económica de los proyectos eólicos marinos en el país, a la vez que proponen líneas de mejora y futuros trabajos en el área.

Palabras clave: Offshore, Gulf of Roses, Spain, offshore wind, offshore design, floating platform, semisubmersible platform, WindFloat, floating offshore

1. Introducción

La transición energética global requiere una alta contribución de las energías renovables para reducir el impacto de los gases de efecto invernadero. La energía eólica marina contribuye a esta transición, y sus principales características son la alta velocidad del viento y la minimización del uso del suelo. Sin embargo, el desarrollo de proyectos eólicos marinos en España se ha visto limitado debido a problemas técnicos, regulatorios y económicos.

En 2024, Europa contaba con 37 GW de capacidad instalada de energía eólica marina. España no cuenta con proyectos eólicos marinos a gran escala, a pesar de que su recurso eólico es uno de los más potentes de Europa. Existen proyectos de pequeña escala y prototipos en Canarias y Santander. La inexistencia de grandes parques eólicos marinos en España se debe a la complejidad de la concesión de permisos y el análisis ambiental, las dudas sobre la viabilidad económica de los proyectos flotantes y la falta de un flujo de trabajo estandarizado.

Este proyecto pretende resolver estos problemas mediante el diseño de un parque eólico marino funcional y económicamente viable en la costa española.

2. Descripción del proyecto

El objetivo de este proyecto es diseñar un parque eólico marino viable de 160 MW con una vida útil de 25 años en la costa española, siguiendo un procedimiento sistemático que demuestra la viabilidad y rentabilidad del uso de esta tecnología en el país.

El proyecto comenzará con una aproximación teórica al tema, proporcionando al lector una mejor comprensión de las tecnologías empleadas en esta energía renovable.

La ubicación del proyecto se ha seleccionado en el Golfo de Rosas, al noroeste de la Península Ibérica. Diversos criterios hacen de esta zona la ideal para el desarrollo de un parque eólico marino: un gran recurso eólico con velocidades medias de entre 8 y 11 metros por segundo, un bajo tráfico marítimo en la zona, la clasificación de la zona como zona de alto potencial para proyectos eólicos marinos por el Plan de Ordenación del Espacio Marítimo (POEM) desarrollado por la UE y el gobierno español, y las condiciones de mar en calma que permiten el uso de estructuras flotantes debido a la profundidad del mar (más de 200 metros).

Las turbinas utilizadas son desarrolladas para proyectos eólicos marinos por Siemens Gamesa y tienen una potencia nominal de 8 MW. Por lo tanto, se necesitarán 20 turbinas para el proyecto. Las plataformas utilizadas para alojar las turbinas deben ser estructuras flotantes debido a la batimetría de la zona (profundidad marina superior a 200 metros). Las plataformas semisumergibles utilizadas en WindFloat Atlantic, en Portugal, son ideales gracias a las similitudes entre ambos proyectos.

El sistema de transmisión de electricidad se diseñará para garantizar una transmisión eficiente y segura. Contará con transformadores, cuadros de protección, un sistema de cableado de matriz, una subestación marina y un sistema de cableado de exportación, desarrollados por diferentes empresas como ABB, Siemens o Semco Maritime.

La Figure 1 muestra un esquema del parque, y la Table 1 presenta sus principales características técnicas.

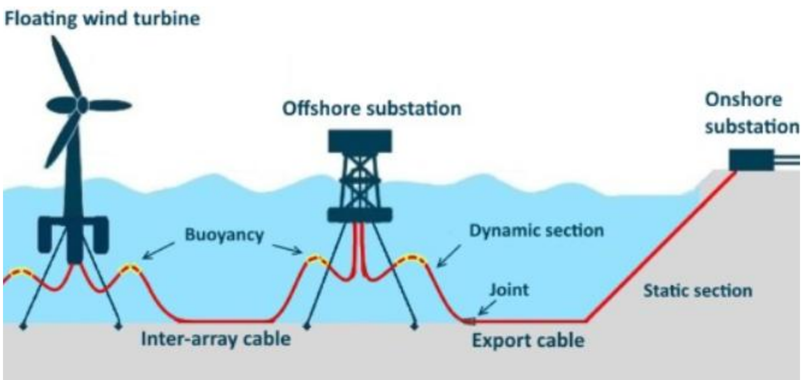

Figure 1. Boceto del parque eólico marino flotante [1].

Project Area	15.6 km^2
Mean wind speed	10.74 m/s
Mean sea depth	304 m
Turbine model	Siemens Gamesa SG 8.0-167 DD
Number of turbines	20
Hub height	100 m
Blade diameter	167 m
Installed capacity	160 MW
Capacity factor (CF)	58.80%
Annual generation	824202.08 MW

Table 1. Características del parque eólico marino.

Se ha desarrollado un estudio ambiental sobre los posibles efectos del parque eólico marino y se proponen soluciones para algunos de los problemas que podría causar. También se deriva un análisis de operación y mantenimiento que muestra el tipo de mantenimiento necesario para los diferentes componentes del parque.

El análisis económico demuestra la viabilidad del parque y proporciona diferentes indicadores de rentabilidad, que se muestran en Table 4.

WACC (%)	5.288
NPV (M€)	37.22 €
IRR (%)	6.205
PB (years)	11.96

Table 2. Métricas de rentabilidad del proyecto.

3. Conclusiones

Este proyecto no solo confirma la viabilidad de un parque eólico marino en el Golfo de Rosas, sino que también sienta las bases para la innovación, la sostenibilidad y la resiliencia. Esto se logra mediante la combinación de un riguroso análisis de recursos, estrategias de mitigación ambiental y un sólido modelo financiero.

De cara al futuro, la implementación de prototipos piloto, la integración con fuentes de energía complementarias y la actualización de tecnologías y metodologías reforzarán el compromiso de España con la descarbonización y crearán un sólido sector de energías renovables.

Este proyecto sienta las bases para animar a investigadores, industria y administraciones públicas a colaborar y a construir una nueva generación de parques eólicos marinos en España, lo que representaría un hito en la lucha contra el cambio climático.

4. Referencias

[1] M. Lerch, M. De-Prada-Gil, y C. Molins, «A metaheuristic optimization model for the inter-array layout planning of floating offshore wind farms», *Int. J. Electr. Power Energy Syst.*, vol. 131, p. 107128, oct. 2021, doi: 10.1016/j.ijepes.2021.107128.

OFFSHORE WIND POWER PRODUCTION

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ABSTRACT

This project presents a study of the design and viability of a 160 MW offshore wind farm in the Gulf of Roses (Girona, Spain). The project describes the methodology for the site selection, technical characteristics and environmental and economic analysis for future offshore wind farms in Spain. The results confirm the technical, environmental and economic viability of offshore wind projects in the country, while also proposing lines of improvement and future works in the area.

Keywords: Offshore, Gulf of Roses, Spain, offshore wind, offshore design, floating platform, semisubmersible platform, WindFloat, floating offshore

1. Introduction

The global energetic transition requires a high contribution of renewable energies to reduce the impact of greenhouse gases. Offshore wind contributes to this transition, and the highlights of this renewable are the high wind speeds, and the minimization of land use. Nevertheless, the development of offshore wind projects in Spain has been limited due to technical, regulatory, and economic issues.

In 2024, Europe had 37 GW of offshore wind installed capacity. Spain does not count with large-scale offshore wind projects, even though wind resource in Spain is one of the most powerful in Europe. There exist small sized projects and prototypes in the Canary Islands and Santander. The inexistence of large-scale offshore wind farms in Spain is caused by the complexity of permit concession and environmental analysis, the doubts on economic viability of floating projects, and the lack of a standardized work flux.

This project aims to solve these problematics by designing a functional and economically viable offshore wind plant in the Spanish coast.

2. Project description

The goal of this project is to design a viable 25-year lifespan 160 MW offshore wind farm in the coast of Spain following a systematic procedure that demonstrates the feasibility and profitability of the use of this technology in the country.

The project will start with a theoretical approach to the topic, giving a better understanding of these renewable energy technologies to the reader.

The selection of the location of the project is the Gulf of Roses in the northwest of the Iberian Peninsula. Multiple criteria makes this area perfect for the development of an offshore wind farm: a great wind resource with mean wind speeds between 8 and 11 meters per second, low maritime traffic in the area, the categorization of the zone as a high potential area for offshore wind projects by the Maritime Spatial Planning Plan

(POEM) developed by the EU and the Spanish government and the calm sea conditions that allow the use of floating structures due to the sea depth of the area (over 200 meters).

The turbines used are developed for offshore wind projects by Siemens Gamesa and have a rated power of 8 MW. Therefore, 20 turbines will be needed for the project. The platforms used to hold the turbines must be floating structures due to the bathymetry of the area (sea depth of over 200 meters). The semisubmersible platforms used in the WindFloat Atlantic in Portugal are perfect thanks to the similarities between these two projects.

The electricity transmission system will be designed to ensure efficient and safe transmission. It will come with transformers, protection switchgears, an array cable system, an offshore substation and an export cable system; developed by different companies such as ABB, Siemens or Semco Maritime.

Figure 2 shows a sketch of the farm, and Table 3 presents the main technical characteristics of the farm.

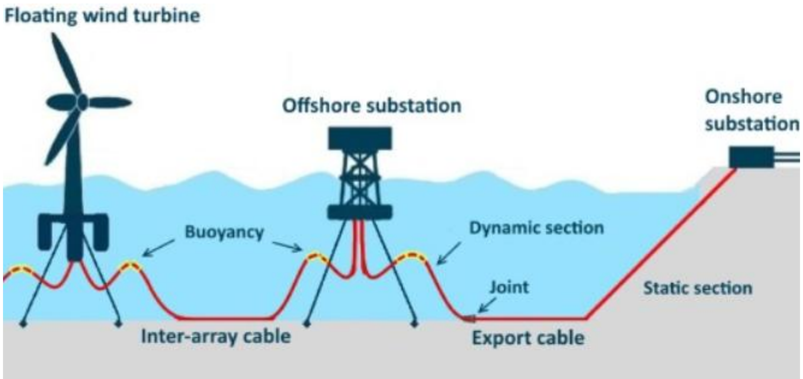

Figure 2. Sketch of the floating offshore wind farm [1].

Project Area	15.6 km^2
Mean wind speed	10.74 m/s
Mean sea depth	304 m
Turbine model	Siemens Gamesa SG 8.0-167 DD
Number of turbines	20
Hub height	100 m
Blade diameter	167 m
Installed capacity	160 MW
Capacity factor (CF)	58.80%
Annual generation	824202.08 MW

Table 3. Offshore wind farm characteristics.

An environmental study of the possible effects of the offshore wind farm has developed, and solutions are proposed for some of the problems that the farm may cause. An O&M analysis is also derived and shows what kind of maintenance is necessary for the different components of the farm.

The economic analysis proves the viability of the farm and provides different profitability metrics, which are shown in Table 4.

WACC (%)	5.288
NPV (M€)	37.22 €
IRR (%)	6.205
PB (years)	11.96

Table 4. Profitability metrics of the project.

3. Conclusions

This project not only confirms the viability of an offshore wind farm in the Gulf of roses but also sets a route sheet for innovation, sustainability and resilience. This is accomplished by combining a rigorous resource analysis, environmental mitigation strategies and a robust financial model.

Looking ahead, the implementation of pilot prototypes, the integration with complementary energy sources and the updating of the technologies and methodologies will strengthen the commitment of Spain to decarbonization and will create a solid renewable energy sector.

This project sets a route sheet that can encourage researchers, industry and public administrations to collaborate and realize a new generation of offshore wind farms in Spain, which would represent a milestone in the fight against climate change.

4. References

[1] M. Lerch, M. De-Prada-Gil, y C. Molins, «A metaheuristic optimization model for the inter-array layout planning of floating offshore wind farms», *Int. J. Electr. Power Energy Syst.*, vol. 131, p. 107128, oct. 2021, doi: 10.1016/j.ijepes.2021.107128.

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Chapter 1. INTRODUCTION

The global energetic transition requires a high contribution of renewable energies to reduce the impact of greenhouse gases. Offshore wind contributes to this transition, and the highlights of this renewable are the high wind speeds, and the minimization of land use. Nevertheless, the development of offshore wind projects in Spain has been limited due to technical, regulatory, and economic issues.

In 2024, Europe had 37 GW of offshore wind installed capacity. Spain does not count with large-scale offshore wind projects, even though wind resource in Spain is one of the most powerful in Europe. There exist small sized projects and prototypes in the Canary Islands and Santander. The inexistence of large-scale offshore wind farms in Spain is caused by the complexity of permit concession and environmental analysis, the doubts on economic viability of floating projects, and the lack of a standardized work flux.

This project aims to solve these problematics by designing a functional and economically viable offshore wind plant in the Spanish coast.

MOTIVATION OF THE PROJECT

The main motivation behind this study is the need to expand and diversify the renewable energy sources. It is an alternative to onshore wind as it presents advantages like higher speed winds or less land occupancy. The urge for more renewable energy is increasing, and offshore wind presents itself as a promising option for the next decades. Spain is a country that presents a high offshore wind potential but a low presence of this technology at this moment. Studying why this happens and presenting possible solutions to solve this problem is also an incentive to develop this research.

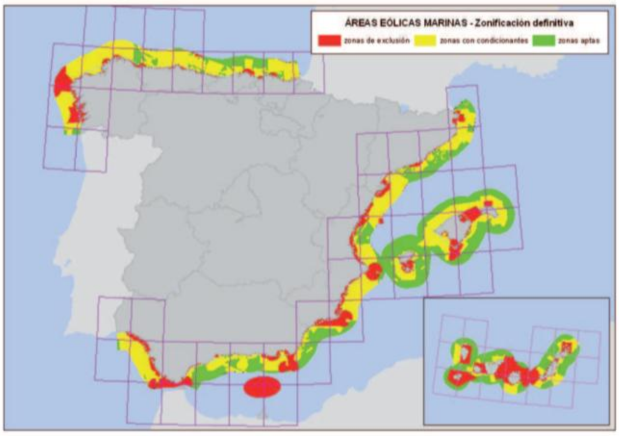

Figure 3. Offshore wind capacity map in Spain [1].

This study also tries to collect and analyze the existing information about offshore wind's economics, regulatory framework and technological advancements. This can contribute to a better comprehension of this renewable energy source and a better understanding of how to expand and implement these farms.

ALIGNMENT WITH THE SUSTAINABLE DEVELOPMENT GOALS

This project has the design of an offshore wind farm, a renewable energy source that is gaining importance nowadays. The design and construction of renewable energy farms has a significant impact on society and the environment. Therefore, it should align with the Sustainable Development Goals [2], which make sure that the impact generated by the offshore wind farm is positive.

The project is mainly aligned with this Sustainable Development Goals:

- SDG 7: Renewable energy: Clean, sustainable energy is not just about the environment. Around 4.3 million people die every year from pollution resulting from indoor cookstoves that use fire or toxic fuels. These deaths are entirely preventable. With your help, we can make sure every person has access to renewable energy by 2030. This project will encourage the use of offshore wind as a feasible alternative renewable energy source.

- SDG 9: Industry, innovation and infrastructure: Without the right infrastructure and technology, developing countries can't make the most of their human and natural resources. Industry plays a critical role in innovation and research, which are crucial for job creation, poverty eradication, gender equality, labor standards, and greater access to education and health care. Together, we can promote inclusive and sustainable industrialization and technology development.
- SDG 13: Climate action: The world's industrialized nations have changed the balance of the earth's carbon cycle over the last 150 years by burning large amounts of fossil fuels. Climate change has the potential to derail other efforts toward sustainable development by altering weather patterns that threaten our food production and increasing sea levels which will displace coastal communities. We need to increase awareness and convey urgency to world leaders so we can begin combating climate change before it is too late. Offshore wind power production is clean energy, and this study attempts to support its use to fight against climate change.
- SDG 14: Life below water: This goal aims to preserve seas, oceans and marine resources, as they cover more than 70% of the Earth, regulate climate and contain various ecosystems. The development of an offshore floating farm that respects the environment is very important to prove that this renewable energy is a powerful alternative.

Chapter 2. STATE OF THE ART

Europe now has 285 GW of wind power installed, distributed in onshore (248 GW) and offshore (37 GW) wind. In the year 2024, the European Union installed 16.4 GW of new wind power, where only a 16% of it was offshore (2.6 GW), most of it in the UK, France and Germany [3]. This onshore-offshore proportion is growing every year as shown in Figure 4, even though it grows slowly. This is caused by different factors like: investment costs, long permit timelines, limitations in transmission capacity…

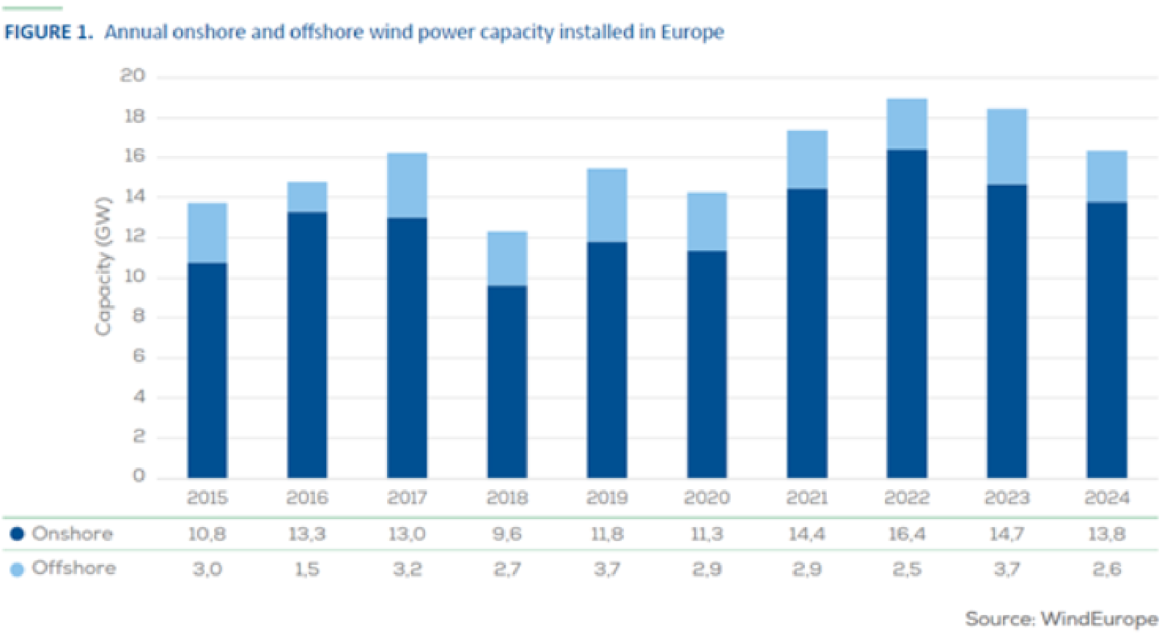

Figure 4. Annual onshore and offshore wind power capacity installed in Europe [3]

The European Union has set objectives for offshore development for the next years in the EU Strategy on Offshore Renewable Energy. The goal is to achieve 60 GW in 2030 and 300 GW in 2050. The main offshore source will be wind and solar, but it is planned that at least 40 of the 300 GW in 2050 will come from other offshore sources like wave or tidal energy [4]. There also exists an auction-based system in Europe that is working properly, as 23.2 GW of offshore capacity were auctioned in the year 2024. Some European countries like the

Netherlands and Denmark have set route sheets for future projects that have a guaranteed viability in the long term.

Onshore wind power in Spain is very developed, meanwhile offshore wind barely exists in the country. There are some prototypes in different locations of the Spanish shore, like BlueSATH (Figure 5) in Santander and Wind2Power in the Canary Islands. There are plans for a project of a 144 MW offshore wind farm in Gran Canaria that will be developed by Ocean Winds [5].

Figure 5. BlueSATH prototype in the bay of Santander [6].

The Spanish PNIEC sets a goal of more than 60 GW of wind energy by 2030, and 3 GW of the total must be offshore wind. To reach that objectives, Spain has set a route sheet with 3 GW of floating offshore and more than 200 million euros in research and innovation [7]. With the addition of auctioning and fixed price contracts, Spain will be able to develop their first offshore wind parks, becoming pioneers in this renewable source.

Chapter 3. DESCRIPTION OF THE TECHNOLOGIES

The aim of this section is to introduce the fundamentals of wind energy and regulatory framework of Offshore Wind Power Production. The overview of these aspects of technology will give the reader all the necessary information to understand the decisions made in the design of the offshore wind power plant in the Spanish coast.

3.1 FUNDAMENTALS OF WIND ENERGY CONVERSION:

Wind resource analysis:

To understand wind power plants, it is necessary to understand how wind works in terms of energy production. Knowing how this renewable energy source works helps optimize the power plants, making them more efficient and increasing the potential energy that can be obtained from them.

The most common way to characterize wind is the two-parameter Weibull distribution, as it is very effective in varying wind regimes. The Weibull distribution is a probability density function (PDF) and it depends on three main factors explained below the equation:

$$WEI2\ PDF: f(V,k,c) = \frac{k}{c} \cdot \left(\frac{V}{c}\right)^{k-1} \cdot e^{-\left(\frac{V}{c}\right)^{\cdot k}}$$

Equation 1. Weibull probability density function

The PDF of the Weibull distribution is a function of the speed of the wind (V), a shape parameter (k) and a scale parameter (c). The shape parameter (k) determines the asymmetry of the distribution, where higher values of the parameter represent uniform winds and lower values represent winds with higher variability. The scale parameter (c), measured in meters per second, represents the width of the wind speed. Higher values of this parameter define higher values of the average wind speed around which the distribution is centered.

The Rayleigh distribution is a specific case of the two-parameter Weibull distribution, where the value of the shape parameter is set to two (k=2). The Rayleigh distribution is usually applied in places with uniform and stable winds. Therefore, this simplified form of the Weibull distribution is not used in places with extreme wind conditions.

$$Rayleigh\ PDF: f(v,c) = \frac{2 \cdot V}{c^2} \cdot e^{-(\frac{V}{c})^2}$$

Equation 2. Rayleigh probability density function

The use of Weibull or Rayleigh distribution depends on the wind conditions of the studied location. In the east coast of China thanks to extreme wind conditions caused by monsoons, Weibull distribution presents a better correlation than Rayleigh. The R^2 is significantly higher in two-parameter Weibull and the RMSE is very low [8].

The selection of the correct PDF has a high impact on the design of a wind power plant as it helps to choose the hardware that will maximize the efficiency of the plant.

Onshore and offshore winds are different in some respects, and therefore some of the assumptions made while analyzing onshore winds cannot be made when analyzing offshore ones, and vice versa.

Onshore winds usually are more variable due to the irregularity of the terrain, which directly affects the choice of the distribution of the farms and the selection of turbines. Onshore wind profiles are also highly turbulent and vary significantly between day and night and between seasons. Therefore, the shape parameter of the WEI2 (two-parameter Weibull distribution) is usually low, representing this variability of the wind. Onshore wind farms usually require a precise selection of the distribution model as the complexity of the winds can cause a wrong estimation of the energy production when a simpler model is used. [9]

On the other hand, offshore winds are more stable and present less turbulence and a higher average wind speed. This happens thanks to the stability of the marine layers, that give the necessary conditions for these consistent and highly energetic winds. The typical values of the average wind speed at 100 meters above sea level is from 7 to 12 meters per second in

Europe, more specifically in the North, Baltic and Atlantic coasts. The average wind speed profile of the region can be appreciated in Figure 6.

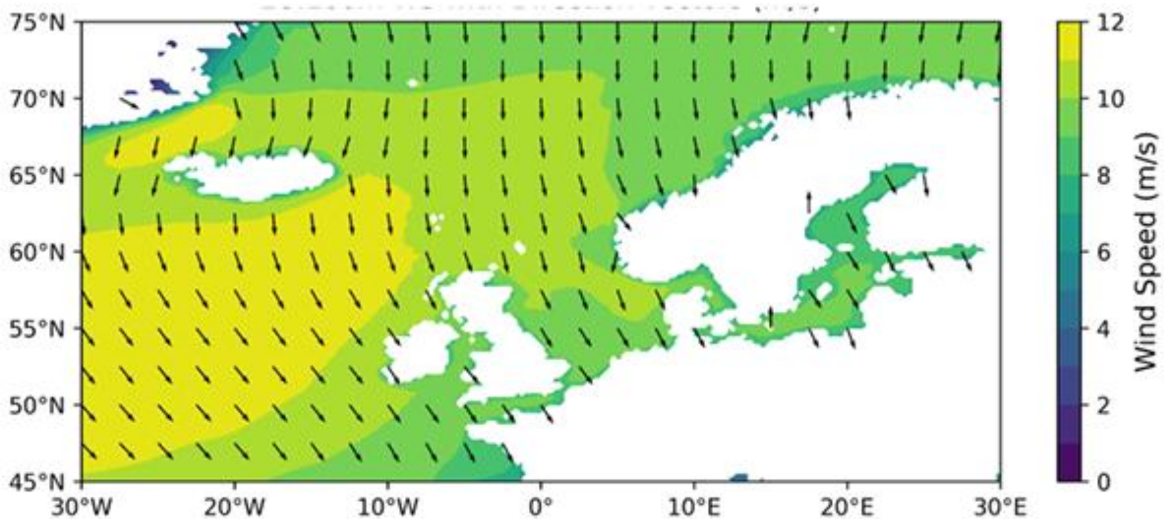

Figure 6. Multiyear average wind speed distribution in European sea areas at 100 m ASL [8].

The variability of wind speed in these regions is typically low which leads to the use of higher shape parameters when using WEI2 distribution.

Offshore locations usually secure more predictable and consistent wind with significantly less turbulence. Nevertheless, picking the right distribution model is an important issue when facing extreme wind conditions, as a too simple model could underestimate or overestimate the real energy production of the farm.

Wind turbine components and operation:

Wind turbines are complex and count numerous parts and devices that help maximize efficiency and obtain the maximum possible amount of energy from the wind.

The rotor and nacelle section are formed by the blades and the hub. The rotor is designed to capture the energy from the wind and transfer the mechanical energy of the movement of the blades to a low-speed shaft. The nacelle counts with different moving parts depending on its design. Geared systems use a planetary or helical gearbox to step up the rotational speed of the low-speed shaft from around 15 to 1500 rpm. These systems are the most used and therefore the most developed and they also are usually lighter than others, but they have higher maintenance costs, and they make more noise [10]. Direct-drive systems omit the gearbox and connect the low-speed shaft to a large diameter permanent magnet generator. This system reduces the number of components, the noise and the maintenance cost, but the weight of the nacelle increases as well as the initial cost.

The control systems are also key in efficiency maximization as they make sure that the turbine and the blades are correctly orientated to the wind. Pitch control systems change the angle of the blades depending on wind conditions. When wind speeds are ideal, the pitch motion system changes the angle of the blades to maximize lift. If the speed of the wind is too high, the angle of the blades is changed so that they will not brake due to high lift forces. A pitch failure can be devastating as they have several consequences in the hydraulic system (like leakage or a reduction of the bulk modulus), causing a decrease in stability and resilience of this control system [11]. The Yaw control system oversees the alignment of the nacelle with the wind. It has azimuth sensors that detect misalignment, and the yaw drives rotate the nacelle slowly to the optimal position.

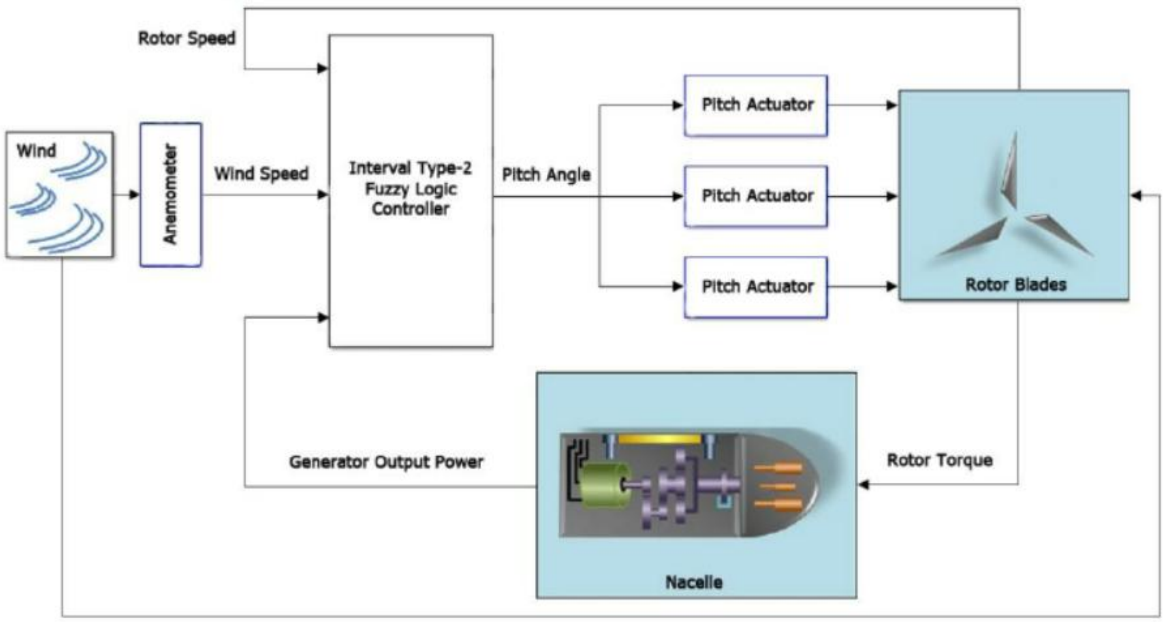

Figure 7. The scheme of Pitch Control System in the wind turbine [12]

There also are safety controls that make sure that all the turbine parts are working between the stablished limits. The most common are rotor speed control, vibration control and temperature control. When one of these systems detects a malfunction, it activates safety protocols like yaw reposition or mechanical breaking.

3.2 REGULATORY FRAMEWORK

The design and construction of an offshore wind power plant is complex in many ways. The technological issues to consider when designing these types of renewable energy farms were addressed in the previous section, but it is also important to have a precise knowledge of laws and regulations. This will help to make decisions and save money. Knowing all the applicable laws and regulations will make the design of the plant easier, because it will be clear which decisions can be taken and which of them are forbidden by law.

This part will be mainly focused on the regulatory framework of the European Union and Spain, as the project will be developed in the Spanish coast.

Main laws and regulations

This section will gather the main laws and regulations that any engineer must consider when designing an offshore wind power plant. This includes regulations that establish objectives on renewable energies and, more specifically, on offshore wind power production and laws that force or forbid determined decisions or technologies.

These laws are mainly obtained from: the EU Renewable Energy Directive (RED II), the EU Maritime Spatial Planning Directive, other EU Directives that mainly focus on the environmental impacts of these technologies, the Spanish Laws on Climate Change and Energy Transition and Spanish Royal Decrees, among others. These laws include:

- Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources: it aims to increase the use of renewable energy sources to combat climate change. It includes rules for financial support for electricity from renewable energy sources, protection against modifications that risk existing projects and accelerated permit procedures for renewable energy projects [13]. It intends to achieve a target of 32% of renewable energy share in the EU by 2030. [14]

- Spanish Law 7/2021 on Climate Change and Energy Transition: it intends to reach climate neutrality by 2050 by setting an objective of at list 42% renewable energy use in the country by 2030 and forbids new hydrocarbon licenses. [15]

- Directive 2014/89/EU on Maritime Spatial Planning (MSP): forces the EU Member States to set a plan on maritime spaces no later than 31 March 2021. This allows and encourages the research of potential offshore wind farm locations that will not conflict with wildlife or other human activities like fishing. [16]

- Directive 2011/92/EU on Environmental Impact Assessment (EIA): mandates a full environmental impact assessment for any project that may have important environmental effects (like offshore wind farms). The procedure, explained in [17], can have an impact in the cost and timelines of the farm.

- Directive 92/43/EEC, Habitats Directive [18]: prohibits habitat deterioration and wildlife harming in Natura 2000 zones, requiring appropriate assessment and blocking projects near this sites.

- Directive 2009/147/EC, Birds Directive [19]: protects wild birds by setting restrictions on activities that could harm them or their migration paths, like the construction of offshore wind farms.

- Royal Decree 962/2024 on Marine Renewable Energy: establishes innovation incentives, concession durations and decommissioning guarantees for offshore renewables and adds constraints on the finance of the projects.

- Royal Decree 1028/2007 on Offshore Electricity Generation: defines the authorization procedures for offshore farms bigger than 50 MW, sets the requirement of impact studies not only in the environment but also in other human activities and defines the required permits for offshore wind farms.
- Law 21/2013 on Environmental Assessment: transposes the Directive 2011/92/EU on Environmental Impact Assessment (EIA) [17] into Spanish law.
- Coastal Law 22/1988: regulates the maritime and terrestrial public domain, sets protective easement belts and sets the requirement of formal concessions to floating or fixed structures.

Resulting challenges:

The existence of these laws has significant consequences in the development of offshore wind farms projects. There are three main effects: complex permitting timelines, difficulty in the choice of the farm location and an increase in costs.

The coexistence of EU and Spanish laws makes the developers must coordinate with different authorities, navigate the MSP plans and Spanish tender calendar simultaneously [20]. This creates long permitting timelines which delay the development of these offshore wind farms.

The MSP plans and EIA procedures are long and ambiguous in some aspects. The difference between suitable zones with environmental constraints and prohibited locations is not always clear and requires a lot of investigation and public consultation. This also delays the development of offshore facilities [21].

The necessity of aligning the project with Natura 2000 and other environmental policies increases the cost of the project and presents possible legal risks if the environmental assessments are poorly done.

Offshore wind objectives of spain

Spain has set an objective of 3 GW of offshore wind by 2030, as it is one of the most promising renewable energy sources, under the 2023-2030 PNIEC (National Energy and Climate Plan). Spain will also contribute to the REPowerEU strategy, that wants to reach 60 GW of offshore wind capacity by 2030 and 300 GW by 2050.

To reach these objectives, the investment in I+D and industrialization of floating turbines is being significantly increased by the Sectorial Agenda of the Wind Industry. [22]

Integrating the regulatory framework to the project

There are two main characteristics of the project that will strongly depend on the regulatory framework of offshore wind farms:

- Zone selection: it will be necessary to use the information from the MSP plans to detect protected zones using the Strategic Environmental Assessment maps while choosing high potential offshore wind locations, focusing on places with high wind potential and low legal risks.

- EIA simplification: in line with the Royal Decree 962/2024 on Marine Renewable Energy, it will be necessary to derive research in wildlife conservation, follow the expectations of the authorities and schedule public consultation to shorten approval cycles.

Using the information of the existing laws and regulations will enable a safer development of the offshore wind farm project.

Offshore wind analysis

As in the previous sections of the project, the discussed topics corresponded to both offshore and onshore wind energy, this section will be focused only on offshore wind. This part will put together the information about offshore wind power production: the different types of offshore platforms and the wire connection of these systems with the grid.

3.3 OFFSHORE WIND TECHNOLOGY

This subsection will contain information on the technological aspects of offshore wind farms. The most characteristic differences between onshore and offshore wind farms are the structure and platform of the turbine and the connection with the grid.

3.3.1 OFFSHORE PLATFORMS

Offshore platforms are very different to offshore ones, as they must face different problems and environmental conditions. Offshore platforms are affected by sea currents (affect the underwater structure, especially if more than one converges there), waves (its height varies depending on the location and some of them can reach a considerable height), the depth of the sea at certain locations and winds with different characteristics from onshore ones (less turbulent and more consistent). These issues significantly affect the choice of platform.

One of the most typical divisions of offshore platforms is the one that depends on sea depth. There exist fixed structure platforms, they are usually used when seabed is 50 meters deep or less and they are made of a fixed structure anchored to the ground, and floating structures, for cases where seabed is more than 50 meters deep, rely on different floatability concepts and have different shapes, construction modes and mechanics in order to stay stable and not sink. In Figure 8, some of the main fixed structures and floating platforms are shown to make comprehension of how each of them works easier.

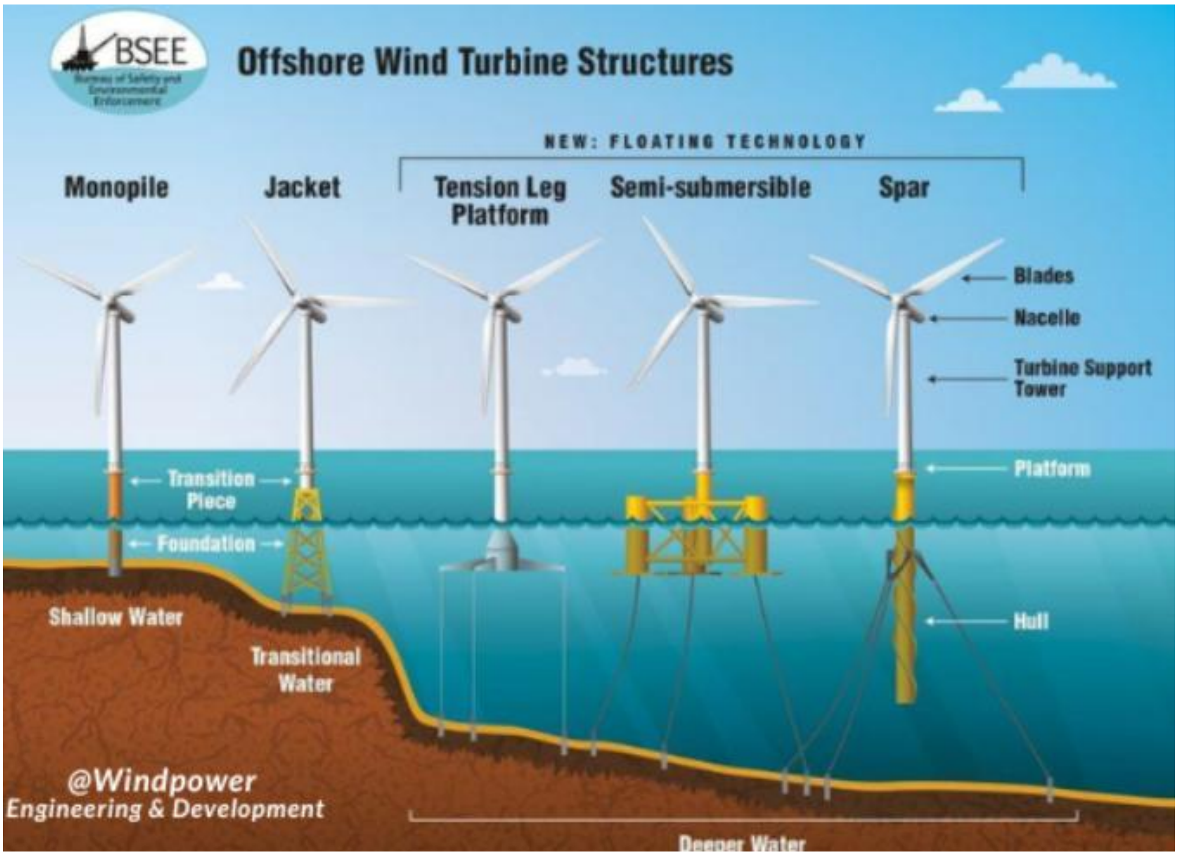

Figure 8. Offshore wind platforms depending on the depth of the seabed [23]

3.3.1.1 FIXED STRUCTURE PLATFORMS

These technologies must be anchored in seabed and that forces them to be built in locations where seabed is not very deep (usually not deeper than 50 meters).

1. **Monopile platforms**

Monopile platforms are commonly used in very shallow waters (less than 30 meters deep), and they are the technology most used in places like the North Sea. It consists of a single steel tube that is partially buried into the seabed. The turbine is mounted on top of the structure afterwards.

Its simplicity makes it the most economical and easier to build, but it also requires transportation and installation elements able to handle these large steel columns. Seabed conditions and the dimensions of the turbine are also characteristics that affect the viability of this technology. Large turbines can compromise the integrity of the platform. An example of a monopile offshore wind platform can be found in Figure 8.

2. Jacket platforms

Jacket platforms are lattice steel structures that count with three or four legs that go from seabed to the turbine tower. These legs are anchored into seabed with piles, making the structure stable even in challenging conditions. The main advantages of Jacket technology are the low weight compared to other fixed structure technologies and the installation range, which is typically larger than in monopile technology.

There exists an offshore wind farm called Neart na Gaoithe in Norway that uses this technology, and one of the Jacket structures is shown in Figure 9. The shallow waters of Norway enable the use of these platforms there.

Figure 9. Jacket structure designed by Sarens [24]

Jacket structures are fabricated on land, and the process is standardized. This would make them relatively cheap, but all the necessary welds and the anticorrosion treatments make the price go up. The tubular structures are transported by ship to the installation site and then mounted using cranes.

3. Gravity-based structures

The platforms of this type of technology consist of a heavy concrete structure with a wide base, and there is no pile-driving required, the structure lays directly on seabed. This last characteristic of gravity-based platforms makes them ideal for situations where avoiding noise pollution is important or locations where seabed cannot be altered or harmed, like places near marine habitats. This technology is used in relatively shallow waters and requires a previous preparation of seabed, as it is necessary to level the ground to guarantee stability.

One of the biggest farms that use this technology is Fécamp in Normandie. This offshore wind farm counts with 71 turbines, all of them held by gravity-based offshore structures. Figure 10 shows some of the structures used in that project and give a visual image of how these platforms are built.

Figure 10. Gravity-based structures used in Fécamp [25]

3.3.1.2 FLOATING PLATFORMS

It is key to understand fluid mechanics and floatability principles to create a viable floating structure. Having knowledge about buoyancy and the interaction between floatability centers and dynamic forces is a requirement for the construction of a workable offshore wind plant.

The most important floating technologies are spar, semisubmersible and Tension Leg Platform (TLP). Each of the previous mentioned relies on different floatability concepts and has different shapes, construction modes and mechanics to stay stable and not sink.

1. SPAR platforms

The classic spar technology was first developed in 1996 for the Oryx Neptune field in 1996. It consists of a cylindrical floating structure that is released in water. The upper part of the cylinder has watertight tanks that help the structure float. The lower tanks, also called soft tanks, can be filled to equalize pressure and reduce the weight of the structure. It also counts with a dozen wires to keep the object still while waves and winds hit the structure. It is required for the stability of the structure that the draft of the spar is bigger than the hub height.

One of the most important examples of SPAR technology in operation is the Hywind project in Scotland. This offshore wind farm counts with 30 MW capacity and was the first floating offshore wind farm as it has been working since 2017 [26]. In Figure 11, all the mentioned parts of a SPAR structure can be seen, the floating cylindrical structure and the wires anchored to seabed.

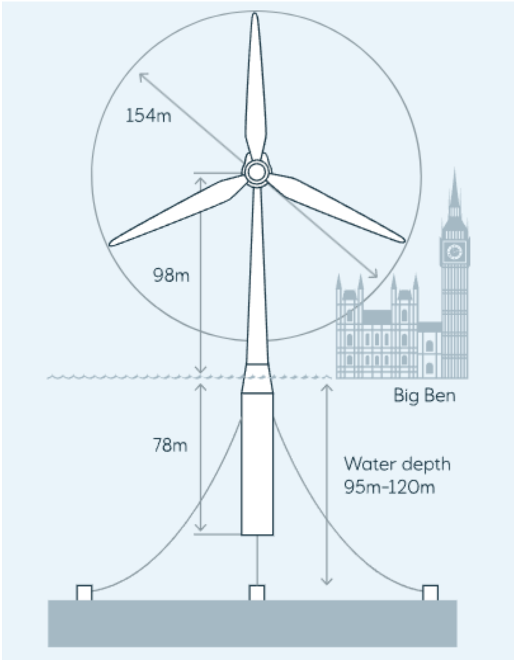

Figure 11. Hywind project SPAR technology platform and turbine [26]

2. Semisubmersible platforms

Semisubmersible technology consists of a set of vertical columns connected with horizontal pontoons. This design is stable thanks to distributed buoyancy, that makes the structure steady in different wave conditions.

The main advantage of semisubmersible floating structures is its easy mounting. The construction and assembly of the structure can be done on land. That makes the semisubmersible technology a highly economic option for offshore wind production. The turbine can be assembled in the dock as well.

One of the most well-known projects that uses semisubmersible technology is the WindFloat Atlantic in Portugal, which uses a three-column semisubmersible structure, as shown in Figure 12.

Figure 12. WindFloat Atlantic turbine in Portugal [27]

3. TLP platforms

The TLP technology or Tension Leg Platform technology is based on the use of tensioned cables anchored to the bottom of the sea, as can be seen in Figure 13. Even though the cables must reach seabed, this technology can work in places with a depth higher than 50 meters. The design of this TLP is very complicated as if it is not designed correctly some of the legs can get loose and the necessary tension to keep the structure standing can be lost.

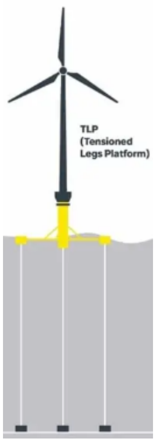

Figure 13. TLP platform sketch [28].

A different way to build a TLP structure was proposed in the Blue H project. This structure is mainly based on the concept of the counterweight. The turbine is supported by a base that is connected to an underwater counterweight by steel tensioned wires.

The Tension Leg Turbine Platform or TLTP consists in a principal column that sustains the turbine and three tensioned legs that are anchored to seabed. This technology can reduce considerably the damage received by waves hitting the structure at resonance frequency.

3.3.2 OFFSHORE WIND ELECTRICAL CONNECTION

The design of the electrical connection of an offshore wind farm consists of three main parts: an array collection system, an offshore substation and an onshore substation.

The array collection system oversees the collection of power from each turbine of the farm and the transmission of this power to the offshore substation. The voltage level used depends on different factors such as the number and capacity of the wind turbines, the distance between the farm and the substation or the structures used to hold the turbines (fixed or floating platforms).

The most typical configuration is a three-phase 66 kV (but it is expected to change to 132 kV in the next years) that uses insulated undersea copper wires. The cross-sectional area of these cables is usually around 25 cm^2, which allows the wires to carry hundreds of amperes. These cables are usually buried one or two meters under seabed and count with accessories like buoyancy elements, protection, connectors, joints and hang-offs. Fiber optic cables are usually incorporated to help with communications, data transfer and cable condition monitoring.

Static array cables are usually used for fixed-bottom wind turbines. They are made of an aluminum core, cross-linked polyethylene (XLPE) insulation and steel that acts like armor.

Dynamic array cables are used for floating wind turbines. These cables can be connected to static array cables using joints, and the main differences between these cables are the core (copper for dynamic and aluminum for static), and the double armoring used in dynamic cables. Dynamic cables are also wider than static ones. In Figure 14 there is a sketch of a dynamic array cable schematic.

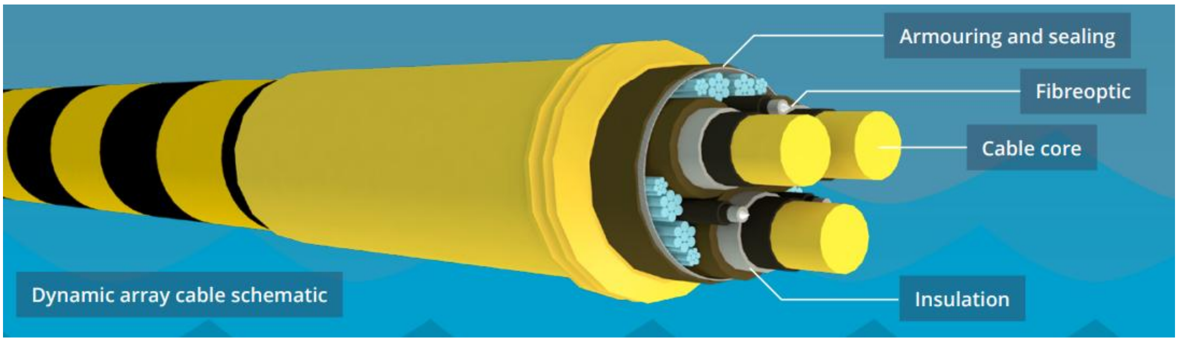

Figure 14. Dynamic array cable schematic [29].

All the information about undersea wiring was found in the Offshore Wind Scotland official web page [29].

All the array cables converge in an offshore substation that transforms the low voltages received into high voltage (around 220 kV). This minimizes losses, as the distance between the offshore and onshore substations is considerably long. The interconnection of the two substations can be done in High Voltage Altern Current (HVAC) or High Voltage Direct Current (HVDC).

- HVAC: altern current is typically used for subaquatic transportation shorter than 50 km. Its main advantage is that it is a very developed, economic and tested transportation system in this range of distances. Therefore, it is the most used nowadays in offshore wind farms. The main disadvantage of HVAC is the reactive losses caused by the insulator surrounding the wires.

- HVDC: direct current is usually more economically viable than AC (as DC transmission is monophasic while AC is usually triphasic) and it presents less losses in the transmission process. The problem with HVDC is the necessity of AC to DC transformers. These AC-DC transformers are expensive and require additional elements that guarantee protection in extreme cases. The most typically used AC-DC converters are Line Commutated Converters (LCC), which require an external power source that makes it less viable for an offshore substation, and Voltage Source Converters, that use Isolated Gate Bipolar Transistors (IGBT) that open and close letting the current pass at determined intervals.

The export cables drive the current to an onshore substation where the voltage is changed to 110 kV using step-down transformers. If HVDC is used there are other elements in these substations such as smoothing reactors and harmonic filters that make the current grid compatible.

Chapter 4. DEFINICIÓN DEL TRABAJO

4.1 JUSTIFICATION

The global energetic transition requires a high contribution of renewable energies to reduce the impact of greenhouse gases. Offshore wind contributes to this transition, and the highlights of this renewable are the high wind speeds, and the minimization of land use. Nevertheless, the development of offshore wind projects in Spain has been limited due to technical, regulatory, and economic issues.

The design of an offshore wind farm in the Spanish coast can solve this problematic and attract foreign companies and investment, helping the transition to renewable energies in the country.

4.1.1 OFFSHORE WIND BREACH IN SPAIN

Spain has an exceptionally good onshore and offshore wind resource. Even though the number of onshore wind farms in Spain is high (more than 1000 farms), there are not large-scale offshore wind farms. The main causes of this absence are the high investment costs, the long permit waiting times and the lack of standardization of floating structures (needed for offshore projects in Spain due to the deepness of the sea). This project aims to cover that breach by applying a methodology for the construction of an offshore wind farm in Spain, selecting an appropriate location and evaluating the technical and economic aspects of the farm using the real regulatory, bathymetric and eolian data of the area.

4.1.2 ALIGNMENT WITH THE NATIONAL AND EUROPEAN OBJECTIVES

Spain has set a goal of 3 GW of offshore wind before 2030, and the EU wants to have 60 GW of offshore installed capacity by that same year. This project helps to achieve this goal by developing a 160 MW offshore wind farm in the Spanish coast. The viability of the project can be used as a route sheet for future offshore wind projects in Spain

4.1.3 SOCIOECONOMIC IMPACT OF AN OFFSHORE WIND FARM

The development of an offshore wind farm can generate employment, not only in the construction phase but also during the operation and maintenance of the farm. It can attract investment from outside Spain and set a landmark for future offshore wind projects in the country. The development of the farm can also encourage Universities and technological centers to invest in research and development (R&D) related to offshore wind farms, helping the energetic transition of the country.

4.2 OBJECTIVES

The final goal of the project is to design a functional offshore wind farm in a viable location of the Spanish coast. To achieve this goal, there are some objectives that must be achieved.

1) Selection of a proper area to build the offshore wind farm, analyzing the environmental and regulatory issues, the wind resource and the bathymetry of the location.
2) Selection of a wind turbine that is proper for offshore projects.
3) Characterization of the structure chosen for the project, and selection of a specific platform for the wind turbines and the offshore substation.
4) Design of the electricity transmission system, selecting the necessary devices for an efficient transmission.
5) Analysis of the environmental effects and the O&M of the farm.
6) Cost analysis of the project, including construction and O&M and expected earnings of the project in the next twenty-five years.
7) A summary of the farm and an analysis of the main difficulties and take-outs of the project will be necessary, to show future developers the main difficulties of designing an offshore wind farm.

The completion of these objectives ensures that the offshore wind farm is feasible and profitable, achieving the main goal of this project.

4.3 METHODOLOGY

The methodology of the project will be based on following the objectives that were previously mentioned.

1) The selection of the location of the farm will be done with a comparison between the most promising places on the Spanish coast. Each place will receive its individual analysis, checking how the laws and regulations apply, the wind resource the bathymetry, and the maritime traffic of each of the possible locations.
2) The turbine selection will be done by analyzing the characteristics of different turbines offered by different companies. The turbine with the most suitable characteristics will be employed in the project.
3) The platform used depends on the depth of the area. If the area is suitable for the use of fixed bottom structures, it will be necessary to find one with the ideal characteristics for the turbine selected. If the area requires a floating structure, due to the lack of standardization, it will be necessary to find a similar project and select the structure used in it.
4) The design of the electricity transmission system will require selecting the voltage levels for each transmission stage (from the turbines to the offshore substation, and from the offshore substation to mainland), and the necessary elements to achieve the transmission to shore (cables, transformers, offshore platforms and protection elements).
5) The environmental and O&M analysis will try to face the possible scenarios that may happen to the offshore wind farm, and it will also propose solutions for these situations.
6) The economic analysis will be a summary of all the costs involved in the project, and the income received annually. The profitability of the project will be explored by analyzing the FCF and calculating the NPV, IRR and payback period of the project. The profitability of the equity investment will also be explored using the same concepts.

7) A summary of the characteristics of the project and an analysis of the main problematics and take-outs of the project will help the development of future offshore wind farms in Spain.

4.4 PLANNING AND ECONOMIC ESTIMATION

The construction of the offshore wind farm is expected to last for fourteen months. This process will be divided into four phases, each of them with its expected duration.

The first phase will be the formalities before construction. In this part of the project development, the goal is to obtain approval of the project and the necessary investment. Then, it will be mandatory to obtain all the necessary permits for the construction and operation of the farm (environmental and field study permits, construction permits, energy production permits, contracts with other companies…).

The second phase will be the civil work necessary for the project, which includes the construction of an assembling dock and the seabed modifications for the construction of the farm (which includes the preparation of an anchoring place for each turbine and the dug of trenches for the cabling system).

In the third phase, the construction of the farm will start. The installation of the cable system, the floating platforms, turbines and electricity transmission gear will be done during this time. This is the phase that will take the most time, and after it, the construction will be finished.

The last phase will be the start-up process. Periodic operation tests and correction of malfunctioning and flaws of the farm will be done during the two months prior to the start of operation of the farm.

Figure 15 shows the expected duration of each of the phases of construction of the farm.

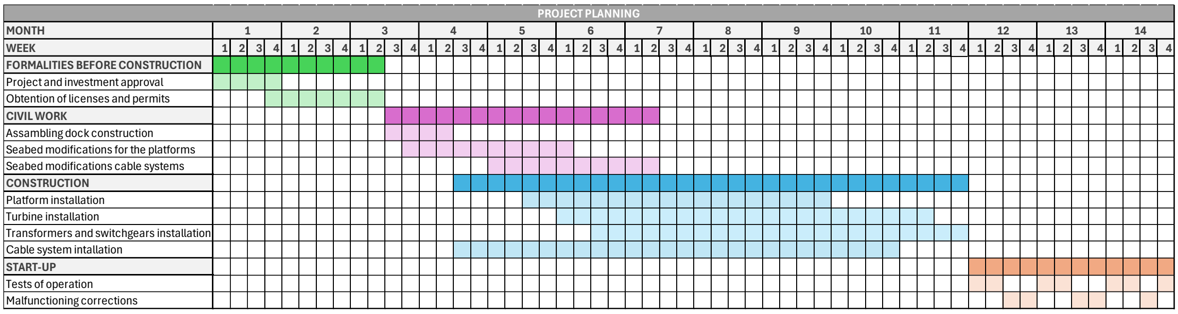

Figure 15. Timeline of the construction of the farm.

For a 160 MW offshore wind farm, a possible estimation of the energy produced annually would be 700 GWh. Therefore, the farm would produce around 17500 GWh in the 25 years of operation, which can be translated as 1050 M€, approximately.

It is important that the investment is not bigger than the expected income. Therefore, and considering all the elements of the farm, civil works necessary and installation and labor costs, it is correct to think that the initial capital expenditure can be around 500 M€. The existence of high O&M costs for offshore wind farms leads to an average annual O&M cost of around 7.5 M€.

With these expected costs and earnings, the park should be profitable, as shown in Table 5.

EXPECTED INCOME (M€)	1050
EXPECTED CAPEX (M€)	500
EXPECTED OPEX (M€)	7.5
EXPECTED EARNINGS (M€)	362.5

Table 5. Expected income, costs and earnings of the farm.

Chapter 5. OFFSHORE WIND FARM DESIGN

This chapter is focused on the design of an offshore wind farm in the Spanish coast. The chapter is divided into two sections: the site selection and the technical characteristics of the park.

For the site selection, various aspects must be considered, like the speed of the wind, the depth of the sea or environmental and regulatory constraints. The technical characteristics will gather all the information about the technology used in the park such as turbines, cables, transformers, converters…

5.1 LOCATION OF THE OFFSHORE WIND FARM

The objective of this subsection is to delimit the surface that will be used for the offshore wind farm. The different optional locations on the Spanish shore will be discussed using the following criteria:

1) The area selected must meet the regulatory and environmental constraints (i.e., it cannot be an environmentally protected zone).
2) A bathymetry analysis must be done to determine which type of platform should be used.
3) The selected location must have an adequate average wind speed to guarantee proper wind power potential.

Following these criteria will ensure that the selected location for the farm does not imply potential legal risks and provides a suitable location for a profitable offshore wind farm (not too costly to build and with a high-power potential).

5.1.1 ENVIRONMENTAL AND REGULATORY FILTER

The first step for the site selection in this project will be to discard the maritime protected areas in Spain. This is key to make sure that the following steps of the design (that strongly depend on the location of the farm) do not have to be taken twice because the location of the farm is a protected area.

There are different laws, regulations and initiatives that delimit different protected areas where building an offshore wind farm is impossible or exceedingly difficult due to environmental restrictions. Using the official map tool of the Spanish Ministry for the Ecological Transition (MITECO), it is possible to see all the protected zones of the Spanish coast, depending on the regulation.

- OSPAR Network of Marine Protected areas: its name comes from two different agreements: the Oslo convention in 1972 and the Paris convention in 1974, both focused on preserving the environment. The OSPAR convention addresses issues related to pollution prevention and habitat conservation in the Atlantic marine ecosystems [30]. The OSPAR Network defines areas that count with special protection and conservation measures to preserve marine ecosystems. It also defines Exclusive Economic Zones for each country in the OSPAR Network [31]. In Figure 16 it is possible to see a map of the OSPAR Network of Marine Protected Areas in the Atlantic coast of Spain.

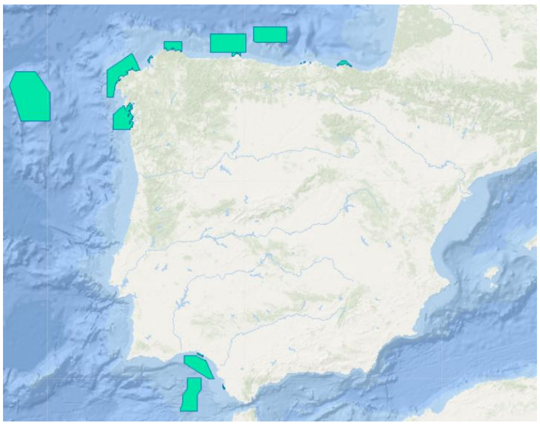

Figure 16. OSPAR Marine Protected Zones in Spain [32]

- The Biosphere Reserve areas: are the zones recognized by the MaB Program of UNESCO. Biosphere Reserves are there to promote the integration of populations and nature, sustainable development, the exchange of knowledge and the respect for cultural values, among others. There are not many areas in the Spanish coast catalogued as Biosphere Reserves, but the most important ones are: the Strait of Gibraltar, the sea area around Menorca Island, the Gata Cape and the Ebro Delta.

- ZEIPM areas: are the zones designated in the Protocol on Specially Protected Areas and Biological Diversity in Barcelona Convention. They have the objective of protecting habitat and species in the Mediterranean Sea. Figure 17 shows the ZEIPM areas in Spain. Those are zones to avoid when choosing the location of the offshore wind farm due to environmental regulations.

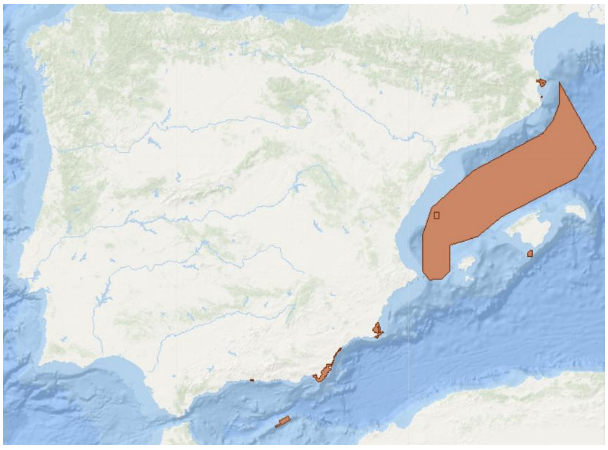

Figure 17. ZEIPM areas in Spain [32]

- RAMPE: stands for Network of Marine Protected Areas of Spain and it is the official Spanish network that includes all the protected marine areas to preserve biodiversity and marine habitats. It includes all the previously mentioned zones and shows the zones that an engineer should avoid when building an offshore wind park, as building it in one of the zones in RAMPE may have legal consequences. Figure 18 and Figure 19 show all the protected marine zones of RAMPE, and these will be the areas to avoid when choosing the location of an offshore wind farm.

Figure 18. RAMPE zones in the Iberian Peninsula and the Balearic Islands [32]

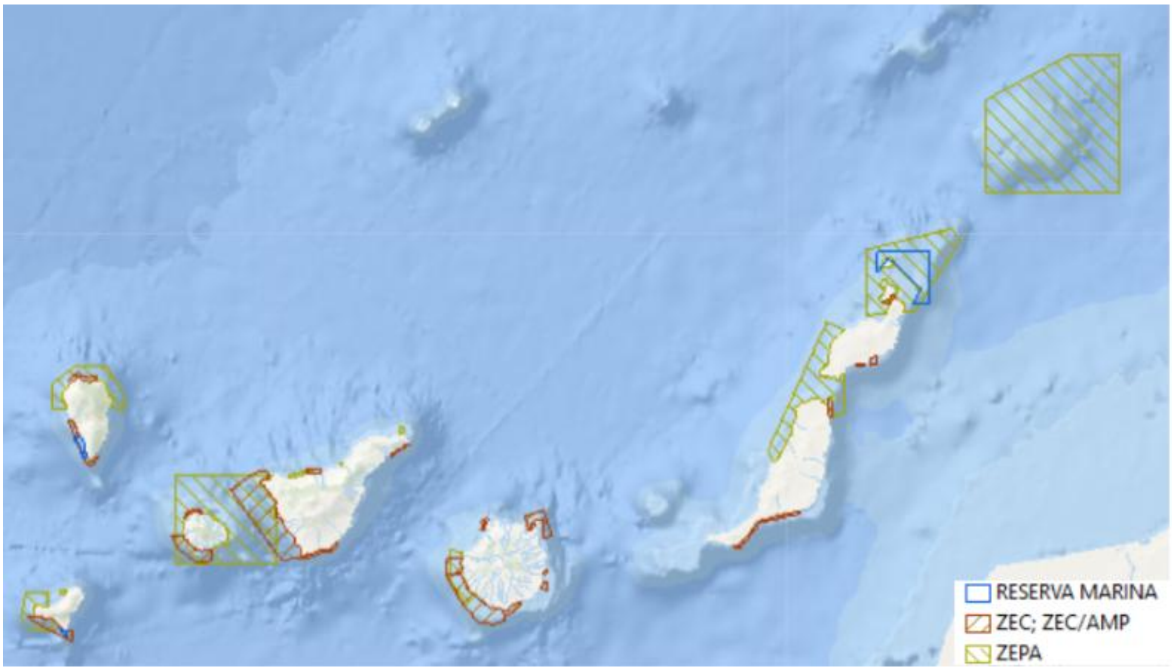

Figure 19. Rampe zones in the Canary Islands [32]

The maps of Figure 18 and Figure 19 are the ones that will be used to decide the final location of the offshore wind farm. Nevertheless, these are not the only ones that will be used. It is going to be necessary to execute a bathymetry and a wind resource analysis as well.

5.1.2 Wind Resource Analysis

This analysis is crucial to the development of a profitable offshore wind power farm. The wind resource in the selected location must be consistent and fast. Using the map tool of Global Wind Atlas [33], it is easy to obtain a map of the mean wind speed in the Spanish territory. This map, shown in Figure 20, is useful for localizing the areas where wind resource is strong, and that helps to define the potential areas to build an offshore wind farm. It shows the average wind speed in Spain, with values between five meters per second (in light blue) and ten meters per second or more (in garnet).

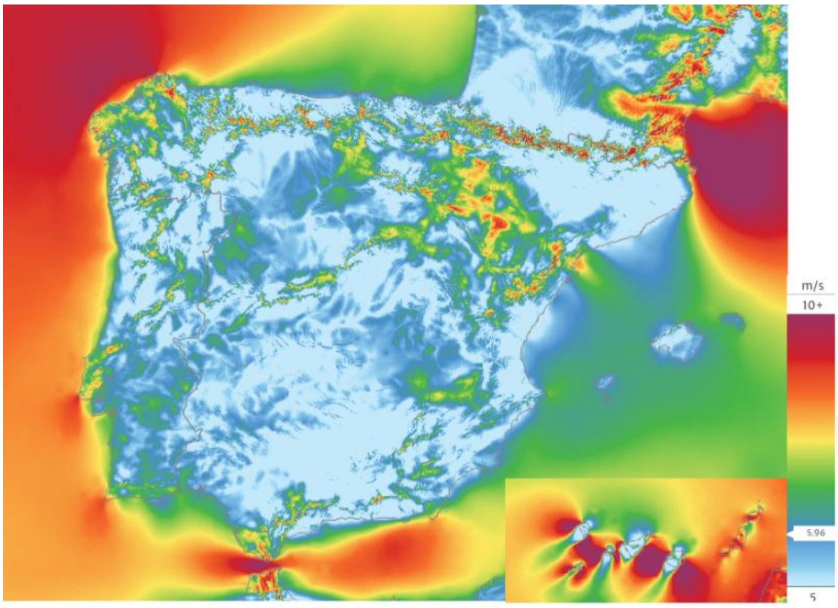

Figure 20. Map of the mean wind speed in Spain at 100 meters high [33]

It is easy to notice the best locations in terms of wind resource by looking at Figure 20. Another helpful map also obtained from Global Wind Atlas reflects the potential wind power of the Spanish territory. This is the map of Figure 21 and shows the mean wind power potential of Spain at one hundred meters high from 0 to 1000 watts per square meter.

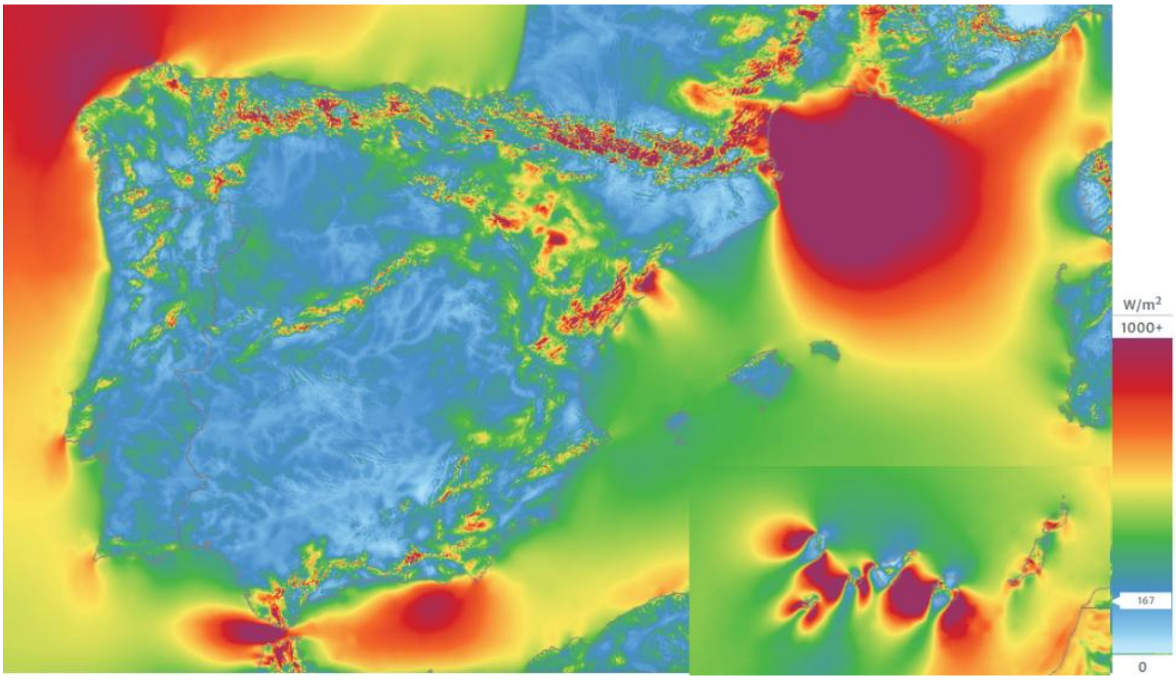

Figure 21. Map of the mean wind potential power in Spain at 100 meters high [33]

After analyzing the maps of Figure 20 and Figure 21, there are six zones with a high wind speed and power potential, and therefore, these are the areas where the offshore wind farm may be developed.

1) Galician coast: located on the northwest of the Iberian Peninsula, it has offshore wind speeds of over 8 meters per second.
2) Ebro Delta: located northeast of the Iberian Peninsula, presents high wind speeds thanks to the flat terrain of the zone and the temperature difference between the Mediterranean Sea and the land.
3) Alboran Sea: it is part of the Mediterranean Sea, underneath the Andalusian coast. There are high wind speeds in this sea, especially near the coast of Almería, thanks to the pressure difference between the Mediterranean Sea and the Atlantic Ocean, as well as the effect of the Strait of Gibraltar.
4) Strait of Gibraltar: it separates Spain from Africa, and there is a high wind energy potential thanks to the pressure difference between the two water mases that the strait separates.

5) Canary Islands: they are in the west coast of the African continent, and there is no grid connection between these islands and the Iberian Peninsula. There is a high mean wind speed in these islands due to the existence of trade winds (constant easternly winds near the equator) that are influenced by the Azores High (a high-pressure system in the Atlantic).
6) Gulf of Roses: it is located in the northwest of Spain, in Gerona, Catalonia. It has a good wind resource thanks to the Tramontana wind, a characteristic wind of that region of the mediterranean sea.

Knowing the wind potential in the Spanish shore, it is possible to reduce the locations of the offshore wind farms to the previously mentioned places. Nevertheless, the bathymetry analysis must be done, and then, the three analysis must be compared to select a non-legally protected site where wind resource and bathymetry are good.

5.1.3 BATHYMETRY ANALYSIS

The bathymetry analysis is the study of the underwater topography of ocean floors. The bathymetry analysis in this project will be focused on the depth of the areas and the irregularity of seabed in the Spanish coast.

Using the same map tool used in the wind analysis section (5.1.2), it is easy to do an analysis of the depth of the Spanish sea areas, as Figure 22 shows.

Figure 22. Sea depth map of the Spanish coast [33]

The map of Figure 22 shows the depth of the sea in a range of 0 to 100 meters. It is easy to appreciate that the Spanish seabed tends to go deeper than one hundred meters quickly. The majority of the existing offshore wind farms in the world use fixed bottom structures, and therefore, the depth of the sea in those places is usually around 50 meters or less. The evolution of floating structures allows the exploit of Spanish offshore wind resource at its maximum level, as it is possible to build offshore wind farms in places where sea depth is bigger than 50 meters.

The analysis of the irregularity of the terrain is important if the offshore wind farm is developed using fixed bottom structures. Therefore, it is not going to be included in this section, and it might be done when deciding the definitive location, and only if this location has a sea depth of less than 50 meters.

5.1.4 FINAL DECISION

There are multiple locations that are suitable for an offshore wind farm, and after careful consideration, the most promising locations for the farm are: the Canary Islands, the Galician coast, the Trafalgar Cape, and the Gulf of Roses. Deeper research into each one of the options is necessary to determine which location will be the definitive for the farm. This research will include maritime traffic, bathymetry, and regulations.

5.1.4.1 CANARY ISLANDS

The Canary Islands is an archipelago located in the African west coast. The grid of the islands is independent of the European grid, and most of the islands are not connected with other islands either. This means that the decision to build the offshore wind farm on one of the coasts of an island will not affect other islands' electricity grid.

Figure 21 and Figure 19 show that there is a high wind power potential in several zones of the archipelago. Nevertheless, the bathymetry analysis shows that most of the zones that are at a proper distance from the shore (around 10 km) have a sea depth of 100 meters or more, which makes the use of fixed bottom structures impossible. The use of floating structures is mandatory in these depths.

In terms of regulation, many of the possible locations are outside of Natura 2000, but there are some reserves that belong to RAMPE. Figure 23 shows a map of the Canary Islands showing the different wind speeds at locations where an offshore wind farm can be built (with conditions).

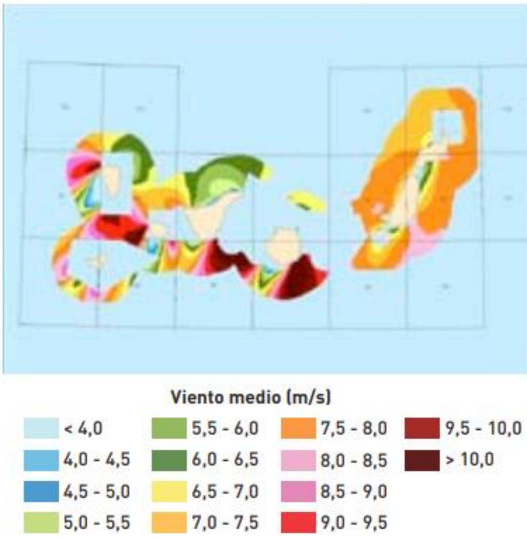

Figure 23. Map of the "suitable with conditions" zones in the Canary Islands. [34]

The most promising location is on the west coast of Gran Canaria Island. It has no legal risk as the zone is compatible with current marine use. Using the EMODnet Map Viewer, an official tool of the European Commission, it is possible to obtain Figure 24 and it is easy to see that the southwest coast of Gran Canaria Island has low maritime traffic, making it a viable location for an offshore wind farm

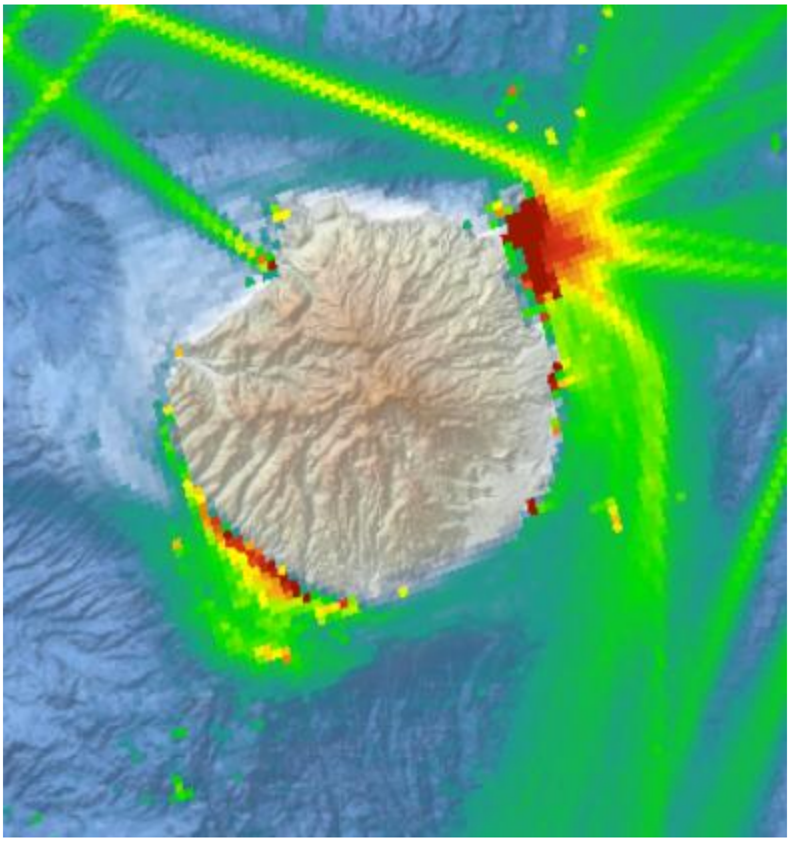

Figure 24. Marine traffic in Gran Canaria [35]

The southwest coast of Gran Canaria is a suitable option for the project. Nevertheless, the bathymetry analysis forces the platforms to be floating structures, and the autonomous grid of the island are reasons to consider other locations, where the project could be easier to develop and bigger, with a greater impact on the Spanish grid.

5.1.4.2 GALICIAN COAST

The Galician Coast is large, so it is important to define an exact location where the farm should be built. The locations with a promising bathymetry analysis are the sea lochs, as they are the sites with a sea depth of around 20 to 50 meters.

The problem with the sea lochs is that in some cases they are environmentally protected, and in others the population of the zone uses them for recreational purposes or fishing activities. Another problem with sea lochs is the high maritime traffic, as shown in Figure 25, as seaports are usually located inside sea lochs for higher protection.

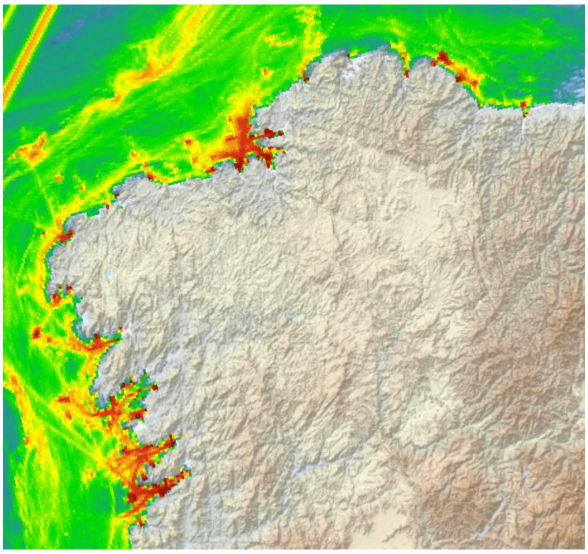

Figure 25. Maritime traffic in the Galician Coast [35]

Even though the bathymetry analysis is good in sea lochs it is very difficult to find a good location to build the offshore farm due to maritime traffic and environmental regulations (see Figure 18).

Outside sea lochs the bathymetry analysis is not as promising, and floating structures must be used there.

Grid connections are easy in this region thanks to all the coastal cities of the area. These cities count with substations, and the most remarkable ones are the high-capacity substations in A Coruña, Vigo and Pontevedra.

The region is suitable for floating offshore wind farms, but the environment regulations and maritime activity forces a revision of other places to select an easier location for the project.

5.1.4.3 CAPE TRAFALGAR

Cape Trafalgar is in the south Atlantic coast of Spain, and it is well known for its high-speed winds. The average wind speed in this region is usually around 7.5 meters per second, but there exists variability due to the topography of the region.

Cape Trafalgar is located near the Strait of Gibraltar, and it is very close to protected areas of the ZEIPM and RAMPE, as Figure 17 and Figure 18 show. This is an issue to consider when deciding the definitive location of the farm if it is done here, as it must be an area where neither ZEIPM nor RAMPE affect.

The maritime traffic near the Cape is not very dense, but it strongly depends on the area selected, as there are points with significant traffic, as Figure 26 shows.

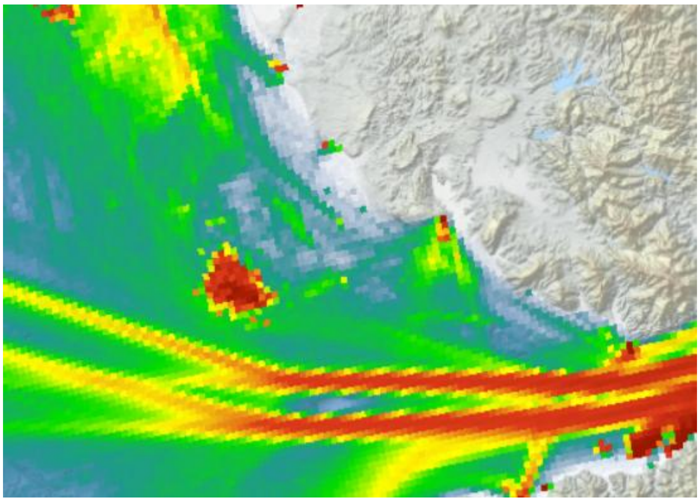

Figure 26. Maritime traffic near Cape Trafalgar [35]

The bathymetry analysis shows that seabed is less than 50 meters deep. It cannot be appreciated in the images of the bathymetry analysis on the previous sections, so Figure 27 can show in detail the depth of the area.

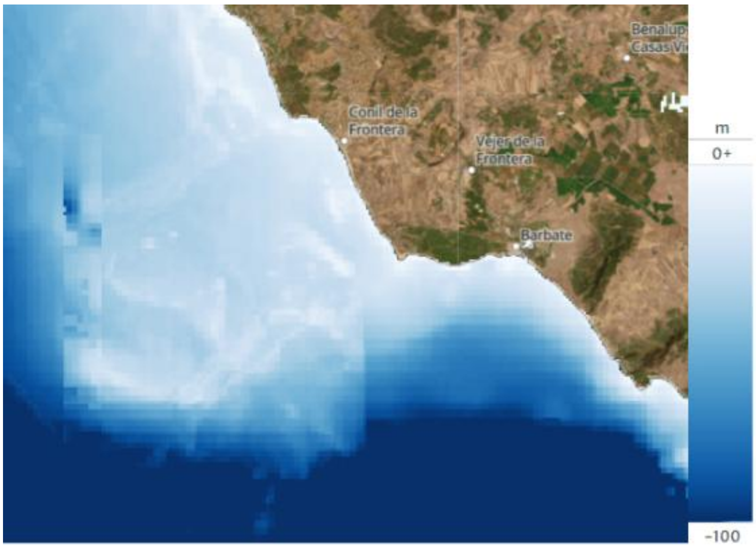

Figure 27. Bathymetry of Cape Trafalgar area [33]

The grid connection is moderately good thanks to coastal cities like Barbate and Conil de la Frontera, both of which have their own substations.

This is one of the most promising areas for future offshore wind projects. Nevertheless, the regulatory issues of the region make necessary consideration of other options.

5.1.4.4 GULF OF ROSES

The Gulf of Roses is in Girona, a region of the northeast of Spain. It is a zone affected by the Tramontana winds, a characteristic wind of this area of the Mediterranean Sea.

Even though part of the gulf is a ZEPA (bird protection) area, it is catalogued as a High Potential Area (HPA) according to POEM and MITECO. It is outside of the major protected areas of the Spanish coast, according to the Royal Decree 150/2023 [36]. The map on Figure 28 shows the area selected in the POEM plans as HPA for offshore wind farms.

Figure 28. HPA for the development of offshore wind farms near the Gulf of Roses [32].

The wind resource in the area is favorable for the construction of an offshore wind farm. These high wind speeds are there thanks to the Tramontana wind. Tramontana is a cold and powerful wind that comes from the north and can gain a speed of more than two hundred kilometers per hour. It has its origin in the Pyrenees and the French Central Massif. Figure 29 and Figure 30 show the mean wind speed and mean wind power potential of the area near the Gulf of Roses.

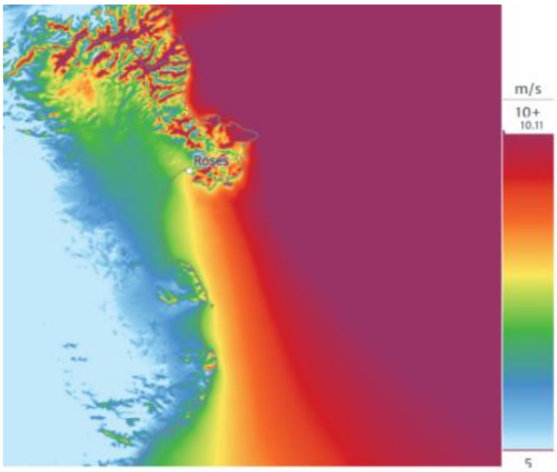

Figure 29. Mean wind speed in the Gulf of Roses at 100 meters high [33]

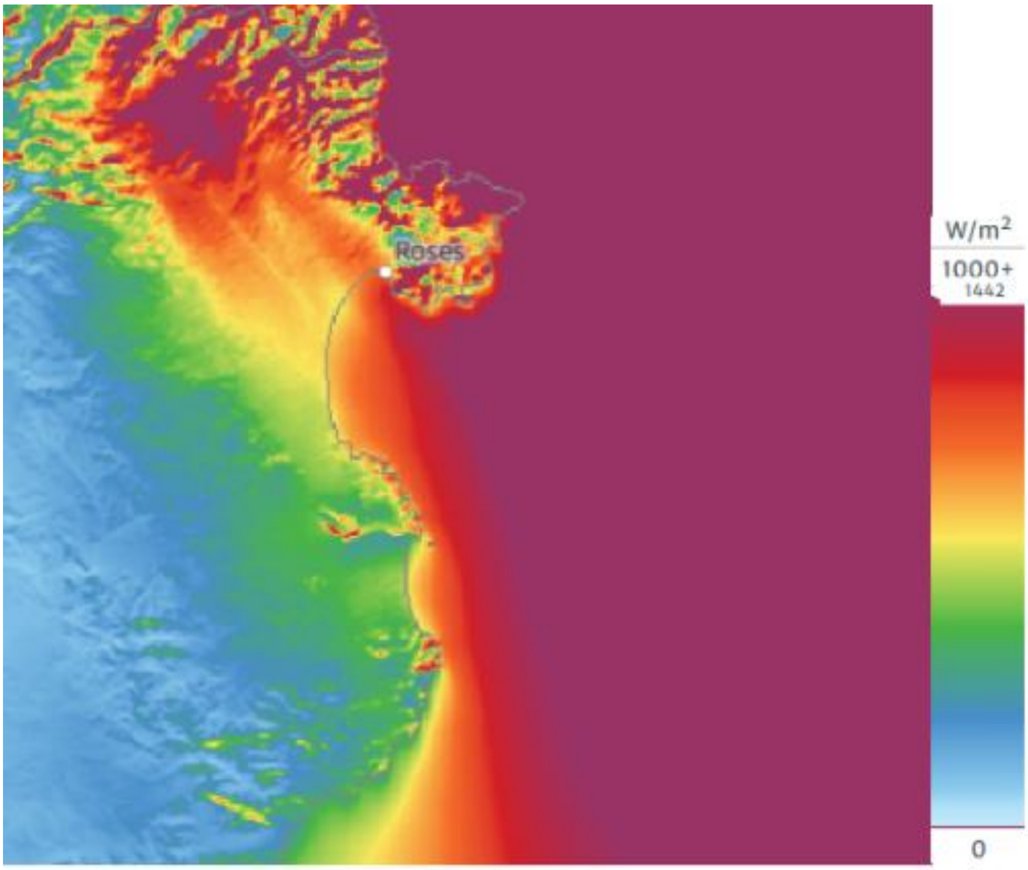

Figure 30. Mean wind power potential in the Gulf of Roses at 100 meters high [33]

The bathymetry analysis of the area is only good near the coast. In the area of the bay, close to the shore, the depth of the sea varies between 20 and 60 meters. Nevertheless, this area is too close to the shore, and it is not feasible to make an offshore farm there. The area selected by MITECO in Figure 28 is further from the shore, so the sea depth of the area is more than 100 meters in average, as Figure 31 shows. This implies that floating platforms will be necessary to build an offshore wind farm in the designated region in by MITECO in the POEM.

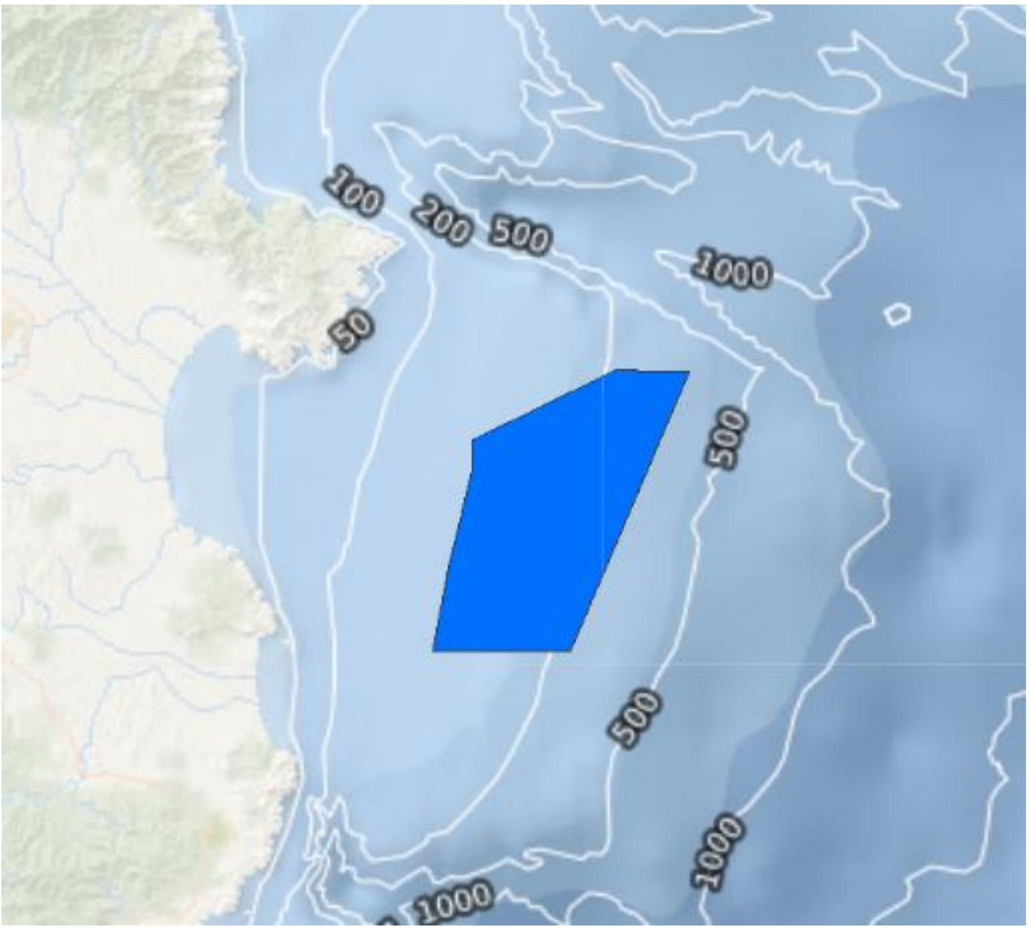

Figure 31. Map of the bathymetry of the HPA for offshore wind in Gulf of Roses [32].

The Gulf of Roses does not have a high density of maritime traffic. Even though it is close to the main ports of Spain in the Mediterranean Sea, maritime traffic in the area designated by MITECO is low. Figure 32 shows the traffic of the area near the Gulf of Roses.

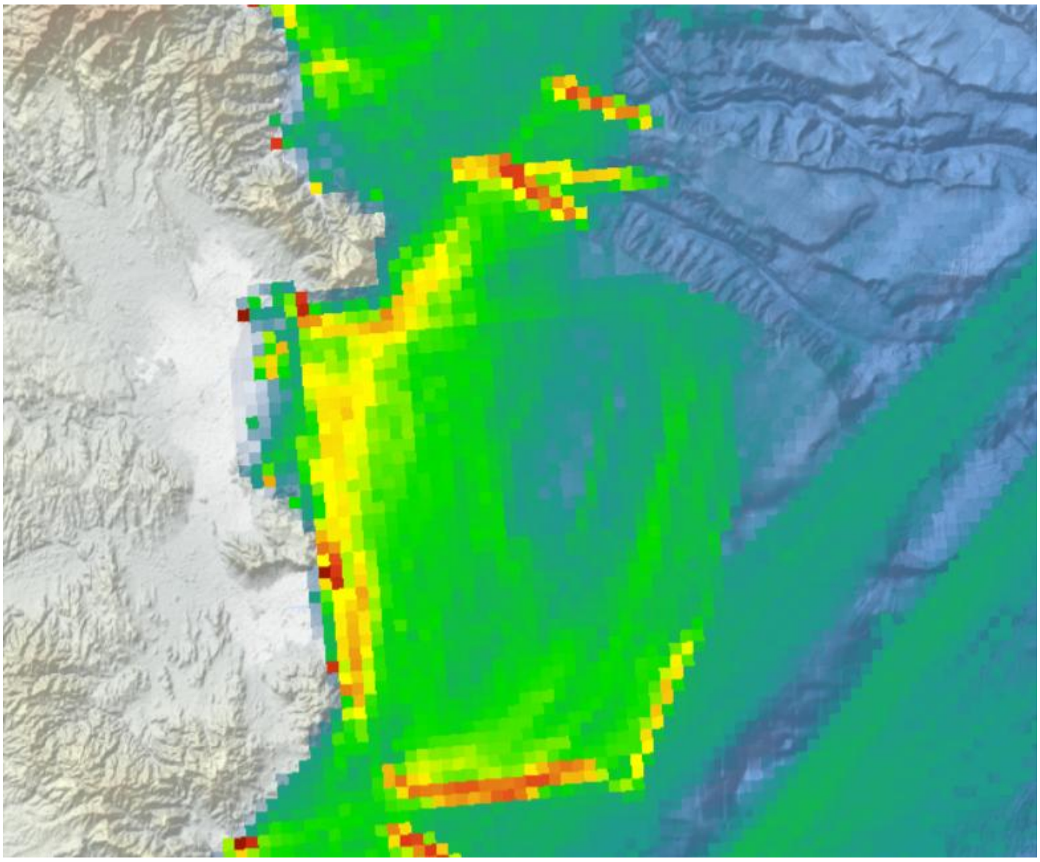

Figure 32. Maritime traffic density map in the Gulf of Roses [35].

The grid connection in the area is easy thanks to the existence of La Farga substation. It is a substation with two main stations: the first one of 400 kV (six positions) and the second one of 220 kV (8 positions). It is one of the most important substations in Catalonia and it can be modified if necessary [37].

The Mediterranean is not a sea with extreme tides or sea currents. It is a clamed sea, but specific conditions can create strong currents. The presence of the rivers Muga and Fluviá can generate local currents, especially near the river mouth. The Mediterranean Sea is also braver during the cold seasons, so stronger currents can be expected during the Winter. The intense winds of the area can also create sea currents. Nevertheless, the Mediterranean Sea under these conditions usually has weaker tides and currents than the Atlantic Ocean. The currents in the Gulf of Roses will be less strong than the currents in the other three possible locations.

In conclusion, the only negative issue of this location is the bathymetry analysis. Nevertheless, there are few zones in Spain with a positive bathymetry analysis, and the area of the Gulf of Roses is considered a HPA zone by the European Union and the Spanish Government. This makes the obtention of permits easier and the waiting times shorter, as the regulatory entities have already defined the area as feasible for offshore wind projects.

The four options present locations that are favorable for turning into an offshore wind farm. After analyzing the main factors that affect the decision, the location selected is the Gulf of Roses. It presents the same disadvantage as the other regions, but the fact that it is a HPA zone designated by the government makes this gulf an extremely attractive location for offshore power production purposes. Figure 33 shows the definitive area of the project, with surface extension and limits. It includes all the HPA selected area in the POEM [32], with around 243 square kilometers, which is a valid surface extension for an offshore wind project with large capacity. It also shows the wind power potential according to Global Wind Atlas [33].

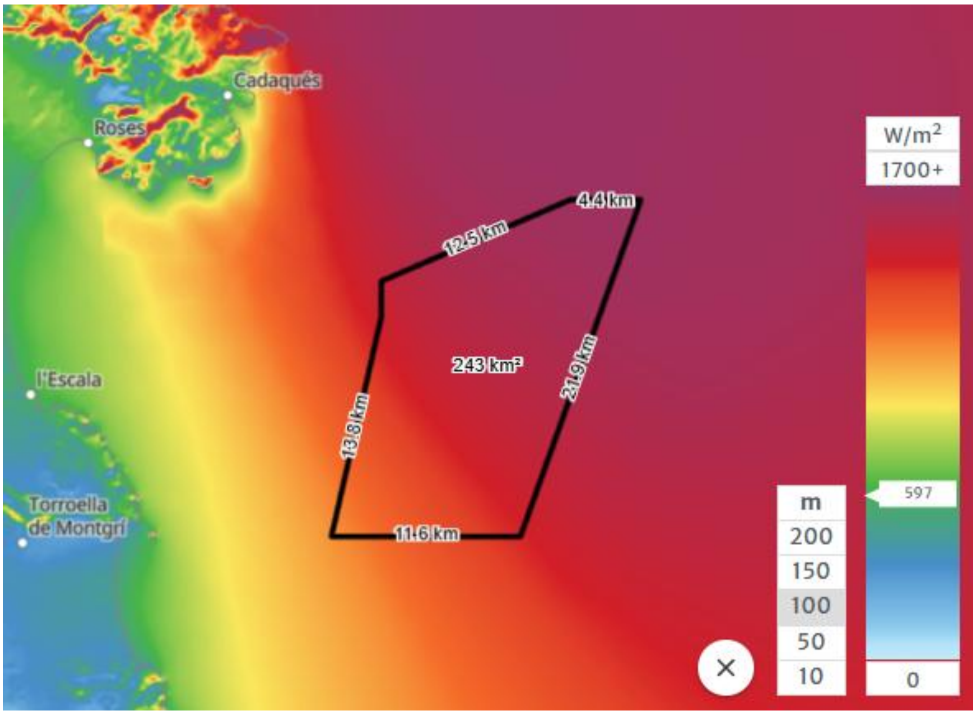

Figure 33. Area for the project with estimated wind power potential [33].

5.2 TECHNICAL CHARACTERISTICS

This second section of the project design will focus on the analysis of the technical characteristics of the farm (like wind resource analysis), and the selection of the technologies used for the development of the project, such as platforms, cables, turbines, transformers…

The characteristics of the wind must be analyzed for the specific case of the Gulf of Roses.

5.2.1 WIND RESOURCE ANALYSIS

The exact location of the project has been determined previously. The main reason for the use of this area as the location for the offshore wind power plant is the fact that it is a HPA zone designated by the EU and the Spanish government. As it is a High Potential Area for offshore wind development, the wind resource should be good in the region. Nevertheless, this is not enough for the design of a real project, and therefore, it is necessary to make a complete wind resource analysis. This wind resource analysis will include wind mean speeds at different heights, predominant wind directions and probability functions for the wind among other parameters.

It is necessary to mention that there exist a measurement buoy in the area, designed and implemented by BlueFloat and Sener for the development of a similar project [38]. The data collected by this measurement buoy is not publicly available, and therefore, it is impossible to access the information collected by the buoy and alternative wind data must be used for the project. The buoy, in Figure 34, not only measures the characteristics of wind, tides and sea currents, but also is equipped with sensors designed to detect birds, crustaceans and bats, which helps to determine the environmental impact of an offshore farm in the location.

Figure 34. Measurement buoy in the Gulf of Roses [39].

According to the map tool of Global Wind Atlas, mean wind speed varies in the area of the project, having the maximum speeds in the northeast section of the area and the minimum speeds in the southwest section and this can be seen by altering the label that was used for these maps in previous sections, from 5 to 10 meters per second to 5 to 13 (see Figure 35).

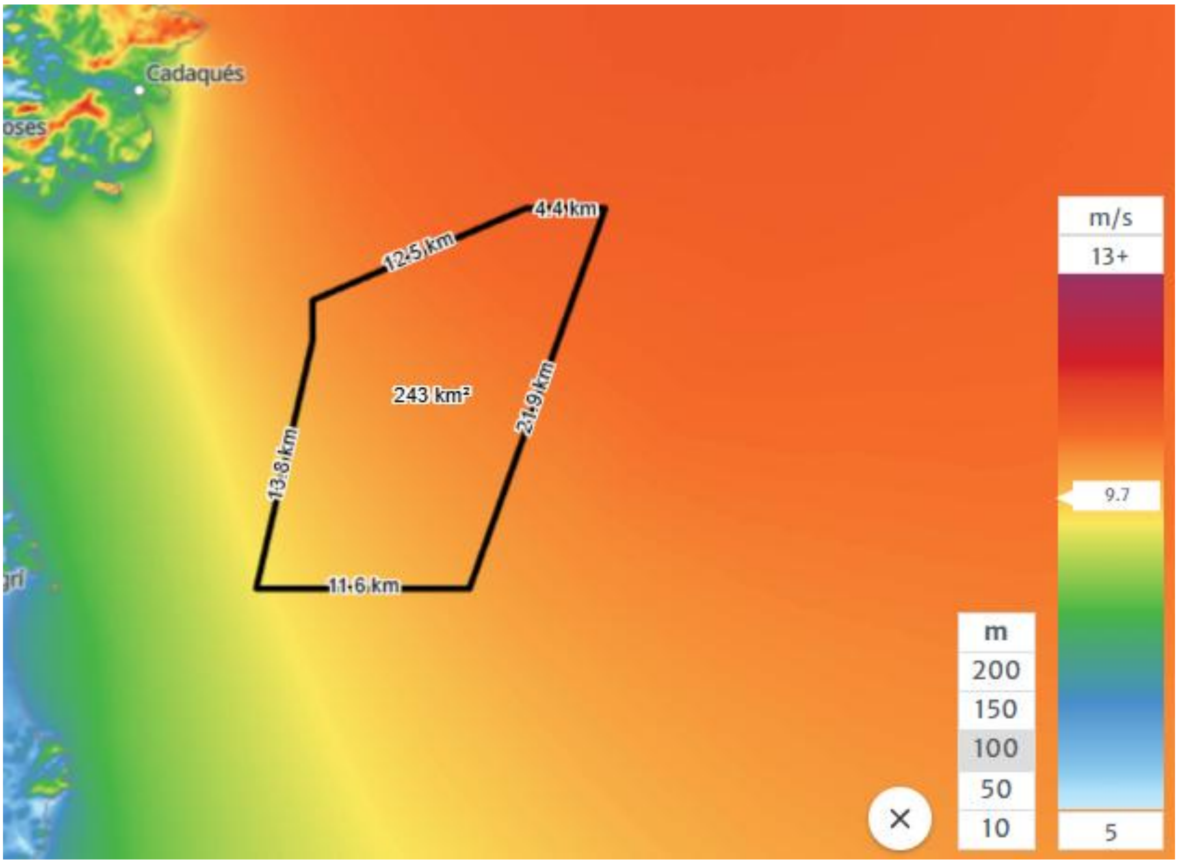

Figure 35. Map of mean wind speed variation in the project area [33].

This variation of the wind speeds in the area creates the necessity of more than one point of measurement, as it is possible that wind characteristics change depending on the point. Therefore, three points of the area will be used for measurement. Table 6 shows the coordinates of the points of measurement.

Point Name	Latitude	Longitude
Alpha	42.06787	3.41594
Bravo	42.13093	3.46577
Charlie	42.20982	3.54407

Table 6. Coordinates of the points of measurement for wind conditions.

Point Alpha corresponds to the point with the lower mean wind speed and point Charlie to the one with the higher mean wind speed. The wind data obtained from the three points of measurement will be analyzed and compared to determine if there exist differences between the wind characteristics. The graphics are from the Iberian Wind Resource Map [40].

Figure 36 shows the hourly mean wind speed during a year in points Alpha, Bravo and Charlie. Even though the speed of the wind variates depending on the point, the hourly variation is the same on each point. This confirms that the wind fluctuates equally in the whole area, and it does not vary depending on how strong the wind is at each point.

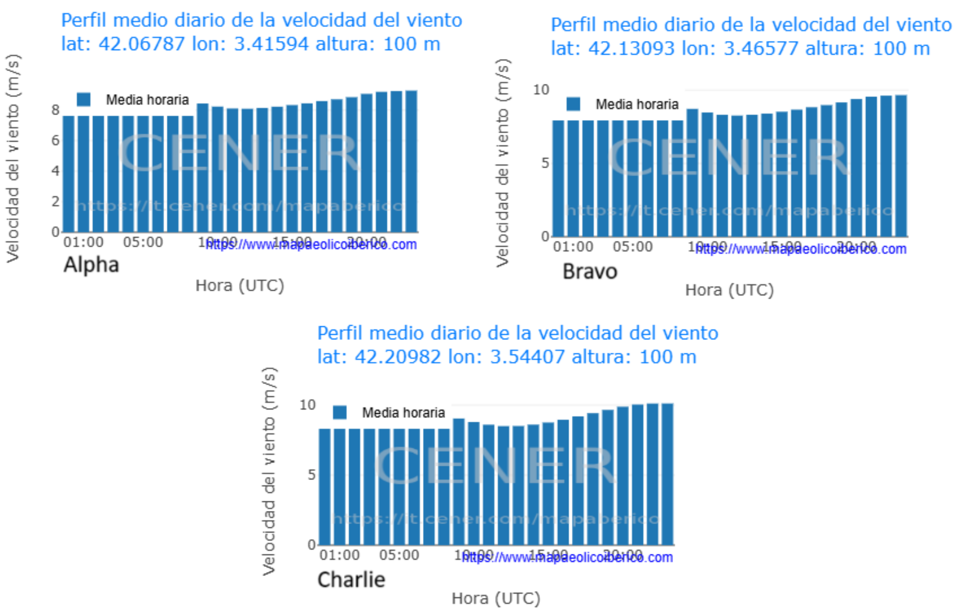

Figure 36. Hourly wind speed during a year in the measurement points [40].

Figure 37 shows the vertical wind speed profile on each point. It is easy to appreciate that the only difference between the three profiles is that Bravo and Chrlie profiles are slightly more to the right than Alpha, because the wind speed on those two regions is higher. The form of the wind profile depends on the height, but not on the location. It is also easy to appreciate that the wind speeds at heights between 80 and 120 meters (typical wind turbine heights) are close to 10 meters per second.

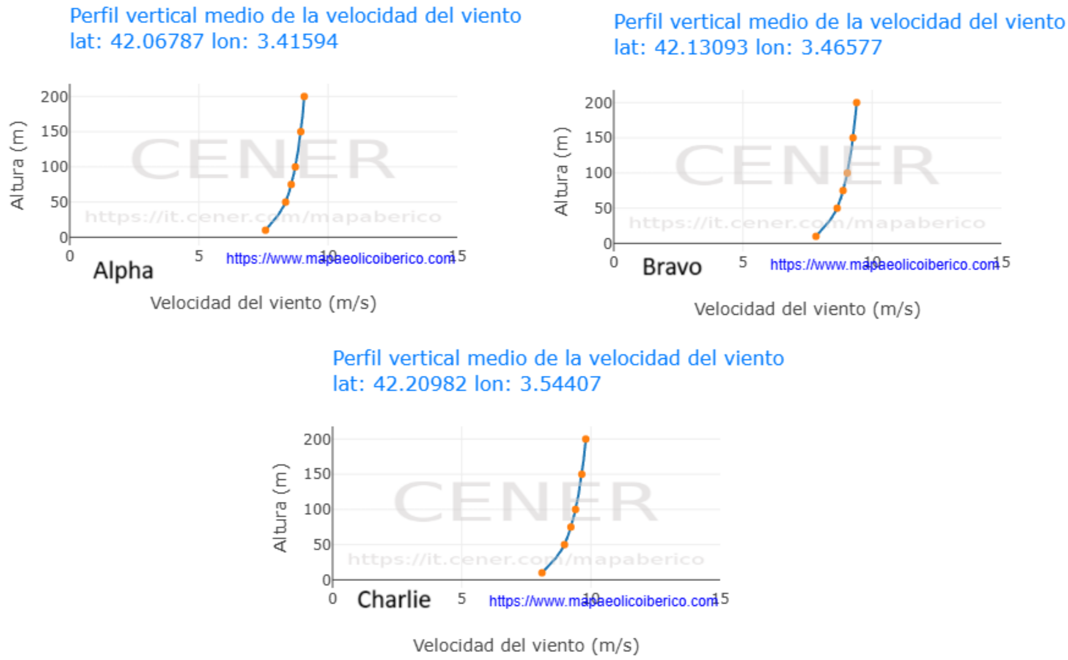

Figure 37. Vertical wind profile in the measurement points [40].

Figure 38 shows the direction of the wind in each one of the points of measurement. It is easy to appreciate that in Alpha, Bravo and Charlie, the direction with the highest wind speed is north northwest (NNW). Nevertheless, point Alpha shows a clear affinity with winds coming directly from the north. In point bravo this affinity still exists, but it is not as significant as in Alpha. The affinity in Charlie is almost null. The conclusion is that in the section with slower winds, the wind from the north is almost as fast as the wind from the NNW. Therefore, there exist more liberty in the way the turbines face the wind in this region, while in zones with higher wind speeds, the turbine must be facing a more specific direction to maximize the efficiency of the farm.

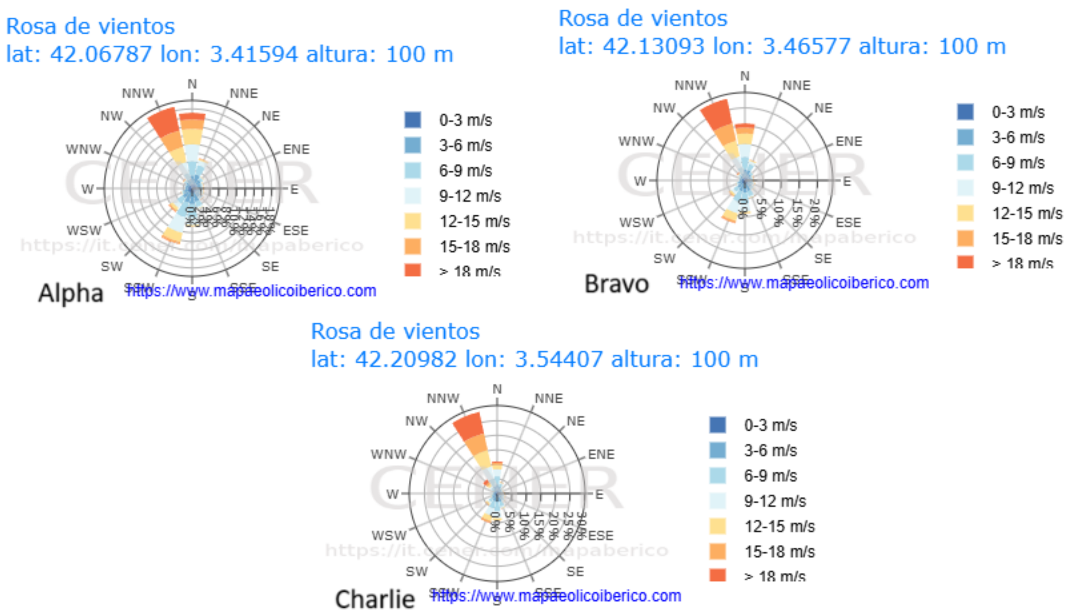

Figure 38. Rose of winds in the three measurement points [40].

Figure 39 shows the Weibull distribution of the measurement points Alpha, Bravo and Charlie. The parameter A (scale parameter) increases from Alpha to Charlie, showing that the wind is lighter in Alpha and stronger in Charlie. The shape parameter (k) also increases from Alpha to Charlie. This means that Charlie is more peaked than the other points, and therefore less spread and more predictable than the other points.

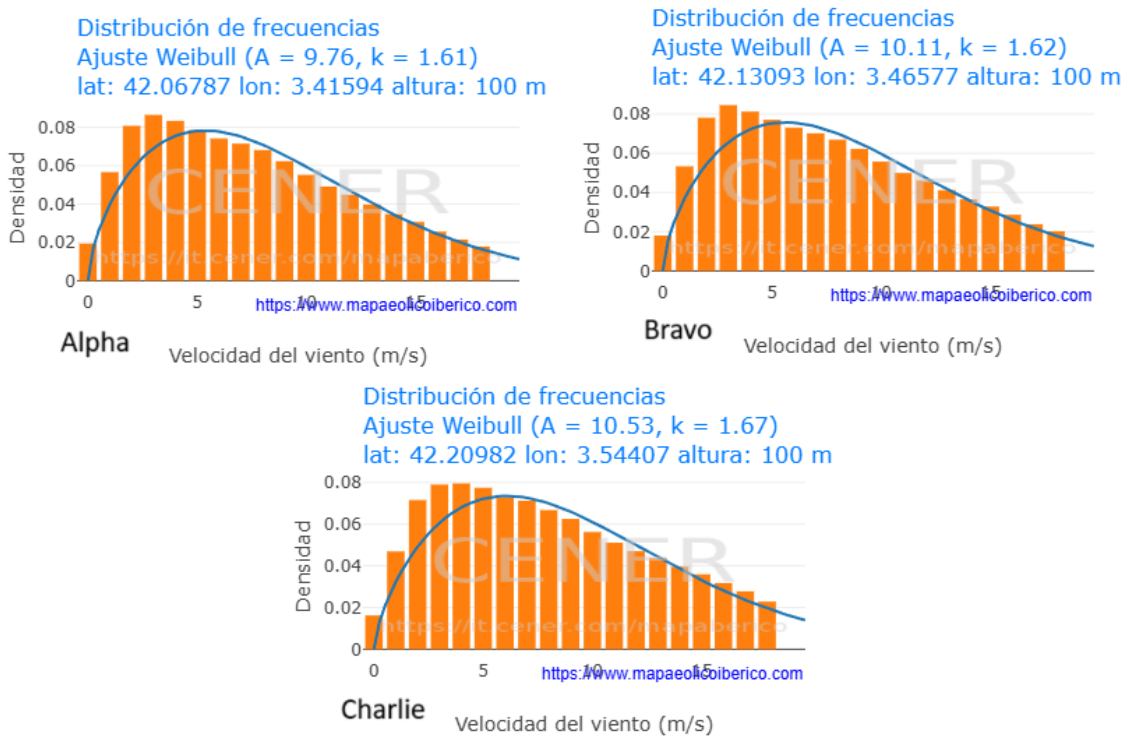

Figure 39. Weibull distribution of the three points of measurement [40]

After conducting an analysis of the wind resource in the area, the main conclusions obtained are the following:

- The wind resource in the area is likeable for an offshore wind farm. High mean speed and a common stable direction in the whole area.
- There exist differences between the characteristics of the wind in different places in the region. Nevertheless, these differences are not significant for the development of the wind farm, and one point can be used to determine the characteristics and energy obtained of the wind farm.

5.2.2 TURBINE SELECTION

Selecting the appropriate turbine for a wind farm is one of the most important parts of the development of the project. To select the turbine that fits the most on the project of an offshore wind farm in the Gulf of Roses, it is necessary to understand: how wind works in the area, which was done in 5.2.1, and how wind turbines are classified depending on the wind characteristics.

The most important wind characteristics to consider when classifying wind turbines are:

- The reference speed (V_{ref}): peak speed in the last 50 years for 10 minutes.
- Average speed (V_{pro}): average annual speed at the height of the rotor.
- A and B: categories for high and low turbulences.
- I_{15}: standard parameter for the intensity of the turbulence at 15 meters per second.
- a: parameter used to calculate the standard deviation of the model of turbulence.

With these parameters, the IEC classifies wind turbined in four different groups from I to IV. Figure 40 shows the parameter values of each one of the classes.

Clases		I	II	III	IV
V_{ref} (m/s)		50	42.5	37.5	30
V_{pro} (m/s)		10	8.5	7.5	6
A	I_{15} (-)	0.18	0.18	0.18	0.18
	a(-)	2	2	2	2
B	I_{15}(-)	0.16	0.16	0.16	0.16
	a(-)	3	3	3	3

Figure 40. Wind turbines classification depending according to IEC 61400-1 [41].

The average speed of the area used for the project is typically over 8.5 meters per second and under 10 meters per second. Therefore, it seems reasonable to use a type I wind turbine.

After careful research, there are two wind turbines that have potential to be the ones used in the offshore wind farm project. Table 7 shows the main information about the two turbines. The goal of the table is to compare both turbines and decide which one fits better into the project.

Wind Turbine	MHI Vestas Offshore V164-8.0 MW	Siemens Gamesa SG 8.0-167 DD
P_N (kW)	8000	8000
$V_{cut\text{-}in}$ (m/s)	4	3
V_{rated} (m/s)	13	13
$V_{cut\text{-}out}$ (m/s)	25	28
D_{rotor} (m)	164	167
H_{hub} (m)	105-140	119 (or site specific)
$P_{density}$ (W/m^2)	378	365,3

Table 7. Information on the possible turbines for the project [42] [43].

By comparing the two wind turbines, the Siemens Gamesa turbine has a lower cut-in wind speed and a higher cut-out speed, which makes it work at lower wind speeds and stop working at faster wind speeds. The power density of the Siemens Gamesa is lower than the MHI Vestas one. Nevertheless, the larger rotor diameter makes the rotor area bigger, producing more power. The hub height is very similar, both turbines have a wide range of height.

For these reasons, the Siemens Gamesa SG 8.0-167 DD is the turbine that will be used for the project. A datasheet with all the full information about the turbine can be found in Anexo I.

For the design of a 160 MW offshore wind farm using Siemens Gamesa 8.0-167 DD, twenty wind turbines will be needed. The hub will be 100 meters high, as it is site specific and there is a significant amount of wind data at that height.

5.2.3 OFFSHORE WIND FARM DISTRIBUTION

The distribution of the offshore wind farm is important to maximize efficiency. It is necessary to distribute the wind turbines across the area in an efficient way.

The optimal layout design for a floating offshore wind farm is the WindMax layout. In this type of layout, the goal is to fit the wind turbines in one or more straight lines (forming a parallelogram), facing the direction of the wind as shown in the example of Figure 41.

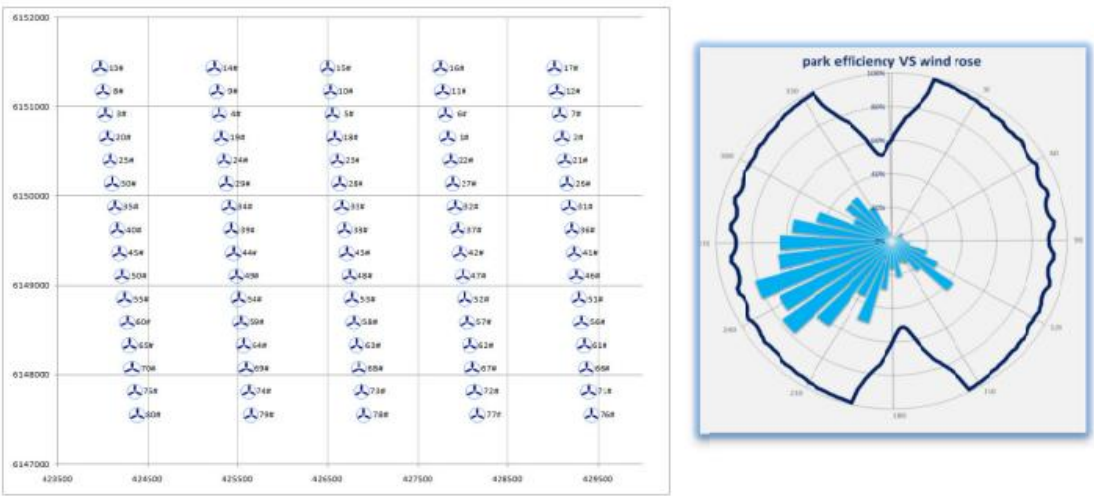

Figure 41. WindMax layout example [44].

The distance between turbines in the same row must be between three and five times the rotor diameter of the turbine to avoid interference between the blades. The rotor diameter of the Siemens Gamesa SG 8.0-167 DD is 167 meters, and therefore, the separation distance of wind turbines across one road must be between 501 and 837 meters.

The distance between turbine rows must be between seven and nine times the rotor diameter. The wind turbines of a row are usually set in between two turbines of the row before. These two things help minimize the turbulent effect of one row to another. The distance between rows should be between 1169 and 1503 meters.

The acceptable values of the distance between turbines are 600 meters for turbines in the same row, and 1300 meters for rows of turbines. These values lead to a 6000x2600 square meters (15,1 km^2) surface fully occupied by wind turbines. This area is much smaller than the HPA POEM area, which was 243 km^2. Therefore, the wind farm will be built in the top right corner of the HPA POEM area, that is the one with the highest mean wind speeds.

In Figure 42 there is a map of the area where the wind turbines will be located, and a rose of winds that shows the main direction of the wind in the area. It is easy to appreciate that the area is oriented in the same direction that the rose of winds points (NNW). It is necessary to mention that the exact form of the area is not a rectangle, because of the need to place a turbine on each of the corners for easier representation.

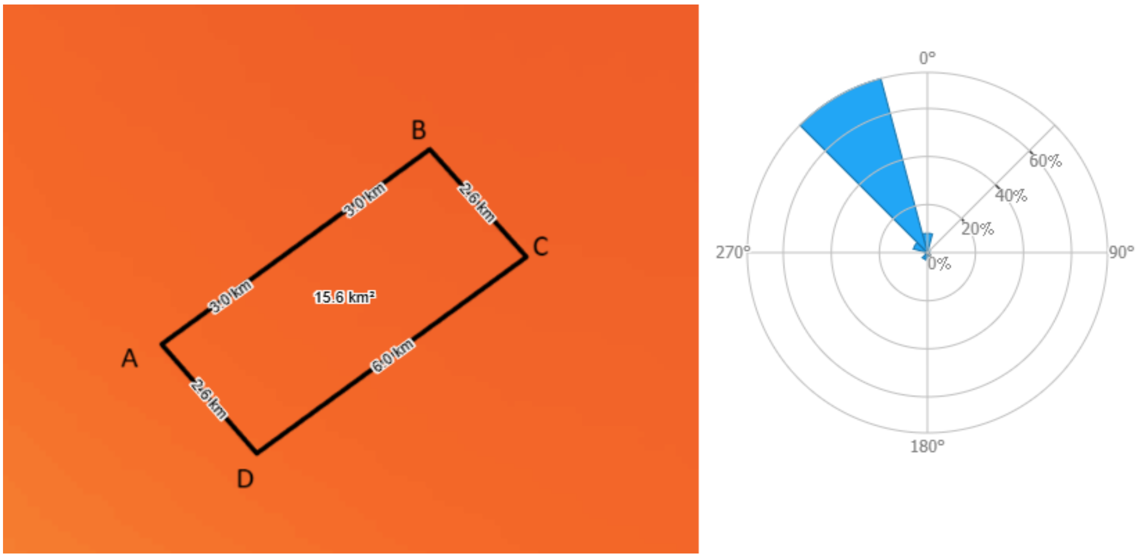

Figure 42. Map of the wind turbine area with the rose of winds.

Table 8 gathers the coordinates of the four corners of the rectangular area. There will be one turbine in each one of these corners, and the rest of them will be located every 600 meters on each side of the longer borders of the area.

Corner	Latitude	Longitude
Corner A	42.20615	3.50131
Corner B	42.23789	3.56031
Corner C	42.22041	3.58149
Corner D	42.18841	3.52211

Table 8. Coordinates of the corners of the wind turbine area.

5.2.4 EXPECTED PRODUCED ENERGY

To calculate the expected energy that the offshore wind farm will produce, it is necessary to know more information about the turbine and the environment.

The first thing necessary for the calculation of the energy produced is the power curve of the wind turbine. After careful research, it is impossible to find the values of the power curve of the wind turbine. Nevertheless, using the information from "Analyzing Europe's Biggest Offshore Wind Farms: A Data Set with 40 Years of Hourly Wind Speeds and Electricity Production" by Grothe et al. [45] it is possible to obtain the values of the power curve using the cubic fit.

Equation 3 shows the way that the power curve values are calculated. $Speed_{min}$ is the cut-in speed, $speed_{split}$ is the change of concavity speed (8 meters per second) and $speed_{max}$ the cut-out speed. The necessary coefficients for the calculation are shown in Figure 43.

$$p(speed_h) = \begin{cases} 0, & if\ speed_{hub} < speed_{min} \\ \alpha_1 speed_{hub} + \beta_1 speed_{hub} + \gamma_1 speed_{hub} + \delta_1, & if\ speed_{min} < speed_{hub} < speed_{split} \\ \alpha_2 speed_{hub} + \beta_2 speed_{hub} + \gamma_2 speed_{hub} + \delta_2, & if\ speed_{split} < speed_{hub} < speed_{rated} \\ p_{rated}, & if\ speed_{rated} < speed_{hub} < speed_{max} \\ 0, & if\ speed_{max} < speed_{hub}, \end{cases}$$

Equation 3. Power depending on the speed for a wind turbine [45]

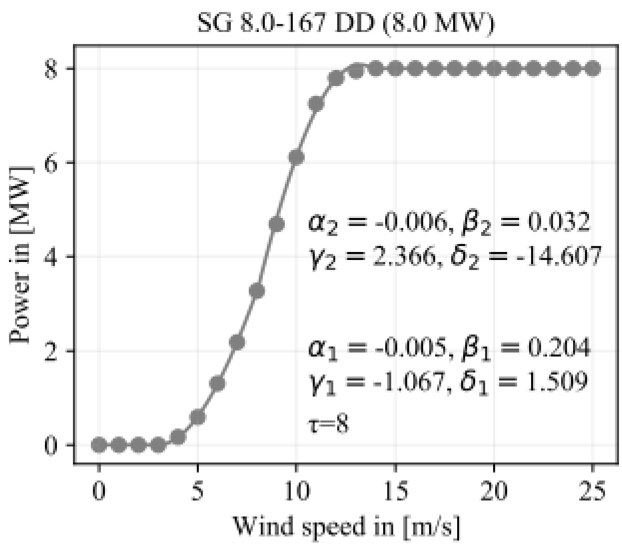

Figure 43. Power curve of the SG 8.0-167 DD wind turbine [45].

It is now easy to obtain the values of the power curve of the turbine, which are necessary to calculate the energy produced by the offshore wind farm. Table 9 shows the values of the power curve of the wind turbine.

V_{wind} [m/s]	$P(V_{wind})$ [kW]
3	9.0000
3.5	59.1250
4	185.0000
4.5	382.8750
5	649.0000
5.5	979.6250
6	1371.0000
6.5	1819.3750
7	2321.0000
7.5	2872.1250
8	3469.0000
8.5	4131.2500
9	4905.0000
9.5	5613.7500
10	6253.0000
10.5	6818.2500
11	7305.0000
11.5	7708.7500
12 to 28	8000.0000

Table 9. Power curve values of SG 8.0-167 DD wind turbine.

Using Equation 1 it is possible to calculate the probability of having a specific wind speed or more. Therefore, it is possible to calculate the probability of having a wind speed in an interval (f(3) shows the probability of having a wind speed between 2.5 and 3.5). Note that it is necessary to obtain the scale and shape parameters of the wind in the area, which can be easily done using the Spanish Wind Map tool [40]. The shape parameter is k=1.67 and the scale parameter is c=10.06.

Using the probability of each interval and multiplying it by the number of hours a year has; it is easy to obtain the number of hours where there is certain wind speed in a year (Equation 4).

$$H_3 = f(3) \cdot 8760 \frac{h}{year}$$

Equation 4. Example of the calculation of hours of the year at certain wind speed.

With the hours of the year at a certain wind speed and the power that the turbine produces at that speed (in Table 9), the energy produced by one turbine can be obtained by multiplying the two values. To find the total energy generated by the twenty turbines, the value obtained is multiplied by 20. This energy generated will not consider losses. It is difficult to estimate all the losses in a farm like this one, so the most typical approach is to consider 20% of total losses. All the values obtained using the previously explained calculations is shown in Table 10.

V_{wind} [m/s]	P(v) [kW]	Weibull Prob	Hours [h/year]	E (kWh/year)	Etot+loss (MWh/year)
3	9.00	0.06	566.21	5095.89	81.53
3.5	59.12	0.07	603.85	35702.51	571.24
4	185.00	0.07	632.67	117043.57	1872.70
4.5	382.87	0.07	653.45	250190.20	4003.04
5	649.00	0.08	666.91	432827.35	6925.24
5.5	979.62	0.08	673.74	660008.79	10560.14
6	1371.00	0.08	674.57	924840.64	14797.45
6.5	1819.38	0.08	670.07	1219100.69	19505.61
7	2321.00	0.08	660.83	1533792.96	24540.69
7.5	2872.13	0.07	647.48	1859634.35	29754.15
8	3469.00	0.07	630.58	2187470.88	34999.53
8.5	4131.25	0.07	610.69	2522896.95	40366.35
9	4905.00	0.07	588.33	2885754.16	46172.07
9.5	5613.75	0.06	564.00	3166144.67	50658.31
10	6253.00	0.06	538.15	3365060.87	53840.97
10.5	6818.25	0.06	511.21	3485563.56	55769.02
11	7305.00	0.06	483.56	3532414.76	56518.64
11.5	7708.75	0.05	455.55	3511716.12	56187.46
12	8000.00	0.05	427.48	3419874.77	54718.00
13	8000.00	0.04	372.25	2977967.66	47647.48
14	8000.00	0.04	319.59	2556759.75	40908.16
15	8000.00	0.03	270.75	2166034.00	34656.54
16	8000.00	0.03	226.49	1811904.58	28990.47
17	8000.00	0.02	187.18	1497428.58	23958.86
18	8000.00	0.02	152.90	1223234.18	19571.75
19	8000.00	0.01	123.52	988121.68	15809.95
20	8000.00	0.01	98.70	789607.07	12633.71
21	8000.00	0.01	78.05	624389.49	9990.23
22	8000.00	0.01	61.09	488734.56	7819.75
23	8000.00	0.01	47.35	378773.51	6060.38
24	8000.00	0.00	36.34	290723.73	4651.58
25	8000.00	0.00	27.63	221040.41	3536.65
26	8000.00	0.00	20.81	166510.30	2664.16

27	8000.00	0.00	15.54	124299.58	1988.79
28	8000.00	0.00	11.50	91967.03	1471.47
				TOTAL	824202.08

Table 10. Energy produced by the farm considering losses.

With the data calculated in Table 10 it is possible to obtain parameters that measure the quantity of the farm. The capacity factor (CF) and the equivalent hours are calculated in Equation 5 and Equation 6.

$$CF = \frac{E_{tot}}{P_{installed} \cdot 8760 \frac{h}{year}} \cdot 100\% = 58.8\ \%$$

Equation 5. Capacity factor of the farm

$$H_{equiv} = \frac{E_{tot}}{P_{installed}} = 5151.263\ hours$$

Equation 6. Equivalent hours of the farm

The CF obtained is above average. The CF of an offshore wind farm is usually in the range of 35% to 55%. This is because of the good wind resource in the area, that affect positively the scale and shape parameters of the Weibull PDF, and therefore, the probability of strong winds increases significantly.

5.2.5 STRUCTURE SELECTION

The bathymetry map of Figure 31 shows that the sea depth in the area where the turbines will be located is in the range of 200 to 500 meters. This means that fixed bottom structures are not viable for the project. Therefore, it is mandatory to choose between the floating offshore platforms discussed in 3.3.1.2.

To select the appropriate floating structure for the project it is necessary to select the sea conditions of the area. The waves of the Catalonian coast are not strong. The mean height of the waves in the area is 0.72 meters, which is below the average wave height of the area. In storm conditions the waves can reach a height of 6 meters, which still is weak compared to waves in other seas [46]. Tides in the mediterranean sea are weak. The amplitude of the tides in the area is around the value of 0.2 meters, and tide currents have a speed of around 0.05 meters per second. Therefore, currents are mostly dominated by the wind. These wind dominated sea currents in the surface are usually between 0.1 and 0.2 meters per second [47]. This analysis shows that the sea conditions of the area are favorable for the use of floating wind structures, as the weak waves, tides and currents will not cause a strong mechanical load on the platform.

Semisubmersible and TLP platforms are optimal for the sea depth of the area (between 200 and 500 meters). SPAR platforms are more reliable at sea depths of 500 meters or more. TLP platforms use expensive and complex tendons, and SPAR platforms have a deep draft that makes them impractical for the sea depth of the area. Semisubmersible platforms are less heavy than TLP and SPAR, and can be mounted by modules, making them easier to transport and mount. Semisubmersible platforms also present advantages in O&M, as its simplicity and moderate draft makes the arrival of maintenance crew and materials easy.

For these reasons, a semisubmersible platform appears to be the optimal solution for the structure selection problem. As there are not many floating offshore farms yet, there are not many options of semisubmersible platforms available. Nevertheless, the platform used for the WindFloat Atlantic project in Portugal has characteristics that match perfectly with the ones of this project. The wind turbine used in the WindFloat project is very similar to the SG 8.0-167 DD, and Table 11 sets a comparison between the two of them. As the values of the hub height and rotor diameter are very similar, the semisubmersible platform must be able to hold the turbine for the project in the Gulf of Roses.

Turbine	WindFloat turbine	SG 8.0-167 DD
P_N (MW)	8.4	8
H_{hub} (m)	108	100
D_{rotor} (m)	164	167

Table 11. WindFloat and SG 8.0-167 DD characteristics comparison.

The semisubmersible platform counts with three tubular columns interconnected with bridges. This gives stability to the structure and facilitates the work of the maintenance crew. It has three anchoring cables that are anchored into seabed. The mounting is done onshore, and the platform is transported to the installation point by towing it from the shore, which lowers installation cost. Figure 44 shows the platform being towed to its destination in the Portuguese coast.

Figure 44. WindFloat Atlantic turbine installation process [48].

5.2.6 ELECTRICITY TRANSPORTATION SYSTEM

Once the energy is generated by the turbines of the offshore wind farm, it is necessary to transport electricity to the mainland, where it can be distributed to the population and companies. This transmission must be done efficiently, minimizing losses and equipment costs. An efficient transmission system increases the earnings obtained by the farm operator.

The transmission is divided into two different steps. The first step is the transmission from the turbine to the offshore substation, and the second step is the transmission from the offshore substation to the onshore substation. Figure 45 shows the system used in the project.

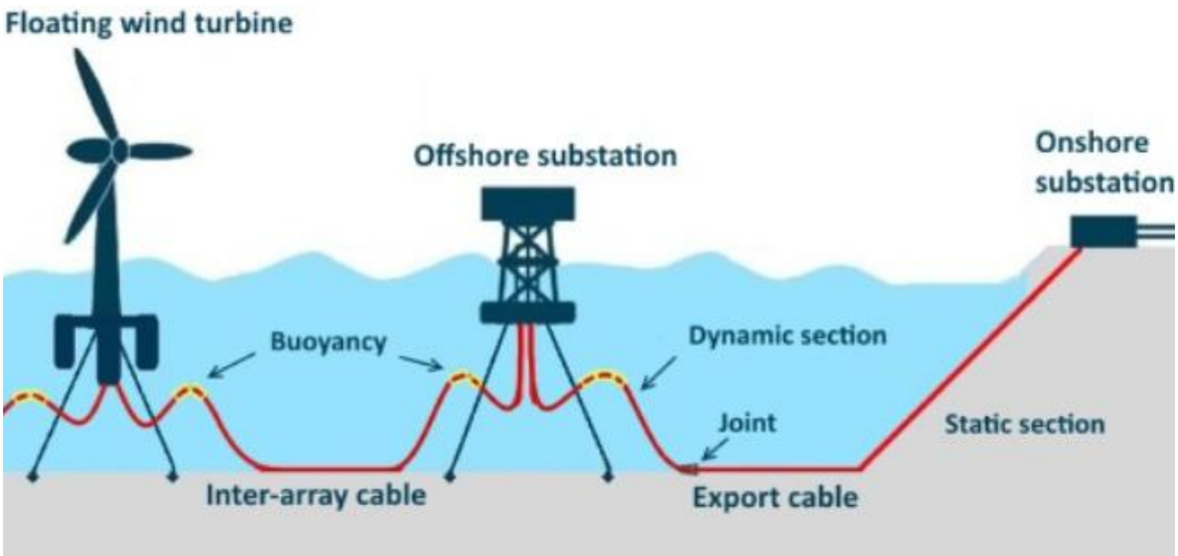

Figure 45. Sketch of the transmission system [49].

As shown in Anexo I, the Siemens Gamsa SG 8.0-167 DD turbine produces electricity at a voltage level of 820 V. This voltage is too low for an efficient transmission, and therefore, it must be step up. This can be done using one transformer in each turbine, or one transformer per group of turbines (groups of five in this case because of the layout of the farm). The most efficient way is to use one transformer per turbine, because even though the initial cost is higher (more transformers and more maintenance cost), this method reduces the losses in array cables and benefits from the experience of other farms implementing this method. It also simplifies the protection systems and lets the turbines work independently if desired.

The transformer used in each turbine will be the ABB WindSTAR 11MVA 0.69/33kV. This transformer is designed to be mounted in offshore turbines. Its modular design makes it simple to adapt to the wind turbine conditions, which makes it ideal for this type of turbine. The specifications sheet can be found in Anexo II. This transformer is designed for 690 V, but it can be changed to 820 V easily, to match the voltage level of the wind turbine.

Between the wind turbines and the offshore substation, it is necessary to introduce switchgears for secondary distribution. These switchgears act as a protection from the electricity grid for the wind turbines. The selected switchgear is the ABB Safeplus 36. It is a completely sealed system with a stainless-steel tank that uses sulfur hexafluoride (SF_6) for protection, ensuring personnel safety, reliability and a virtual maintenance-free system. The selection of an ABB switchgear has been made for compatibility reasons. Knowing that the transformer of the turbines will be designed by ABB, a switchgear of the same company ensures compatibility between the two devices. The specifications sheet of the ABB Safeplus 36 can be found in Anexo I.

The connection of the wind turbines with the offshore substation can be done in different ways. The most versatile one is the net method. In this method, the wind turbines are divided into groups, and therefore, if one group of turbines fail, the rest of them are not affected and can function properly. Due to the layout of the project (two rows of ten turbines), it has been decided to divide them into 4 groups with 5 turbines per group. This ensures that the farm can work during failure times and economic losses are reduced.

The transportation of the power from the turbines to the offshore substations will be done using AC current and requires a cable that can withstand a power of 8 MW (for the connection between turbines) and 40 MW (one group of five turbines) at a voltage level of 33 kV. The cables that connect each group of turbines with the offshore substation must act like the ones shown in Figure 45. The "lazy wave" form obtained using buoyancy elements helps mitigate the effects of waves and currents, protecting the integrity of the structure. Once the cables touch seabed, they are buried 1 meter below the ground, for protection reasons. The wires used for the project will be the (N)A2XS(FL)2Y 19/33KV cables, designed by Prysmian [50]. All the specifications of this cable model can be found in Anexo IV. These cables are dynamic three phase wires with XPLE insulation and polyethylene sheath. They are designed for floating offshore wind farms among other applications, and they offer a variety of cross-sectional areas depending on the needs of the project, which can be seen in Table 12.

Cross-section (mm²)	Direct in ground trefoil (A)	Direct in ground flat spaced (A)	Air trefoil (A)	Air flat spaced (A)
70	186	192	230	278
95	221	229	280	338
120	252	260	324	391
150	281	288	368	440
185	317	324	424	504
240	367	373	502	593
300	414	419	577	677
400	470	466	673	769
500	535	524	781	884
630	608	578	903	996
800	681	630	1029	1105
1000	753	681	1165	1219
1200	885	790	1274	1305

Ground temperature: 20°C; Air temperature: 30°C
Depth of laying: 0,8 m; Soil resistivity, moist: 1,5 K.m/W
Screen bonded at both ends

Table 12. I_{max} of (N)A2XS(FL)2Y 19/33KV cable depending on the area [50].

Using the three-phase equation for power (Equation 7) it is possible to obtain the maximum current that the wire must withstand, and therefore, it is easy to select the appropriate cross-section area for the different power levels.

$$I = \frac{P}{\sqrt{3} \cdot V \cdot \cos(\varphi)}$$

Equation 7. Current in three phase systems formula.

Assuming a power factor of 0.9, in the connection between turbines (8 MW) the maximum current is 155 A, and a wire with 70 mm² cross-section area can be used without risks. For the connection of the groups of turbines with the offshore platform (40 MW) the maximum current is 778 A, and a wire with 1200 mm² cross-section area is necessary to transport that amount of current. To estimate the length of wire that will be used it is necessary to determine the connection between turbines. The option used for the project will be the one shown in Figure 46. This option uses some more 1200 mm^2 cable distance, but the use of 70 mm^2 cable is significantly reduced compared to other options.

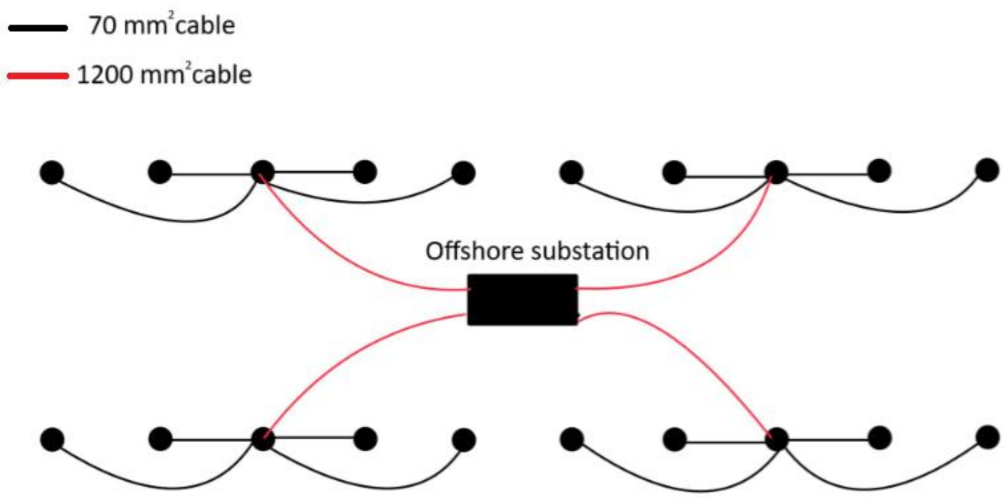

Figure 46. Wire distribution of the offshore wind farm.

The length of cable must be estimated, as the conditions of the area make the exact calculation of cable length extremely complicated. The difference between seabed depth and the use of the "lazy wave" effect makes calculations difficult. Therefore, the use of 70 mm^2 cable will be used for 16 connections between turbines: 8 connections of 600 meters and 8 of 1200 meters (in a straight line). Assuming that the average sea depth is 300 meters and that the cable gets to seabed at a 60º angle, the cable length between two turbines can be calculated as:

$$L_{70} = D_{T-T} + 2 \cdot \frac{300}{sen(60)} \cdot (1 - \cos(60))$$

Equation 8. Cable distance between two turbines

Using Equation 8, the total 70 mm^2 cable length used is 20000 meters.

To calculate the total 1200 mm^2 cable length, Equation 8, but instead of using the distance between turbines, it is necessary to use the distance between the middle turbine of each group and the offshore substation. This distance can be calculated using the Pythagoras theorem.

$$D_{T-S} = \sqrt{1300^2 + 1500^2} = 1985\ m$$

Using this distance, the total length of 1200 mm^2 cable is 9325 meters. Nevertheless, it will be necessary to buy more wire length than the calculated, in case there are unexpected inconveniences.

For the second part of the transmission system, it is necessary to use a floating platform for the offshore substation, a transformer that steps up from 33 kV to an export voltage level and export cables to take the power from the offshore substation to the mainland.

The floating offshore substation platform is one of the most difficult to find. The existing floating substation platforms are designed and owned by private companies that do not share the data, to prevent plagiarism. Therefore, the specifications sheet of these platforms is impossible to find. Nevertheless, it is mandatory to use a platform for the purposes of the project, and the company Semco Maritime has designed a semisubmersible substation platform for floating offshore projects, the FOSS-400. It was originally designed to hold 400 MW transformers, so a smaller transformer can fit in the platform. It with a 3-column design that ensures stability and safety for the devices. Its design is like the one used for the platforms of the turbines but adjusted for substation purposes. A more detailed explanation can be found on the Semco Maritime website [51]. Figure 47 shows a model of the platform.

Figure 47. Model of the Semco Maritime floating substation platform [51].

The transformer will step up the voltage level from 33 to 132 kV for the transmission to the onshore substation. The transformer used will be a 160 MVA 132/33 kV. This transformer weighs two hundred tons, and its dimensions are 10x4x5 meters, so it fits in the Semco Maritime platform without problems. Its nominal power is enough to manage the power produced by the farm and has an ONAN and ONAF cooling system perfect for the humid conditions of the sea. The companies do not share the specifications of these transformers unless there is a real buying intention. Nevertheless, it was possible to find a spec sheet of an average 160 MVA 132/33 kV. These specifications may vary depending on the company that provides the transformer in the final stage, but the variation will not be significant for the project. This specification sheet can be found in Anexo V. The name of some companies that sell these types of transformers are ABB or Siemens, which will also provide other elements of the transmission system as previously mentioned.

The export cable system will also be done in HVAC, as the distance from the offshore substation to the shore is less than 50 kilometers, and it does not require the use of numerous extra devices to change from AC to DC and vice versa. The distance to the onshore substation is estimated to be between 20 to 30 kilometers, depending on the availability of the existing substations of the area like La Farga.

ABB has an XLPE submarine cable system guide that can be useful to determine the ideal cable for this transmission. The use of a three-core cable will be impactful on the costs of the farm, as only one cable will be used instead of three single core cables. The copper core also makes the transmission more efficient, and the XPLE insulation and steel, aluminum and lead protection make the ABB XLPE Submarine Cable System 2GM5007 the cheapest, safest, and most efficient option for the export to mainland.

The current that the cable will need to manage will be calculated using a 0.9 power factor.

$$I_{exp} = \frac{P}{\sqrt{3} \cdot V \cdot \cos{(\varphi)}} = \frac{160\ 000\ kW}{\sqrt{3} \cdot 132\ kV \cdot 0.9} = 777.6\ A$$

Using Table 13, the safest cross section area of the XLPE 3-core cable is 1000 mm^2, as the rated current of the 800 mm^2 cable is too close to the value calculated above.

100-300 kV XLPE 3-core cables		
Cross section mm²	Copper conductor	Aluminium conductor
	A	A
300	530	430
400	590	485
500	655	540
630	715	600
800	775	660
1000	825	720

Table 13. Current rating for three-core submarine cables (2GM 5007) [52].

The specifications of the cable can be found in Table 14.

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Lead sheath thickness	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm²	mm	mm	mm	mm	mm	kg/m	kg/m	μF/km	A/km	mH/km
Three-core cables, nominal voltage 132 kV (Um = 145 kV)										
185	15.8	18.0	54.2	2.1	165.0	41.4	44.9	0.13	3.0	0.47
240	18.1	17.0	54.5	2.1	166.0	41.8	46.3	0.14	3.4	0.44
300	20.4	16.0	54.8	2.1	167.0	42.4	48.0	0.16	3.8	0.42
400	23.2	15.0	55.6	2.1	168.0	43.6	51.1	0.18	4.3	0.40
500	26.2	15.0	59.0	2.3	176.0	48.6	58.0	0.20	4.6	0.38
630	29.8	15.0	62.6	2.4	185.0	53.3	65.2	0.21	5.1	0.37
800	33.7	15.0	66.5	2.5	194.0	59.0	74.0	0.23	5.6	0.36
1000	37.9	15.0	71.3	2.7	206.0	66.6	85.4	0.25	6.1	0.35

Table 14. Specifications of the 3-core ABB XLPE 2GM 5007 cable [52].

All the chosen elements for the transmission system are exceptional options. Nevertheless, the market is noticeably big, and there exists the possibility that there are elements with distinct characteristics that make them better choices for this project. For this reason, these elements can be changed before the construction of the farm if there is an option that matched the necessities of the farm in a better way.

5.2.7 ENVIRONMENTAL IMPACT

An offshore wind farm always has an impact on the environment, affecting seabed, sea life, birds and humans near the area. The purpose of this section is to analyze the possible side effects of the construction of a 160 MW offshore wind farm in the Gulf of Roses and find possible solutions to mitigate these environmental problems.

- Seabed and sea life:

Offshore wind farms usually have a high impact on the seabed of the area. Nevertheless, this impact is mostly caused by fixed bottom structures, because this type of structure must be anchored directly to the floor. This produces sediment lifting that reduces the quality of the water and changes the environment of most of the sea creatures, especially crustaceans that bury themselves in the ground. The use of semisubmersible platforms mitigates this effect, as it almost does not alter seabed (the tensioned cables that connect the turbine with seabed do not have a high impact).

The vibration of wind turbines has a more significant effect on sea life. Sea mammals like dolphins and whales use sound to communicate. The vibration of the turbines may interfere with the communication system of sea creatures affecting the lifestyle of whales, dolphins and turtles among others. To reduce this vibration, it is mandatory to have proper maintenance of the wind turbines. If the turbines are revised frequently for possible malfunction, the initial vibrations should not increase, reducing the impact of the farm on the environment.

The buried cables that transmit the power from the turbines all the way to mainland also lift sediments, affecting wildlife around them. If the cables are buried 1 meter below seabed, the impact on the environment is significantly reduced, only affecting wildlife in the moment of the construction. The lifting of sediments while burying the cables can affect the quality of the water and the amount of sunlight received in the bottom of the sea. This is inevitable, but the effects can be reduced by burying the cables in low population areas during the night.

The marine flora should not be very affected by the farm. The plants in the bottom of the sea might be affected in the moment of construction, but the appearance of floating platforms can help algae to proliferate.

- Birds:

Wind farms are one of the greatest problems for birds. The height of the turbines and the high speeds of the blades cause death to thousands of birds in Spain. This is because wind farms can be in the migratory paths of the birds. This can kill the birds that decide to migrate though wind farms, or make them change the migratory path, causing an extra energy use by the birds. A solution for this can be the use of bright colors and reflective elements in the blades, that will make them easier to spot for the birds.

The noise produced by the turbines can also modify the behavior of birds in the area. Nevertheless, as the farm is in the sea, there should not be a stationary group of birds in the area. There exists the possibility that the area is used as a hunting area by birds. If this is the case, the noise, light and maritime traffic of the offshore wind farm can interfere with bird activity. In that case, there are two possible scenarios: the evacuation of the birds from the area, or the use of platforms as a resting place for the birds.

- Humans:

The existence of the new offshore wind farm has many repercussions in the human activity of the nearby area.

The closest turbine to the shore is nineteen kilometers away from the coast. At this distance, an offshore wind farm is almost imperceptible from the shore. As shown in Figure 48 , the visual impact between 15 and 22 kilometers is very low, and Figure 49 shows that at less than a kilometer, it is almost impossible to hear the noises of the turbine.

Figure 48. Visual impact of wind turbines from the coast [53].

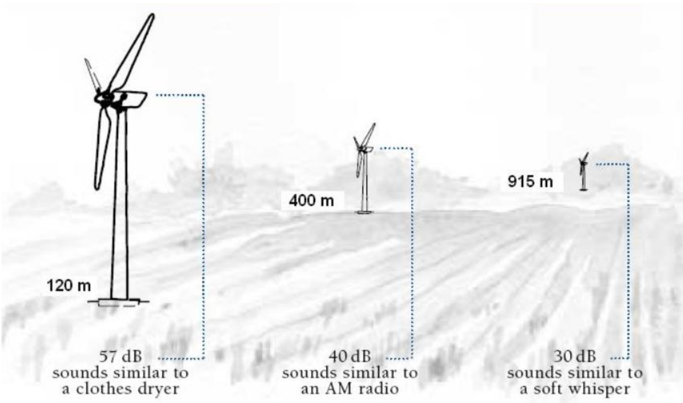

Figure 49. Noise impact of wind turbines from the coast [54].

The construction of an offshore wind farm has other effects from the social and economic perspective. It generates employment in the area and attracts companies to the area for the development of the project. This causes a change in the lifestyle of the nearby population and causes a growth in the area near the farm.

To conclude the environmental impacts section, it is important to remark that the area where the project will be developed has been designated as a High Potential Area for offshore wind power production by the Spanish Government and the European Union. This means that experts have studied the area and decided that it is suitable for an offshore wind project, not only because of the wind resource, but also because of the low risk of bad environmental consequences.

5.2.8 Operation and Maintenance of the Farm

An offshore wind farm counts with numerous devices that need proper inspection and maintenance to make the farm work efficiently during its lifetime. A robust Operation and Maintenance (O&M) of the offshore wind farm maximizes the earnings by preventing malfunctioning, which reduces the reparation costs.

The semisubmersible floating structures require corrosion protection because of the sea water. It is necessary to apply cathodic protection systems and marine coating to prevent problems in the platform. This includes periodic inspection of the corrosion protection systems. It is also necessary to include monitoring of the structural integrity of the platform. Visual and ultrasonic inspections are required to check the integrity of the semisubmersible platforms, spotting cracks and irregularities. The mooring lines that keep the structure anchored to the ground must be maintained too. Tension and fatigue monitoring are key to prevent failure. The mooring cables must be replaced when the tension and fatigue tests suggest it.

Turbine maintenance requires constant inspections in its different parts. The blade inspections can be visual, as the most important problem with the blades is the visible damage due to bird collisions and the delamination and erosion effects due to the wind.

These inspections can be made using drones, which reduces the human risk and costs. It is also important to check the unions between the blades and the nacelle, to prevent undesired vibration or failure. The rotor requires the inspection of mechanical parts such as screws, retainers and bearings, the inspection of the union between the rotor and the main axis and the inspection of oil and lubrication. The maintenance of rotors is standardized and mainly involves regular cleaning and timely replacements. The gearbox also requires oil and lubrication inspections, as well as visual checks of the physical elements. Other elements inside the nacelle also require maintenance, such as the main axis, the multiplier and the generator. All these elements have the same maintenance method: inspection of physical elements oil and cooling fluids and the timely change of these elements. The control systems like pitch motion and yaw controllers are monitored from the distance. The state of these elements is checked using computer systems that show the characteristics in real time. Nevertheless, it is also necessary to check the systems physically to prevent unexpected flaws that the computer might not be able to detect. The turbine hub maintenance is like the blade maintenance, visual inspection and ultrasonic experiments are enough to detect possible structural failures. This inspection can be done using drones or specialized teams using ropes to analyze the hub.

The electric transmission system requires different maintenance methods. The substation and the transformers can be monitored externally, as they count with multiple sensors and alarms that alert when there is malfunction in these systems. The inspection and element substitution of transformers and substation pieces must be done during calm days to prevent work accidents and guarantee the safety of the personnel. The array cable system also counts with sensors that warn the maintenance employees about malfunctioning. Nevertheless, inspection in person is also necessary, using submarine cameras and professional divers to check the flaws with a higher degree of detail. The export cable system will also benefit from submarine cameras and divers, and the reparation or substitution of cable elements of the farm will be done during calm sea conditions due to the risk that this maintenance implies.

The maintenance methods mentioned in this section are a combination of preventive, predictive and correctional maintenance. It is necessary to prevent failure by doing regular inspections of the elements and devices of the farm, and the prediction of the failure must be done correctly using computer systems and ultrasonic and vibration methods. Once a possible future malfunction is detected, it is corrected before it can paralyze the operation of the farm. If a flaw is not detected in time, it is necessary to make an emergency maintenance that can stop the farm and reduce production and income. If this happens, this maintenance is prioritized over the others, to minimize the time the farm is not working (but only if weather and sea conditions are safe for the maintenance crew).

Chapter 6. ECONOMIC ANALYSIS

It is mandatory to make an economic analysis of the farm to prove its viability. This analysis will study the costs and earnings of the offshore wind farm to determine if it is a feasible and profitable project. The earnings will be obtained from the sale of electricity, which tends to vary significantly nowadays, and therefore it is necessary to make an estimation of the price. The costs will be counted from the start of the construction to the dismantling of the farm. With all the information of the costs, some profitability measures will be calculated, like the NPV, the IRR or the investment payback.

6.1 COSTS

The costs of the farm will be divided into four different sections: the costs of permits, the costs of construction, the costs of maintenance and the costs of dismantling.

6.1.1 COSTS OF PERMITS

The development of an offshore wind farm requires the acquisition of determined permits. The obtention of these permits allows the offshore wind farm developers to accomplish the necessary steps to build the farm. These permits cost money and usually have long waiting times.

The permits that may be involved in the development of the farm are listed in Table 15, with an estimated cost that affects the initial investment necessary for the development of the project.

Permits and licenses	Cost (€)
Environmental Research Permit	650000
Construction Permit	400000
Electricity Production and Sale Permit	150000
Other permits	50000
TOTAL PERMIT COST	1250000

Table 15. Costs of the necessary permits.

Environmental permits are necessary to make a field investigation of the area, which will help to determine if the area is suitable for an offshore wind project. These permits should be easy to obtain, as the Gulf of Roses is a high potential area for offshore wind defined in the POEM by the Spanish Government and the EU. The construction permits are needed to build the farm and can be obtained after the environmental analysis is accepted. The energy production and sale permits will allow the farm to work and connect to the grid, allowing the electricity to be sold. Other permits might be needed as well as application and processing fees.

6.1.2 COSTS OF CONSTRUCTION

This section will analyze the costs of the construction of the farm. These costs will include the purchase and transportation of the elements and equipment and the costs of installation, labor costs and civil work. This section will be divided into the initial costs (CAPEX), which are the cost of the turbines, the cost of the civil work, the cost of the transmission system and other possible costs (such as control and meteorological stations); the O&M costs (OPEX); and the dismantling costs.

6.1.2.1 INITIAL COSTS (CAPEX)

This subsection will analyze the initial costs of the project, estimating the necessary initial investment that the project will need. This section should also include the permit costs that were previously analyzed, and they will be added in the summary of this section.

6.1.2.1.1 TURBINE COSTS

The turbine costs will include the purchase of the turbines and floating platforms, their transport and installation. The transport will include the land transport of the turbines and platforms, the rent of docks in the port of Roses and ships for sea transport. The total estimated cost is presented in Table 16. The cost of transportation and installation is around 20 million €, doubling the cost of an onshore wind farm due to the difficulties on maritime transportation and installation in the sea. The cost of the offshore floating platforms may seem high, but this is because of the non-standardization of these elements, which makes them significantly more expensive than onshore and offshore fixed bottom foundations.

Code	Element	Unit	Length (m)	Width (m)	Deepness/Height (m)	Cost per unit (€/ud)	# Units	Total Cost (€)
100	TURBINE CONSTRUCTION COSTS							
101	Supply of SG 8.0-167 DD	ud	-	-	-	8,000,000.00	20.00	160,000,000.00
102	Supply of WindFloat platform	ud	-	-	-	6,000,000.00	20.00	120,000,000.00
103	Land Transportation	-	-	-	-	100,000.00	20.00	2,000,000.00
104	Dock and Boat rent	-	-	-	-	250,000.00	20.00	5,000,000.00
105	Sea Transportation	-	-	-	-	50,000.00	20.00	1,000,000.00
106	Installation	-	-	-	-	500,000.00	20.00	10,000,000.00
TOTAL TURBINE COSTS								298,000,000.00

Table 16. Turbine construction costs.

6.1.2.1.2 CIVIL WORK COSTS

The civil work of a floating offshore farm is not as big as the one needed for an onshore wind farm. Even though there are not many civil works necessary, the cost is still high due to the inconveniences of working in the sea. These works are the preparation of the anchoring points of the floating platforms (which require modifications in the seabed), the digging of trenches for the array and export cables and the burying of these trenches after the cables are installed and the construction of an assembling dock for the turbines and floating platforms.

It is necessary to remark that all the costs are simplified. This means that the supply of materials and rent or purchase of machinery has been included and divided in the cost per unit. This gives a better understanding of which of the civil works of the project has a higher cost and makes the cost table understandable to all the public.

All the costs related to the different civil work are listed in Table 17.

Code	Element	Unit	Length (m)	Width (m)	Deepness/Height (m)	Cost per unit (€/ud)	# Units	Total Cost (€)
200	ASSAMBLING DOCK CONSTRUCTION							
201	Dock purchase	ud	-	-	-	1,000,000.00	1	1,000,000.00
202	Hard-stand paviment	m^2	200	100	-	60.00	20000	1,200,000.00
203	Assambling dock cover deck	m^3	100	50	20	20.00	100000	2,000,000.00
SUBTOTAL 200								4,200,000.00
210	FLOATING PLATFORMS ANCHORING							
211	Dug for anchoring total (21 holes)	m^3	15	15	15	40.00	77625	3,105,000.00
212	Concrete blocks total (21)	m^3	15	15	15	45.00	77625	3,493,125.00
SUBTOTAL 210								6,598,125.00
220	SEABED MODIFICATION FOR CABLING PURPOSES							
221	Dug for array cables (70 mm^2)	m^3	4000	1	1	100.00	4000	400,000.00
222	Dug for array cables (1200 mm^2)	m^3	6500	1	1	100.00	6500	650,000.00
223	Dug for export cables	m^3	25000	1	1	100.00	25000	2,500,000.00
224	Filling of the trenches	m^3	35500	1	1	150.00	35500	5,325,000.00
SUBTOTAL 220								8,875,000.00
TOTAL CIVIL WORK COSTS								19,673,125.00

Table 17. Civil work costs of the project.

6.1.2.1.3 ELECTRICITY TRANSMISSION SYSTEM COSTS

This subsection will gather the initial costs related to the elements of the transmission system. These costs include the supply of the transmission elements: transformers, switchgears, array and export cables and offshore floating platform; and the transportation and installation of these elements in the park.

It is necessary to mention that the dug of trenches for the wiring system and the seabed modifications for the substation platform are not included in this section as they were included in the civil work costs.

Table 18 shows the previously mentioned costs and provides the initial investment necessary for the construction of the transmission system from the turbines to the onshore substation.

Code	Element	Unit	Length (m)	Width (m)	Deepness/Height (m)	Cost per unit (€/ud)	# Units	Total Cost (€)
300	MEDIUM VOLTAGE ELEMENTS							
301	Supply of ABB WindSTAR 11MVA 0.69/33kV transformer	ud	-	-	-	1,000,000.00	20	20,000,000.00
302	Transport and installation ABB WindSTAR 11MVA 0.69/33kV transformer	ud	-	-	-	50,000.00	20	1,000,000.00
303	Supply of ABB Safeplus 36 switchgear	ud	-	-	-	60,000.00	20	1,200,000.00
304	Transport and installation ABB Safeplus 36 switchgear	ud	-	-	-	20,000.00	20	400,000.00
305	Supply of (N)A2XS(FL)2Y 19/33KV 70 mm² cable (3 phases)	m	12000	-	-	10.00	12000	120,000.00
306	Transport and installation (N)A2XS(FL)2Y 19/33KV 70 mm² cable (3 phases)	m	12000	-	-	450.00	12000	5,400,000.00
307	Supply of (N)A2XS(FL)2Y 19/33KV 1200 mm² cable (3 phases)	m	19500	-	-	250.00	19500	4,875,000.00
308	Transport and installation (N)A2XS(FL)2Y 19/33KV 1200 mm² cable (3 phases)	m	19500	-	-	900.00	19500	10,275,000.00
SUBTOTAL 300								43,270,000.00
310	HIGH VOLTAGE ELEMENTS							
311	Supply of Semco Maritime Offshore Floating substation	ud	-	-	-	20,000,000.00	1	20,000,000.00
312	Transport and installation Semco Maritime Offshore Floating substation	ud	-	-	-	1,000,000.00	1	1,000,000.00
313	Supply of 160 MVA 33/132 kV transformer	ud	-	-	-	15,000,000.00	1	15,000,000.00
314	Transport and installation Supply of 160 MVA 33/132 kV transformer	ud	-	-	-	700,000.00	1	700,000.00
315	Supply of 3-core ABB XLPE 2GM 5007 1000 mm² cable	m	25000	-	-	600.00	25000	15,000,000.00
316	Transport and installation 3-core ABB XLPE 2GM 5007 1000 mm² cable	m	25000	-	-	900.00	25000	22,500,000.00
SUBTOTAL 310								74,200,000.00
TOTAL ELECTRICITY TRANSMISSION SYSTEM COSTS								117,470,000.00

Table 18. Electricity transmission initial costs

6.1.2.1.4 OTHER INITIAL COSTS

This subsection will present other costs that have not been mentioned in the previous subsections of the CAPEX section. These costs could include labor costs, the construction of a meteorological station in the farm area, and the dumping of residuals from the civil work operations.

The construction of a meteorological substation will not be necessary due to the existence of a measurement buoy developed by BlueFloat and Sener in the area, mentioned in 5.1.2. To access the data measured by this buoy it may be necessary to sign a contract with the developers. This cost was added to this section.

The time of construction of the offshore wind farm will be twelve months, with two extra months in case of unexpected problems or contingencies. The estimated number of workers is 150 workers, and twenty of them must be specialized workers and engineers with a higher average salary.

The estimated costs of this subsection are listed in Table 19.

Code	Element	Unit	# Units	Hours/person (h/pers)	Cost per unit (€/ud)	Total hours (h)	Total Cost (€)
400	LABOR COSTS						
401	Workers	ppl	130.00	3,136.00	25.00	407,680.00	10,192,000.00
402	Specialized workers	ppl	20.00	3,136.00	40.00	62,720.00	2,508,800.00
SUBTOTAL 400							12,700,800.00
410	Dumping of residuals	m^3	106,375.00	-	50.00	-	5,318,750.00
420	Contract buoy data	ud	1.00	-	700,000.00	-	700,000.00
TOTAL OTHER COSTS							18,719,550.00

Table 19. Other initial costs

6.1.2.1.5 SUMMARY OF CAPEX

The purpose of this subsection is to summarize the different initial costs in one table (Table 20), showing the initial necessary investment for the construction of the offshore wind farm.

Code	Subsection name	Cost (€)
0	Permits	1,250,000.00
1	Turbines	298,000,000.00
2	Civil Work	19,673,125.00
3	Electricity transmission system	117,470,000.00
4	Other	18,719,550.00
TOTAL CAPEX		455,112,675.00

Table 20. Total CAPEX of the project.

6.1.2.2 OPERATION AND MAINTENANCE COSTS (OPEX)

This section gathers all the annual costs related to the operation and maintenance of the offshore wind farm. These costs include the O&M of the turbines, the floating platform, civil work and all the elements involved in the transmission of the power generated to the mainland.

Other annual costs have been included in this section, such as the permit renovation and taxes that must be paid for the operation of the park and the insurance fees of the equipment in case of unexpected failure.

The labor costs are implicit and divided into the O&M costs, and therefore, they haven't been shown explicitly.

Table 21 shows the annual O&M costs of the farm.

Element	# Units	Cost per unit (€/ud)	Total Anual Cost (€)
O&M Turbine SG 8.0-167 DD	20	200,000.00	4,000,000.00
O&M WindFloat floating platform	20	50,000.00	1,000,000.00
Maintenance of the Civil Work	1	45,000.00	45,000.00
O&M Transformers	21	10,000.00	210,000.00
O&M Switchgears	20	7,500.00	150,000.00
O&M Array cable system	1	65,000.00	65,000.00
Maintenance of the Offshore Substation platform	1	50,000.00	50,000.00
O&M Export cable system	1	75,000.00	75,000.00
Permit renovations and taxes	1	30,000.00	30,000.00
Isurance of the equipment	1	400,000.00	400,000.00
TOTAL ANUAL COST			6,025,000.00

Table 21. Annual O&M costs of the farm.

6.1.2.3 DISMANTLING COSTS

The lifespan of this project is 25 years, and after this time, the offshore wind farm must be removed completely. This means that the turbines, floating platforms and transmission elements must be removed. The civil work necessary for the park must be reverted too, leaving the area in the same condition it was found before the construction of the park.

The labor costs of this section will also be divided into the different dismantling tasks and will not be shown explicitly.

The dismantling cost will be added in the last year of the operation of the farm, as it is then when that cost will be assumed. Therefore, this cost will be taken away from the earnings of that year.

The dismantling costs of elements like turbines, platforms and transmission devices are expected to be around half of the transport and installation costs, while the civic work reversion cost should be like the initial civic work CAPEX. This is because it is necessary to return the seabed to its initial condition, which makes the cost not change significantly.

Table 22 shows the dismantling costs.

Element	# Units	Cost per unit (€/ud)	Total Anual Cost (€)
Dismantling of Turbine SG 8.0-167 DD	20	250,000.00	5,000,000.00
Dismantling of WindFloat floating platform	20	170,000.00	3,400,000.00
Reversion of the Civil Work	1	16,345,000.00	16,345,000.00
Dismantling of Transformers	21	25,000.00	525,000.00
Dismantling of Switchgears	20	9,500.00	190,000.00
Dismantling of Array cable system	1	7,827,500.00	7,827,500.00
Dismantling of the Offshore Substation platform	1	500,000.00	500,000.00
Dismantling of the export cable system	1	11,325,000.00	11,325,000.00
TOTAL DISMANTLING COSTS			45,112,500.00

Table 22. Dismantling costs of the project.

6.2 INCOME OF THE OFFSHORE WIND FARM

To calculate the income of the offshore wind farm it is necessary to know the energy that the farm produces every year. This is calculated in 5.2.4, and this value will be used for the 25 years of operation of this farm. There exists the possibility that production is reduced some years due to malfunctioning of the elements, or increased thanks to better and more consistent winds, but these cases will not be considered because of their randomness.

The other necessary parameter for the calculation of the income of the offshore wind farm is the sale price of the energy produced. The selection of the electricity sale price is complicated, as it varies significantly over the years. The average price of 2024 will be the price chosen for this project, as it is impossible to predict the exact price for the future 25 years [55]. This energy sale price of 63.04 €/MWh will be used to calculate the income of the farm until the year 2051.

As the calculation of the income will be the same every year, it will only show the annual income and the total income after the 25-year lifespan (Table 23). The year 2026 has been considered as the year of construction, and therefore, there is no expected energy produced for that year.

	Annual	Total
ENERGY GENERATED [GWh]	824.20	20,605.05
SALE PRICE [€/MWh]	63.04	63.04
INCOME [M€]	51.96	1,298.94

Table 23. Annual and total expected income of the farm.

6.3 Profitability of the Project

This subsection will analyze the profitability of the project. To derive this analysis, it will be necessary to define some characteristics of the necessary investment in the project.

First, it will be necessary to define the time of amortization. This is the number of years that it will take to amortize the initial investment. Eighteen years should be enough to amortize this debt properly, as it is the typical estimated time for a project of this magnitude.

The calculation will be derived as if the developer company invested part of their capital to assume 30% of the initial capital expenditure necessary for the project. The rest of the necessary investment will be received from a loan from a bank, with a debt interest of 5.5%.

A conservative value for the expected profitability of the project will be 8%, and it is the one that will be used in the project.

6.3.1 Project Accounts and Profitability Metrics

The first step will be to derive the Profit and Loss Account, that will determine the benefit before taxes of the project (Table 24). The IVPEE tax is applied to the expected benefits of an electricity production farm and must be applied before the BBT.

Profit and Loss account	0	1	2	3	4	5	6	7	8	9	10	11	12
Year	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Annual income	0	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96
Annual costs	0	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03
EBITDA	0	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93
IVPEE tax (7% of the income)	0	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64
Amortization (18 years)	0	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3
BBT	0	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01

Profit and Loss account	13	14	15	16	17	18	19	20	21	22	23	24	25
Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
Annual income	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96	51.96
Annual costs	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03	-6.03
EBITDA	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93	45.93
IVPEE tax (7% of the income)	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64	-3.64
Amortization (18 years)	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	0	0	0	0	0	0	0
BBT	17.01	17.01	17.01	17.01	17.01	17.01	42.3	42.3	42.3	42.3	42.3	42.3	42.3

Table 24. Profit and Loss Account of the project.

The BBT is used to calculate the Free Cash Flow, where other taxes and costs are added, and the amortization is reverted (Table 25).

FREE CASH FLOW	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051
BBT	0	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	17.01	42.3	42.3	42.3	42.3	42.3	42.3	42.3
Corporate tax (25%)	0	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-4.25	-10.6	-10.6	-10.6	-10.6	-10.6	-10.6	-10.6
Exercise result	0	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	12.76	31.72	31.72	31.72	31.72	31.72	31.72	31.72
Amortization (18 years)	0	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	25.28	0	0	0	0	0	0	0
CAPEX	-455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dismantling costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-45.1
FCF	-455	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	31.72	31.72	31.72	31.72	31.72	31.72	-13.4
FCF CUMULATED	-455	-417	-379	-341	-303	-265	-227	-189	-151	-113	-74.7	-36.6	1.399	39.44	77.48	115.5	153.6	191.6	229.7	261.4	293.1	324.8	356.5	388.3	420	406.6

Table 25. Free Cash Flow of the project.

It can be appreciated that the cumulated FCF is positive, which means that the farm is expected to provide a benefit of 406.6 million €. The metrics used to explore how good the profitability of the project is will be: the NPV, the IRR and the payback period.

The NPV represents the difference between cash in-flows and out-flows during the 25 years of operation of the farm. The discount rate used to calculate the NPV will be the WACC, which is another metric that represents the average financing cost of a project. The NPV must be positive for the project to be profitable. In this project, the NPV is 37.22 M€, and therefore the project should be profitable.

The IRR represents the discount rate that would be necessary for the NPV to be zero. Therefore, the IRR must be higher than the WACC. In this case the IRR is 6.205%, which is higher than the WACC (5.288%).

The payback period is the amount of time it takes for a project to equal the initial investment thanks to the income. Thanks to the constant in-flow rate of the project it is easy to calculate the payback period, which is 11.96 years. This means that in less than a half of the expected lifespan of the farm, the initial investment would be recovered.

6.3.2 INVESTOR ACCOUNTS AND PROFITABILITY METRICS

To encourage the investment of capital in this project, the profitability of the particular investment or equity.

The first step is to calculate the annual debt of the loan with the bank. Knowing that the interest is 5.5%, and that the debt must be amortized in 18 years, Table 26 shows the annual debt with the bank.

DEBT	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
Total remaining Debt	318.6	318.6	300.9	283.2	265.5	247.8	230.1	212.4	194.7	177	159.3	141.6	123.9	106.2	88.49	70.8	53.1	35.4	17.7
Lineal amortization	0	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
Interests (5.5% of the debt)		17.52	16.55	15.57	14.6	13.63	12.65	11.68	10.71	9.734	8.761	7.787	6.814	5.841	4.867	3.894	2.92	1.947	0.973
Annual Debt with the Bank	0	35.22	34.25	33.27	32.3	31.33	30.35	29.38	28.41	27.43	26.46	25.49	24.51	23.54	22.57	21.59	20.62	19.65	18.67

Table 26. Annual debt with the bank.

With the annual debt, it is possible to calculate the Debt Cash Flow (DCF), shown in Table 27. It is necessary to subtract the tax over interests, which is 23% for loans greater than 50 000 €.

Debt Cash Flow	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
Total debt	318.6																		
Annual Debt with the Bank	0	-35.2	-34.2	-33.3	-32.3	-31.3	-30.4	-29.4	-28.4	-27.4	-26.5	-25.5	-24.5	-23.5	-22.6	-21.6	-20.6	-19.6	-18.7
Impositive tax over interests	0	4.38	4.137	3.894	3.65	3.407	3.164	2.92	2.677	2.434	2.19	1.947	1.704	1.46	1.217	0.973	0.73	0.487	0.243
DCF	318.6	-30.8	-30.1	-29.4	-28.6	-27.9	-27.2	-26.5	-25.7	-25	-24.3	-23.5	-22.8	-22.1	-21.3	-20.6	-19.9	-19.2	-18.4

Table 27. Debt Cash Flow of the investment.

Using the DCF and the FCF, it is possible to calculate the Investment Cash Flow (ICF), shown in Table 28, and the profitability metrics of the investment.

Investment Cash Flow	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044
Free Cash Flow	-455	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04	38.04
Debt Cash Flow	318.6	-31.2	-30.4	-29.7	-28.9	-28.2	-27.4	-26.7	-25.9	-25.2	-24.4	-23.7	-22.9	-22.2	-21.4	-20.7	-19.9	-19.2	-18.4
Investment Cash Flow	-137	6.852	7.602	8.351	9.101	9.85	10.6	11.35	12.1	12.85	13.6	14.35	15.1	15.85	16.6	17.35	18.1	18.84	19.59
CUMULATIVE ICF	-137	-130	-122	-114	-105	-94.8	-84.2	-72.8	-60.7	-47.9	-34.3	-19.9	-4.84	11.01	27.6	44.95	63.04	81.89	101.5

Table 28. Investment Cash Flow of the project.

The values obtained for NPV, IRR and payback period can be seen in Table 29. They confirm that the investment is profitable, as the NPV is positive, the IRR is greater than the expected profitability (8%), and the payback period is at half of the lifespan of the farm.

NPV (M€)	7.43 €
IRR (%)	8.52
PB (years)	12.72669

Table 29. Profitability metrics of the investment.

Chapter 7. RESULTS, CONCLUSIONS AND FUTURE

This section will be divided into two different parts. The first one will be an analysis of the results of the project, the capacity of the farm, the location, the devices used… The second one will gather the conclusions and take-outs obtained from this project.

RESULTS

The result of this project is the design of a completely functional offshore wind farm. The characteristics of this farm are going to be summarized in this section. The offshore wind farm has a capacity of 160 MW and a lifespan of 25 years.

The location of the project is a 15.6 km^2 area located inside a high potential area for offshore wind power production 20 kilometers away from the Gulf of Roses in Girona, Catalonia. This area presents a mean wind speed of 10.74 m/s and an average sea depth of 304 meters, which forces the use of floating platforms for the turbines and the offshore substation.

The park uses 20 Siemens Gamesa SG 8.0-167 DD turbines held by WindFloat semisubmersible floating platforms. The turbines are 100 meters tall and have a blade diameter of 167 meters. The annual generation of the farm is 824202 MWh, more than the initially expected generation.

For the transmission of electricity to the shore, an ABB step-up transformer raises the voltage from 820 V (turbine level) to 33 kV. An ABB switchgear protects the turbines from failure of the transmission system. The power is transmitted by an array cabling and transported to an offshore floating substation, whose floating platform is designed by Semco Maritime. Another step-up transformer raises the voltage level to 132 kV, and the export cable system sends the generated power to mainland.

The environmental analysis of the project explores the different impacts the offshore wind farm may produce in sea ecosystems, birds and humans, and presents solutions that can help mitigate these impacts.

The economic analysis classifies all the costs of the project and divides them into the different stages of the development of the offshore wind farm. In the analysis, the free cash flow and the investment cash flow are calculated. To prove the economic viability of the project, profitability metrics of the project and the investment are calculated, like the NPV, the IRR and the payback period.

CONCLUSIONS

The first thing to analyze in this section is the accomplishment of the objectives. The main goal of this project was to create a replicable methodology for future offshore wind farms development in Spain. This project can act like a route sheet for future projects.

The area selection filtering was successful, as the choice of location for the project was done by analyzing the environmental issues, regulatory limitations, the wind resource, bathymetry and maritime traffic of each possible site.

The selection of the proper elements of the wind farm according to the information gathered from the location choice section was also accomplished. This section does not only give the elements necessary for the construction of the farm but gives an explanation on why those elements are preferred over others for this specific project. This can help future offshore wind farm developers with a perspective of which issues affect the most the selection of every specific device necessary for the construction of a farm like this one.

The evaluation of environmental impacts and the summary of the necessary O&M operations of the offshore wind farm gather the possible issues that future offshore wind farm developers may have to face during the design, construction and operation of their own projects.

The economic analysis of the project does not only show the viability of a project like this one but also serves as a template for the economic viability analysis of other offshore wind projects. Each project will have to face different costs and will have different production income, but the economic analysis derived in this project gathers the main economic aspects of every offshore wind project.

This is what was accomplished in the project, and can be summarized into four main points:

- Creation of a replicable methodology, with a standardized workflow for future similar projects in Spain.
- Demonstration of technical viability, showing that offshore wind farms can be developed in Spain even in large-scale projects
- Environmental issues analysis and mitigations, which can help the development of future offshore wind farms in the Spanish coast.
- Setting of bases for financing and profitability, by showing the profitability of the project with the selected financing methods it is feasible to develop similar projects in the future.

It is also important to know which things could have been done in a better way during the design of the project. Therefore, some of the things to improve for future projects are going to be included below.

For the analysis of the characteristics of the area, it is possible to obtain more accurate data using specialized measurement buoys. These buoys can provide data about the wind, tides, sea currents and nearby wildlife more accurately, which considerably helps the development of the project. It can also provide a seasonal analysis, allowing the farm operator to take determined measures depending on the season of the year.

The use of computer simulations could benefit some aspects of the project. For example, the floating platforms could be modeled using computer programs to test their behavior during certain weather conditions. This would help in determined areas with more aggressive weather and sea conditions like the Galician or the Canary coast.

Another issue to improve in future projects is the recycling of parts of the elements removed in the dismantling of the farm. It could be useful to propose alternative uses for the devices (or parts of them) employed in the operation of the farm, to continue with the green footprint this project attempts to set.

FUTURE WORKS

This subsection will explain the future works that must be done for the future of offshore wind projects in Spain.

The construction of a pilot wind farm in the area can help to confirm the technical viability of the project, speeding the development and construction of this project, and encouraging the development of similar wind farms across the country.

The integration of offshore solar energy in the designed offshore wind farm will help the farm to produce even more energy, making it potentially more profitable. The combination of offshore wind and solar photovoltaic is nowadays being explored and developed. This would help to take more advantage of the area used.

Another future job is the use of this methodology in other regions of the country. Applying this methodology for the development of similar offshore wind projects would help with the transition to renewables of Spain.

It is also important to keep this methodology updated, by constantly checking for new or recently developed technologies that do not exist nowadays. The use of other technologies depending on the characteristics of the area is crucial for the design of a good offshore wind farm. For example, in areas where sea depth is greater than one-kilometer, semisubmersible platforms are not useful as it is better to use SPAR structures.

It is also important to check for innovative financing methods for these projects in Spain. For example, in the north of Europe there exists a bidding-based system that has already financed numerous offshore wind farms.

Ultimately, this project not only confirms the viability of an offshore wind farm in the Gulf of roses but also sets a route sheet for innovation, sustainability and resilience. By the combination of rigorous analysis, environmental mitigation analysis and robust financial models, this project has laid the foundation for Spain to lead the use of offshore wind in the world.

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ANEXO

ANEXO I

Data sheet of Siemens Gamesa SG 8.0-167 DD [42].

Datasheet

Power

Rated power:	8,000.0 kW
Flexible power ratings:	8,000.0 - 9,000.0 kW
Cut-in wind speed:	3.0 m/s
Rated wind speed:	13.0 m/s
Cut-out wind speed:	28.0 m/s
Survival wind speed:	79.8 m/s
Wind zone (DIBt):	-
Wind class (IEC):	Ib, S

Rotor

Diameter:	167.0 m
Swept area:	21,900.0 m²
Number of blades:	3
Rotor speed, max:	10.3 U/min
Tipspeed:	90 m/s
Type:	B81 / 81.4m
Material:	Glass fibre reinforced epoxy and balsa
Manufacturer:	Siemens Gamesa Renewable Energy A/S
Power density 1:	365.3 W/m²
Power density 2:	2.7 m²/kW

Gear box

Type:	direct drive
Stages:	-
Ratio:	-
Manufacturer:	-

Generator

Type:	Permanent magnet synchronous
Number:	1
Speed, max:	10.8 U/min
Voltage:	820.0 V
Grid connection:	power conversion system
Grid frequency:	50 Hz
Manufacturer:	Siemens Gamesa

Tower

Hub height:	119 / site specific m
Type:	steel tube
Shape:	conical
Corrosion protection:	coated
Manufacturer:	-

ANEXO II

Data sheet of ABB 11MVA 0.69/33/66 kV transformer [56].

Voltage	33 kV	66 kV
KV class	36 kV	72.5 kV
Rated power	> 10 MVA	> 10 MVA
Cooling	KFWF	KFWF
Insulation liquid	Ester	Ester
Insulation material	High-temperature class	High-temperature class
Tapping range	± 2 x 2.5%	± 2 x 2.5%
Low voltage	> 400 V	> 400 V
Frequency	50 or 60 Hz	50 or 60 Hz

ANEXO III

Specifications sheet of ABB Safeplus 36 switchgear [57].

Technical data - SafePlus modules

Compact switchgear, electrical data (overview does not show rated values applicable for Metering modules)							
1	Rated voltage	U_r	kV	36		38	
2	Rated power frequency withstand voltage	U_d	kV	70		80	
	- across disconnector		kV	80		95	
3	Rated lightning impulse withstand voltage	U_p	kV	170		170	
	- across disconnector		kV	195		210	
4	Rated frequency	f_r	Hz	60		60	
5	Rated normal current (busbars)	I_r	A	600		600	
6	Rated short-time withstand current	I_k	kA	20	25	20	25
7	Rated duration of short-circuit	t_k	s	3	1	3	1
8	Rated peak withstand current	I_p	kA	52	65	52	65
9	Internal arc classification IAC AFL	I_A/t_A	kA/s	20/1	25/1	20/1	25/1
10	Internal arc classification IAC AFLR	I_A/t_A	kA/s	25/1	25/1	25/1	25/1
11	Loss of service continuity	LSC2-PM (for C-, D-, De- and V-module), LSC2A-PI (for F-module)					
Making and breaking capacities C-module with switch-disconnector and Grounding switch							
12	Rated normal current	I_r	A	600		600	
13	Rated mainly active load breaking current	I_{load}	A	600		600	
14	Number of operations for mainly active load breaking	n		100		10	
15	Rated distribution line closed-loop breaking current	I_{loop}	A	600		600	
16	Rated cable-charging breaking current	I_{cc}	A	-		-	
17	Rated line-charging breaking current	I_{lc}	A	-		-	
18	Rated earth-fault breaking current	I_{ef1}	A	-		-	
19	Rated cable- and line-charging breaking current under earth-fault conditions	I_{ef2}	A	-		-	
20	Rated short-circuit making current	I_{ma}	kA	52	65	52	65
21	Rated mechanical endurance class (Grounding switch)			M0		M0	
22	Rated short-circuit making capability class (Grounding switch)			E2	E1	E2	E1
23	Electrical and mechanical classes (switch-disconnector)			M1		M1	
Making and breaking capacities V-module with vacuum circuit-breaker, downstream disconnector and Grounding switch							
	Rated voltage			36		38	
24	Rated short-circuit breaking current	I_{sc}	kA	20		20	
25	DC time constant of the rated short-circuit breaking current	τ	ms	45		45	
26	DC component	p_{cs}	%	30	-	30	-
27	Rated first-pole-to-clear factor	k_{pp}		1,5		1,5	
28	Rated short-circuit making current (circuit-breaker)		kA	52	65	52	65
29	Rated cable-charging breaking current	I_c	A	-		-	
30	Rated line-charging breaking current	I_{lc}	A	-		-	
31	Electrical and mechanical classes (circuit-breaker)			E1[2)], M1, S1		E1[2)], M1, S1	
32	Rated out-of-phase breaking current	I_d	kA	-		-	
33	First-pole-to-clear factor for out-of-phase conditions (system with effectively and non-effectively grounded neutral)			-		-	
34	Rated short-circuit making current (Grounding switch)	I_{ma}	kA	20	25	20	25
35	Rated short-circuit making capability class (Grounding switch)			E2	E1	E2	E1
36	Rated mechanical endurance class (Grounding switch)			M0		M0	
37	Rated mechanical endurance class (disconnector)			M0		M0	
Making and breaking capacities Dc-module							
38	Making and breaking capabilities not applicable as the D-module has no switching devices. Rated values are listed in lines 1-11.						

General data

General data	
Type of Ring Main Unit	Metal enclosed
Number of phases	3
Whether RMU is type tested	Yes
Pressure test on equipment tank or containers	Until pressure relief device opens
Whether facility is provided with pressure relief device	Yes
Insulating gas	SF_6
Nominal operating gas pressure	1,4 bar abs. at 20°C
Gas diffusion rate	less than 0,1 % p.a.
Expected operating lifetime	30 years
Whether facilities are provided for gas monitoring	Yes, temperature compensated manometer can be delivered
Material used in tank construction	Stainless steel sheet, 2 mm
Busbars	300 mm² Cu
Earth bar (external)	120 mm² Cu
Earth bar bolt dimension	M10
Operations	
Means of switch-disconnector operation	Separate handle
Means of fuse-switch-disconnector operation	Separate handle and push-buttons and/or opening and closing trip coils
Means of circuit-breaker operation	Integrated handle and push-buttons and/or opening and closing trip coils
Total opening time of circuit-breaker	approx. 40 - 80 ms
Closing time of circuit-breaker	approx. 50 - 90 ms
Mechanical operations of switch-disconnector	1000 CO (Class M1)
Mechanical operations of Grounding switch	1000 CO
Mechanical operations of circuit-breaker	2000 CO (Class M1)
Principle switch-disconnector	2 position puffer switch
Principle Grounding switch	2 position Grounding switch with downstream Grounding switch in F-modules
Principle circuit-breaker	Vacuum interrupter with axial magnetic field contacts
Switch-disconnector	
Rated making operations on short circuit current (class E3)	5
Rated making operations on short circuit current (class E2)	**3**
Rated operations mainly active load (class E3)	100
Rated operations mainly active load (class E2)	**30**
Fuse-links	
Length, D, of fuse-links to be used in fuse canister	537 mm
Contact diameter, ØA, of fuse-links to be used in fuse canister	45 mm
Maximum diameter, ØC, of fuse-links to be used in fuse canister	88 mm
Standard dimensions	According to IEC60282-1 type 1/DIN 43625/ANSI
Maximum fuse-link rated current	63 A

Normal service conditions - indoor according to IEC 62271-1:2017 subclause 4.1.2	
Maximum ambient air temperature	+ 40°C [1]
Maximum ambient air temperature - average value measured over a period of 24 hours	+ 35°C [1]
Minimum ambient air temperature ambient air temperature	- 25°C [2]
Altitude for erection above sea level	...1500 m [3]
Maximum relative humidity - average value measured over a period of 24 hours	95%
Weight table	
Maximum weights for SafeRing 36	
2-way DeV/DeF	550 kg
3-way CCV/CCF	800 kg
4-way CCCV/CCCF	1050 kg
4-way CCVV/CCFF	1100 kg
3-way CCC	750 kg
4-way CCCC	1000 kg
Maximum weights for SafePlus 36	
1-way (C-, D-, De-module)	250 kg
1-way (F-, V-module)	300 kg
2-, 3- and 4-way	as for SafeRing
M – metering module	600 kg
Degree of protection	
High voltage live parts, SF_6 tank	IP 67
Front covers / operating mechanisms	IP 2X
Cable covers	IP 3X
Fuse canisters	IP 67
Colours	
Front covers	RAL 7035
Side and cable covers	RAL 7035
Switch area	Medium Grey Pantone 429C

[1] Derating allows for higher maximum temperatures.
[2] For lower minimum air temperature, please contact ABB.
[3] For higher altidude, please contact ABB.

ANEXO IV

Specifications sheet of the (N)A2XS(FL)2Y 19/33KV cable

(N)A2XS(FL)2Y 19/33KV CPR F

Aluminum medium voltage cables 33kV

F_{ca} CPR

Medium voltage cables for rated voltages from 6 kV (Um = 7,2 kV) up to 33 kV (Um = 36 kV) used in outdoor applications such as industrial installations and electrical stations. The cables are suitable for laying in ground, in trench or in ducts, in water, free in air or indoors. The ingress of water in case of a damaged outer sheath is limited by the longitudinal and transversal watertight screen area.
Conductor shape round, class 2 = stranded; black outer sheath

STANDARDS AND CERTIFICATIONS

RoHS

EN 60228	Conductors of insulated cables
IEC 60502-2	Cables for rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV)
EN 60754-1	Test on gases evolved during combustion of materials from cables. Halogen acid gas content.

CABLE DESIGN

Conductor material	Aluminium
Core insulation material	XLPE
Screen construction	Wire screen and counterhelix tape
Screen material	Copper, bare
Longitudinal water blocking screen	Yes
Longitudinal water blocking cable	Yes
Longitudinal water blocking construction	Water swellable tape(s)
Radial water blocking cable	Yes
Material outer sheath	Polyethylene (PE)
Cable shape	Round

ELECTRICAL & THERMAL PARAMETERS

Nominal voltage U0 [V]	19,000
Nominal voltage U [V]	33,000
Test voltage [kV]	63
Rated voltage U0/U (Um)	19/33 (36) kV
Max. conductor temperature [°C]	90
Max. conductor temperature at short circuit [°C]	250
Laying temperature (min) [°C]	-20
Laying temperature (max) [°C]	50

CHEMICAL PROPERTIES

CPR reaction to fire	Fca
Resistant to UV	Yes
UV resistant	Yes
Silicon free	Yes
Lead free	Yes

CHARACTERISTICS

Outdoor installation	Yes
Underground installation	Yes
Suitable as installation cable	Yes
Bending radius (rule)	During installing: 15 x D single-core cables

SUSTAINABILITY COMMITMENT

Our commitment to a low-carbon future remains unwavering as we strive to create sustainable solutions while upholding quality standards. We prioritize sustainability and environmental protection in our daily operations, collaborating with local communities to ensure workplace safety and safeguard the areas we operate in.

Sustainability and environmental responsibility is evident also in our **packaging** solutions across the CEE region. We use fully recyclable drum cover foils to minimize environmental impact. Our packaging for rings is made from 30% recycled materials, supporting a circular economy. Additionally, our boxes are made from recyclable, environment-friendly cardboard, promoting eco-conscious choices. By choosing Prysmian, you are not only selecting high-quality products but also contributing to a greener future.

Check for more details about our sustainability commitment here: Sustainability: report and responsibility

CABLE PROPERTIES

Basic construction	SAP code	Nominal thickness insulation [mm]	Nominal diameter over insulation [mm]	Nominal outer diameter [mm]	Cable weight [kg/km]	Bending radius, during laying (min) [mm]	Conductor resistance at 20° C [Ohm/km]	Short circuit current conductor (Isec) [kA]	Short circuit current screen (Isec) [kA]	DOP number
1x120RM/16	17010100187	8	30.4	38.1	1,275	572	0.253	11.6	2.6	
1x150RM/25	20396841	8	31	39.8	1,469	600	0.206	14.5	6.7	1003520
1x150RM/35	17170001071	8	31	39.8	1,562	600	0.206	14.5	8.5	1003520
1x240RM/25	20406878	8	35	44	1,855	660	0.125	23.1	7.1	1003520
1x240RM/35	17170001072	8	35	44	1,954	660	0.125	23.1	8.7	1003520
1x300RM/25	20396831	8	37.7	46.7	2,132	704	0.1	28.8	7.2	1003520
1x400RM/35	20406955	8	40.6	50	2,563	750	0.0778	38.3	9.3	1003520
1x500RM/35	20396710	8	43.6	53.2	2,973	798	0.0605	47.8	9.4	1003520
1x630RM/35	20396832	8	46.9	56.8	3,489	851	0.0469	60.2	9.7	1003520
1x800RM/35	20414885	8	51.1	61	4,132	915	0.0367	76.5	10	1003520
1x1000RM/35	17170001065	8	55.3	65.7	4,855	986	0.0291	95.3	10.2	1003520
1x1200RM/35	17170001066	8	59.2	69.8	5,497	1,047	0.0247	114	10.4	1003520

CURRENT CARRYING CAPACITY

Cross-section (mm²)	Direct in ground trefoil (A)	Direct in ground flat spaced (A)	Air trefoil (A)	Air flat spaced (A)
70	186	192	230	278
95	221	229	280	338
120	252	260	324	391
150	281	288	368	440
185	317	324	424	504
240	367	373	502	593
300	414	419	577	677
400	470	466	673	769
500	535	524	781	884
630	608	578	903	996
800	681	630	1029	1105
1000	753	681	1165	1219
1200	885	790	1274	1305

Ground temperature: 20°C; Air temperature: 30°C
Depth of laying: 0,8 m; Soil resistivity, moist: 1,5 K.m/W
Screen bonded at both ends

ADDITIONALTECHNICAL PARAMETERS

(N)A2XS(FL)2Y 1200/35 19/33 kV

- I = 788,3 A
- C = 0,408 μF/km
- L = 0,293 mH/km
- RDC(20 °C) = 0,0247 Ω/km
- R+ = 0,0442 Ω/km
- X+ = 0,0920 Ω/km
- R0 = 0,3420 Ω/km
- X0 = 0,0405 Ω/km
- Z = R + jX
- XC = 7,803 kΩ/km

Inputs:

- Soil resistivity: 1,5Kxm/W;
- Soil temperature: 20 °C;
- Air temperature: : 35 °C;
- Single circuit;
- Trefoil formation;
- Directly buried;
- Metallic screen connected solidly bonded (at both ends);
- Load factor: 1;
- Laying depth: 0,8 m for MV and 0,5 m for LV.

ANEXO V

Specification sheet of a 160 MVA 33/132 kV transformer [58].

PRINCIPAL PARAMETERS (128/160 MVA TRANSFORMER):

The transformer shall conform to the following specific parameters: -

Sl. No.	ITEM	Specification of160 MVA x-mer	
1.1	Rated Voltage Ratio: kV	220/132/33	
1.2	Highest system voltage	245/145/36 KV	
2.	No. of windings	Auto transformer with tertiary	
3.	Type of cooling	ONAN/ ONAF	
4.	**MVA rating corresponding to cooling system**:		
	a) ONAN Cooling	80% (128/128/402.66MVA)	
	b) ONAF Cooling	100%(160/160/53.33MVA)	
5.	Method of connection	HV & IV Star LV Delta	
6.	Connection Symbol (vector group)	YN yn0, d11,	
7.	System earthing	Effectively earthed	
8.	(a) Percentage impedance's, Voltage on normal tap and MVA base corresponding to HV rating and applicable tolerances:	% Impedance	Tolerance
	(i) HV – MV	8.35	±10%
	(ii) HV/ LV	30	±15%
	(iii) MV / LV	20	±15%
	(b) Insulation resistance at an ambient temp. of 30 deg with 5 KV megger for 600 seconds duration	HV-IV/E & LV/E- 3000 M ohm HV-IV/LV - 4000 M ohm	
	(c)) Polarization Index i.e. Ratio of megger values of 600 secs to that of 60 secs	>= 2	
	(d) DAR (Dielectric Absorption ratio) i.e. ratio of IR value of 60 sec. to 15 sec.	>= 1.3	
9.	**Anticipated continuous loading of**		
	a. HV, IV windings:	Not to exceed 110% of its rated capacity	
	b. Tertiary winding	Suitable for no load operation as well as for loading to its rated capacity with capacitive or inductive loading or combination of both (Subject to a maximum of 33% of the rated capacity of HV winding	

10.	**Tap changing gear:-** 1) Type	OLTC for IV variation.		
	2) Tap range & steps	-10% to + 10%, steps 1.25%		
	3) Rated for	150 KV & 1000 A (Minimum)		
11.	Over voltage operating capability and duration	110% rated voltage Continuous 125% rated voltage for 60 secs. 140% rated voltage for 5 secs.		
12.	Minimum Air core reactance of HV windings.	20%		
13.	The voltage for which star point shall be insulated to the earth	The insulation class of the neutral end of the winding shall be graded to 95 KV.		
14.	(a) Max. Flux density in any part of core and yoke at rated MVA, frequency and normal voltage (Tesla)	1.6		
	(b) No load current of the transformer at 105 % of rated voltage	0.5% of rated current (Maximum)		
	(c)) Current density in winding	<= 3 Amp/ sq. mm (max.)		
15.	Insulation levels: For windings	HV	IV	LV
	a) 1.2/50 microsecond wave shape impulse	950	650	250
	b) Power frequency voltage withstand (kV rms.)	395	230	95
	c) Tan delta values of winding	The measured Tan delta values of winding shall not exceed 0.45% at 20^0C temperature. In case Tan delta of transformers during testing at works of manufacturer is measured above maximum ceiling of 0.45% at 20^0C temperature, then CSPTCL reserves right not to accept such of the transformer. This requirement is to be confirmed specifically by the Bidders in their offer.		