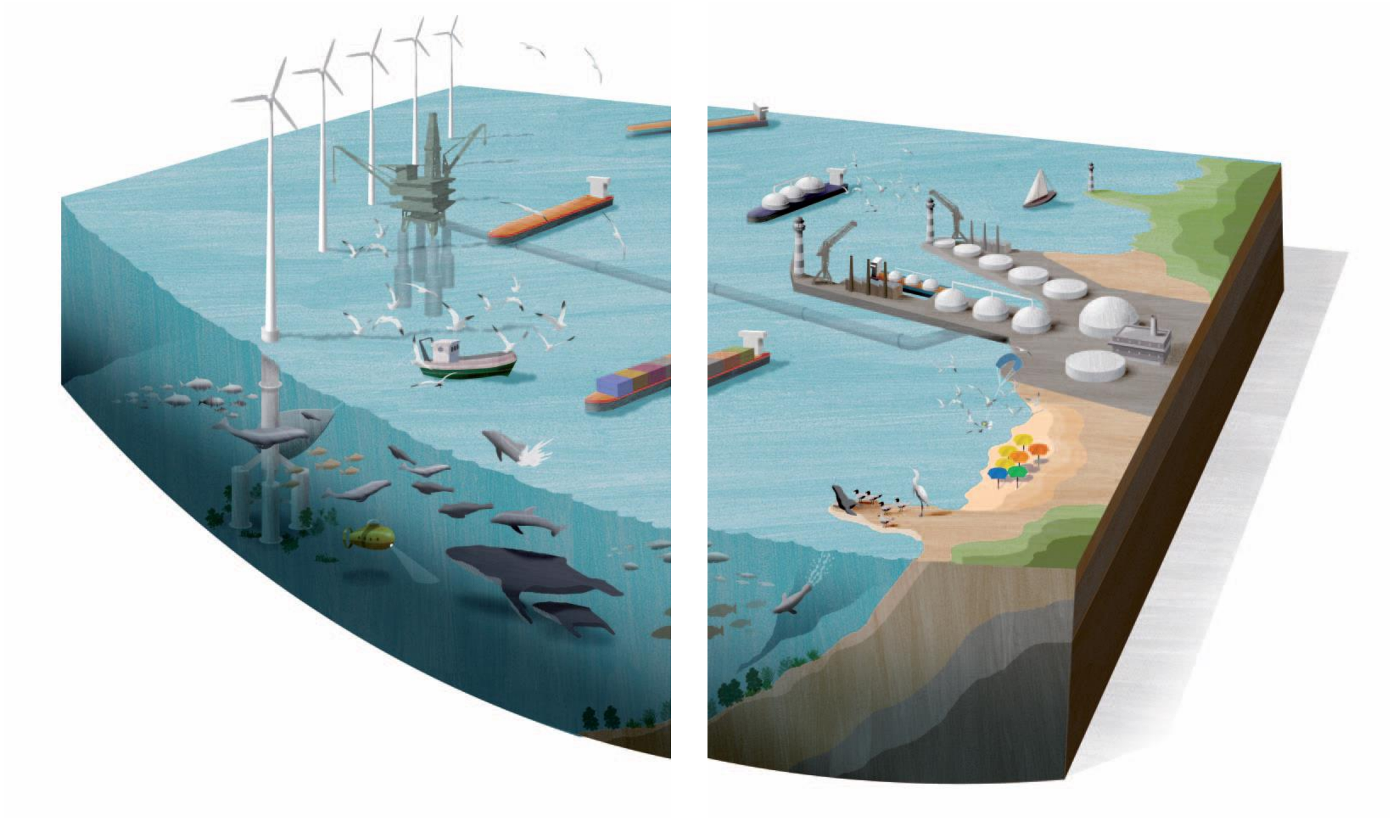
MASTER THESIS:

Offshore wind park sitting and micro-sitting in Petalioi Gulf, Greece



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OFFSHORE WIND PARK SITTING AND MICRO-SITTING IN PETALIOI GULF, GREECE

A THESIS SUBMITTED AS PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE M.Sc. (Eng.) in SUSTAINABLE ENERGY PLANNING AND MANAGEMENT OF AALBORG UNIVERSITY

BY

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ABSTRACT

The point of departure of this study was the concerns expressed about a sitting analysis that is conducted by the Greek government indicating the most suitable locations for the installation of offshore wind parks. Based on these concerns, a lot of the locations found as suitable might eventually be prohibited mainly due to conflicted marine uses and eventually the proposed capacity of offshore wind parks will get smaller. Aiming to address these concerns, the main research question of this project is formed as "How different factors affect the sitting and micro-sitting of an offshore wind park in Petalioi Gulf, Greece?"

The methodology chosen to be used in order to address the research question is based on the technology theory; technology is a combination of four components: knowledge, technique, organization and product, meaning that if any of the above components change it will eventually affect the others. Considering as the product of offshore wind energy technology the installation of an offshore wind park, this project aims at investigating how its implementation can be affected by changes in knowledge and technique.

The knowledge refers to the main factors which are necessary to be known when investigating the prospect of offshore wind park sitting in a specific region, which found to be physical, spatial and environmental. Both the physical and spatial characteristics of Petalioi Gulf found to be favorable and through a GIS analysis, an area of about 55 km^2, located in water depths from 30 to 50 m and at a minimum distance of 1.5 km and a maximum of 13 km from shoreline is identified. However, from an environmental perspective, the sitting gets more complicated. The reason for that is mainly the lack of spatially-defined environmental data, which cannot be included into the sitting analysis. However, an environmental investigation showed that Petalioi Gulf might be a region with high ecological importance and a more detailed and up-to-date analysis is required before any human intervention to the Gulf.

The technique refers to the technical factors which are necessary to be known when investigating an offshore wind park's micro-sitting in a specific region. The factors examined in this project are the wind turbine's size, their support structure and their arrangement. Due to the study area's good wind potential and high water depth the use of large wind turbines (5M) is considered, resulting in a total installed capacity of 250 MW. Then a turbine spacing of 10Dx7D is considered leading to a park efficiency of 92% and finally, due to the potential high ecological importance of Petalioi Gulf, the use of Jackets is considered as the most environmental friendly option. Based on these characteristics and through an energy analysis conducted in WindPRO, the final annual energy production of the offshore wind park is estimated to be 708.8 GWh.

However, based on the examined micro-sitting and annual energy production, such an investment is not economic feasible when considering a discount rate higher than 5%. However, attention is drawn to fact that external benefits and costs should be incorporated into the study and optimization scenarios should be developed in order to conclude on the park's economic feasibility.

Part 1
Theoretical Background of Offshore Wind Energy

1. INTRODUCTION

Along with other European countries, Greece is also committed to the climate change and energy target for 2020, also known as the "20-20-20" target, set by the European Union. This target requires a 20% decrease in GHGs emissions and a 20% decrease in energy consumption of the EU through improvement in energy efficiency both by 2020 and compared to 1990 levels and an achievement of 20% renewable energy share in the total energy consumption of the EU by 2020. This target was not only considered, by the Greek government of the year 2009, as an obligation, but it was also considered as an opportunity for Greece to increase its national energy security, reduce its greenhouse gas emissions and boost its economic sector, by attracting investment capital and technical knowhow (Ministry of Environment Energy and Climate Change 2010).

In this direction, the Greek government has set some specific energy targets, among which is to decrease its lignite-based electricity sector and facilitate the transition towards renewable energy sources, achieving a 40% share of renewable energy sources in its electricity generation mix by 2020. In order for this target to be achieved the Government has set interim targets regarding the installation of renewable energy sources. More specifically, the Greek government intends on installing the following capacities by 2020; *"7.5 GW of wind energy plants, 2.2 GW of PVs, 250 MW of CSP plants, 120 MW of geothermal energy, 250 MW of small hydro plants, 350 MW of large hydro plants and 880 MW of pumped storage plants*" (Ministry of Environment Energy and Climate Change 2010). It can be seen that the biggest target for Greece is the growth of wind energy installation, including the development and exploitation of offshore wind parks, an innovative action for Greece.

1.1 Why Offshore Wind Energy?

Wind power has been used since ancient times in many different applications such as grinding grains, pumping water, sawing woods or sailing ships. Despite the fact that until the thirteenth century wind-powered engines have become an integral part of rural societies, they started being sidelined, due to the gradual appearance of more reliable inexpensive fossil-fuelled engines (Burton, et al. 2001).

The oil crisis of 1973, made it clear that the abundance of inexpensive fossil fuels would soon come to an end. At the same time, concerns about global air pollution, due to the extensive use of fossil fuels, introduced a new way of thinking, the use of alternative renewable energy sources. As a result, renewable energy sources have started being exploited extensively, with wind energy growing with a fast pace, see Figure 1. This growth was a result of many different governmental support mechanisms, which have been firstly implemented in the United States, Denmark and Germany (Manwell, Mcgowan and Rogers 2009).

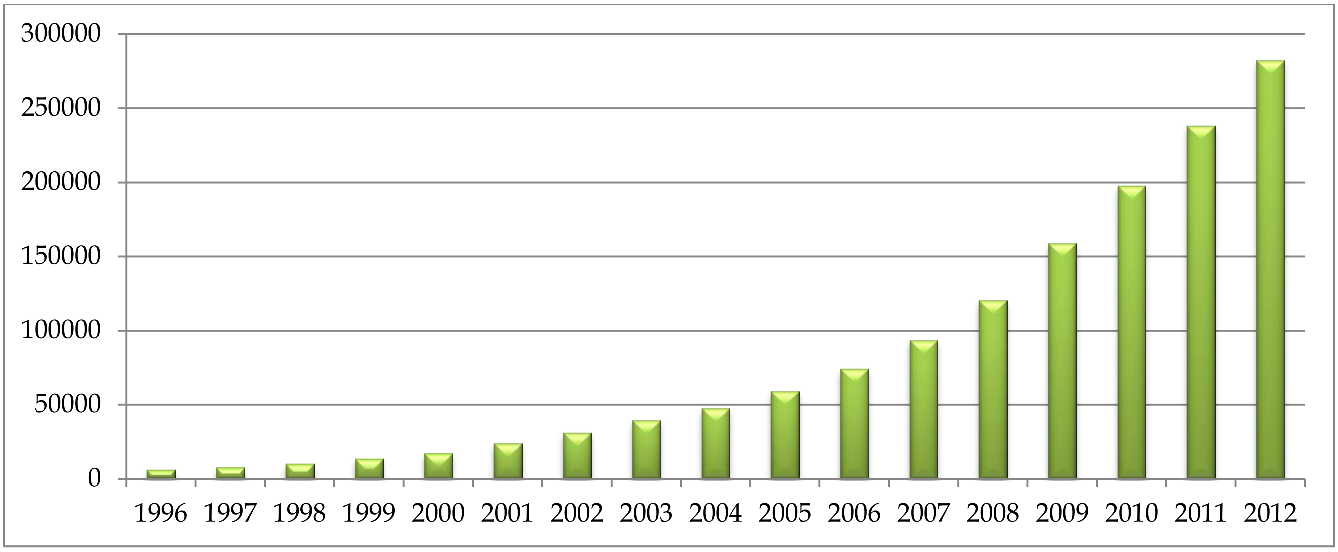


Figure 1: Global Cumulative Installed Wind Capacity 1996-2012 (in MW) **(Danish Wind Industry Association 2012)**

Since the 20th century, large scale wind parks have started operating in many countries all over the world for power generation. Although wind energy development has mainly occurred inland, offshore wind parks have also appeared, as a solution to the several problems related to onshore wind parks.

According to (Hederson, et al. 2003), onshore wind energy development has started facing many problems due to the multiple conflicted land uses and the great resistance from the public due to potential local environmental impacts – mainly visual and noise impacts. This has led to the offshore wind energy development, which according to the same source has many advantages, but disadvantages as well.

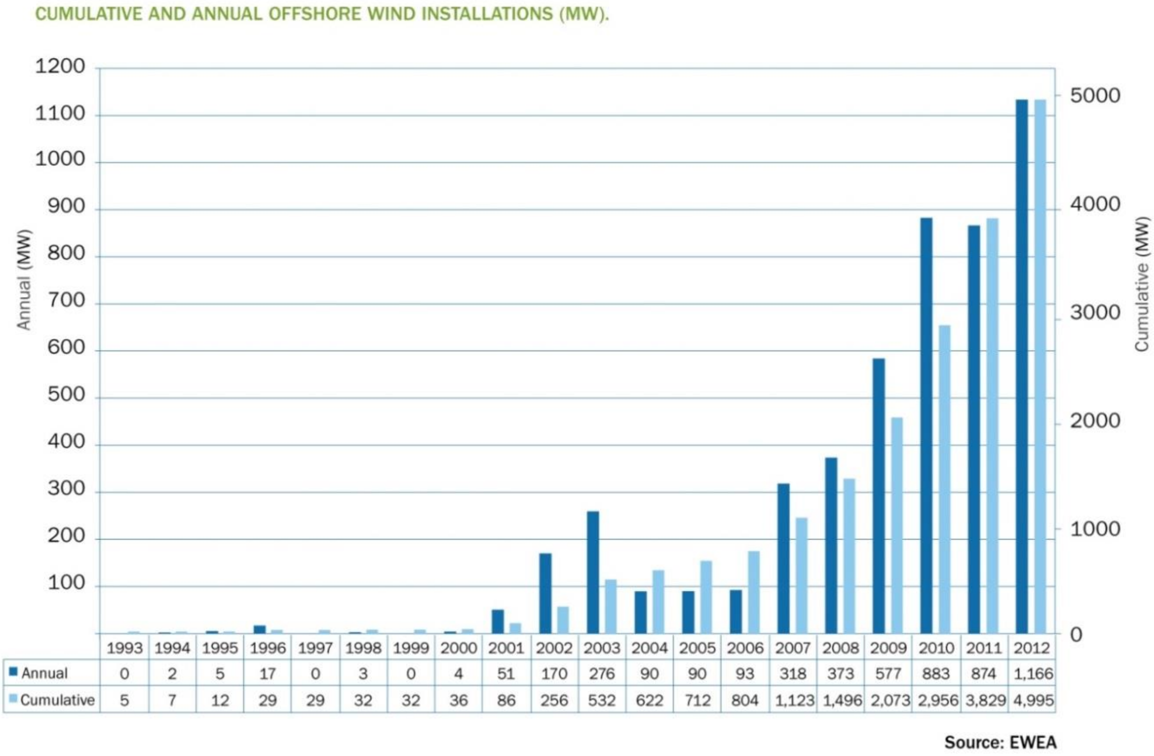
To begin with, the existence of large uninterrupted marine areas, free off physical obstacles, allows large-scale wind parks to be installed. This advantage together with the higher and steadier wind speeds that occur above the sea makes offshore wind parks more productive with higher capacity factors. In fact, offshore wind installations can demonstrate capacity factors which range between 20% and 50%, while onshore installation's capacity factor ranges between 20% and 30% (Kaldellis and Kapsali 2013). Furthermore, visual and noise impacts could be significantly reduced by locating the wind turbines at a high distance from the shore and thus from the population.

In addition to these advantages, there are also disadvantages mainly regarding the high investment cost of offshore wind projects. This is due to the more expensive technologically-advanced equipment for offshore wind parks, installation, integration into the electrical network and operation and maintenance (O&M). For example, O&M costs of offshore wind turbines can be even three times higher than the cost of on-land turbines and this is mainly due to the higher expenses of transporting the technicians to the offshore wind parks (Kaldellis and Kapsali 2013).

By the end of 2012, offshore wind capacity represented 10% of the annual installed wind capacity in the European Union, when it was only 3% of the annual installed wind capacity in 2002 (The European Wind Energy Association 2013).

The first commercial offshore wind park was installed in Denmark in 1991, at a distance of 1.5 to 3 km from the coast of Lolland island (Kaldellis and Kapsali 2013). The park has a total rated power of 4.95 MW, with eleven wind turbines of 450 kW each (Kaldellis and Kapsali 2013). The following years more offshore wind parks were installed in Denmark and other European countries; the United Kingdom, the Netherlands and Sweden, increasing the knowledge and experience about offshore wind development and advancing the relevant technology in order for higher power output to be achieved.

Over the years larger offshore wind turbines are used and bigger offshore wind park projects are taking place (The European Wind Energy Association 2013a). More specifically, examining the year 2012, the average capacity of offshore wind turbines used was 4 MW, which is 11% higher than the average capacity of turbines used in the previous year (The European Wind Energy Association 2013a). Moreover, in 2012 offshore wind park projects had an average of 271 MW, which is 36% higher than the average size of offshore projects in 2011 (The European Wind Energy Association 2013a). Figure 2 shows the course of offshore wind development in Europe over the last years.



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Annual	0	2	5	17	0	3	0	4	51	170	276	90	90	93	318	373	577	883	874	1,166
Cumulative	5	7	12	29	29	32	32	36	86	256	532	622	712	804	1,123	1,496	2,073	2,956	3,829	4,995

Figure 2: Cumulative and annual offshore wind capacity in Europe through 1993-2012 (in MW) **(The European Wind Energy Association 2013a)**

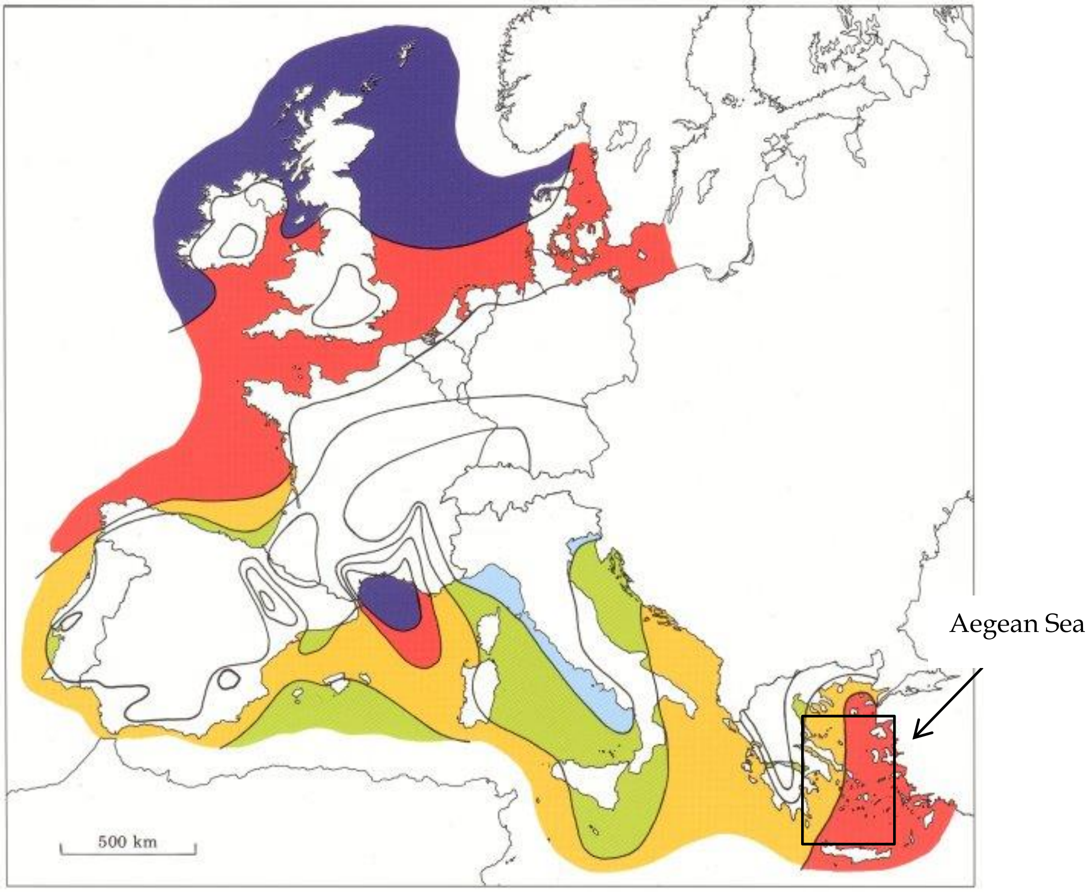
By the end of 2012, 55 offshore wind parks were operating in ten European countries, reaching a cumulative capacity of almost 5 GW (The European Wind Energy Association 2013a). This capacity contributed to an electricity production of 18 TWh, meeting 0.5% of total EU electricity demand (The European Wind Energy Association 2013a).

According to estimations, offshore wind capacity will increase to 40 GW by 2020 and to 150 GW by 2030 (The European Wind Energy Association 2011). As a result, based again on estimations for 2020, 148 TWh of electricity could be produced, meeting 4% of total EU electricity demand and avoiding 102 Mt of CO_2 emissions annually. However, what is more impressive is the estimations for 2030, based on which offshore wind capacity will exceed onshore capacity, generating 562 TWh of electricity, which is equal to 14% of total electricity demand in Europe, and avoiding the production of 315 Mt of CO_2 emissions in 2030 (The European Wind Energy Association 2011).

Although the already operating offshore wind parks are primarily located in the North Sea followed by Atlantic and the Baltic Sea, the Mediterranean Sea is expected to enter the offshore wind market, by installing 14 GW by 2030.

1.2 Offshore Wind Development in Greece

Greece and specifically the Aegean Sea, has the second largest offshore wind resources in Europe and the largest offshore wind resources in Southern Europe. More specifically, the Aegean Sea has average wind speeds of up to 11 m/s in 200 m height above the sea, see map 1.



Wind resources over open sea (more than 10 km offshore) for five standard heights										
	10 m		25 m		50 m		100 m		200 m	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Map 1: European wind resources over open sea **(Riso National Laboratory 1989)**

The high offshore wind speeds of Greece were the main incentive for the policy shifting from onshore wind energy exploitation towards offshore. Although as mentioned above, offshore wind projects require higher costs, it is nowadays a trend that seeks to take advantage of the benefits that the open sea offers and avoid the problems that onshore wind parks cause. Thus, for Greece, offshore wind energy development is seen as a great opportunity to exploit its significant offshore wind resource potential, enhance its electricity mix with renewable energy sources and at the same time replace a small portion of onshore wind energy projects, avoiding some of the problems that onshore wind parks already cause, which are mainly complaints about visual, noise and environmental impacts.

Table 1 shows a roadmap suggested by the Ministry of Environment, Energy and Climate Change, about the onshore and offshore wind energy capacity to be installed in order to contribute towards the binding “20-20-20” target and the interim target of the share of renewable energy to the electricity sector by 2020.

Table 1: Roadmap of the capacity to be installed and the gross electricity generation from wind energy technology in 2015-2020

	2015		2016		2017		2018		2019		2020	
	MW	*GWh*	*MW*	*GWh*	*MW*	*GWh*	*MW*	*GWh*	*MW*	*GWh*	*MW*	*GWh*
Onshore	4303	9674	4856	10425	5430	11538	6003	12831	6576	14790	7200	16125
Offshore			**50**	**107**	**100**	**213**	**150**	**321**	**200**	**450**	**300**	**672**

Source: (Ministry of Environment Energy and Climate Change 2010)

In contrast to the 300 MW to be installed off-shore until 2020, according to Table 1, a much larger potential for offshore wind development has been indicated as during the years 2007 to 2010 about 20 applications of offshore wind parks had been deposited in the Regulatory Authority for Energy (RAE) by private-owned companies, the total capacity of which exceeds the 5 GW. Although these applications started being reviewed in order to get approval for electricity generation license, a new law, designed by the Greek Government of 2010, stopped the procedure of revision. The reason was that the new law would provide for a completely different approach to offshore wind development, in which a crucial role would play the Greek government and then the private-owned companies. This was Law 3851/2010, which is further described below.

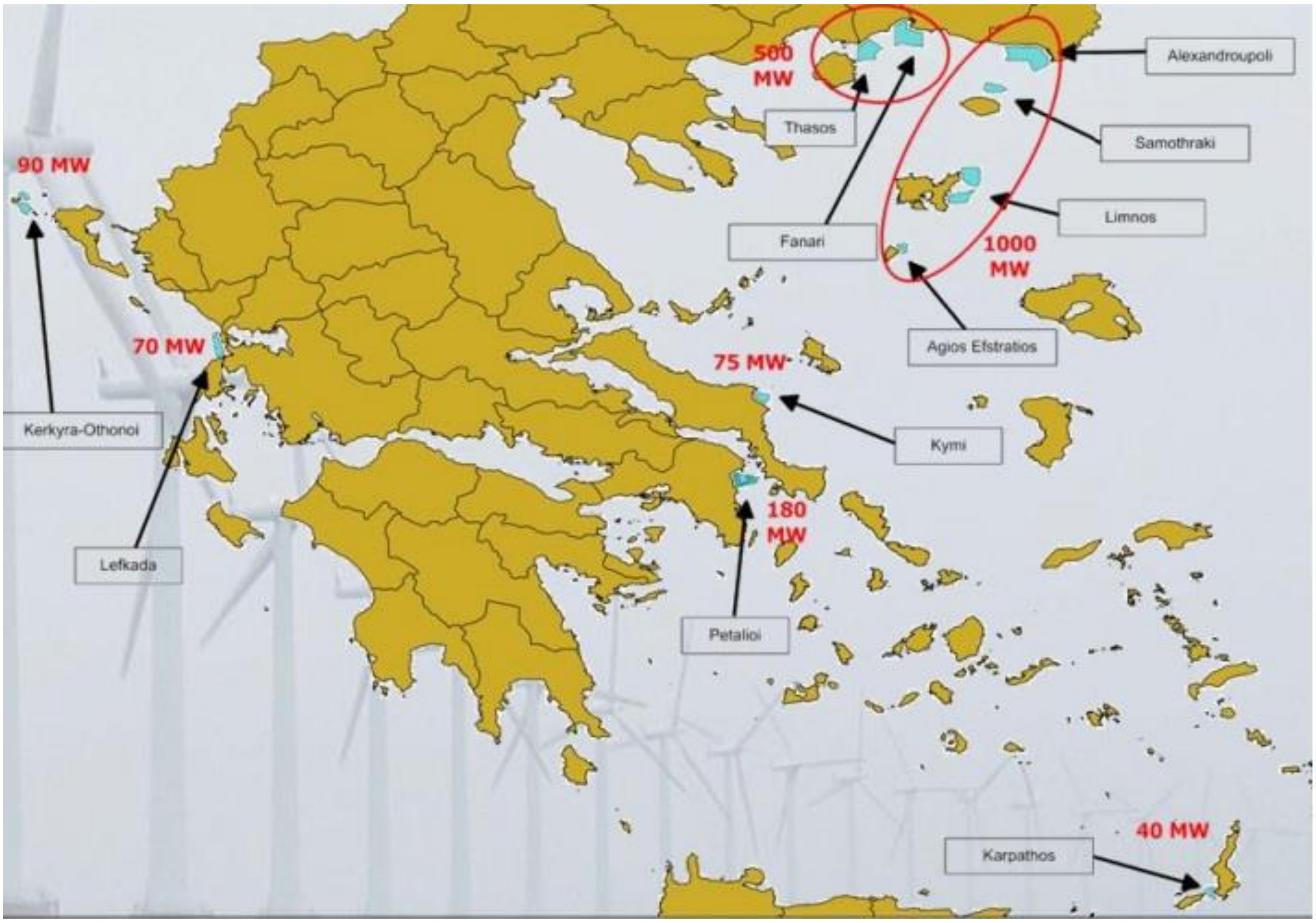
1.3 Offshore wind development according to Law 3851/2010

Law 3851/2010 specified procedures that should accelerate the development of renewable energy sources. Among the specified procedures for different renewable energy sources, Law 3851/2010 exclusively refers to offshore wind parks development, for which there has not been any regulation before, apart from a number of sitting criteria set by the Special Spatial Framework described by Law 2464/2008.

Law 3851/2010 provides for a specific procedure that should be followed in order for offshore wind energy development to proceed quickly and effectively. More specifically, the law required that the State should make a preliminary analysis of the Greek Seas, indicating the areas where the construction and operation of offshore wind parks is acceptable, areas in which there are no conflicting sea uses or possible environmental consequences. The State should tackle any barrier that offshore wind energy projects could face, including the assessment of environmental impacts and the arrangement of political and administrative issues, in order to ensure that the selected areas receive any license required in order for their construction to begin. At a second stage, Law 3851/2010 provides for an open public tendering procedure in order for the exploitation rights for the selected areas to be transferred to the interested parties, the investors.

The main target of this procedure is for the State to attract investors for offshore wind development, by preparing the whole licensing procedure for them, facilitating them to start the construction of the wind parks immediately after the tendering procedure. In this way, the investors would mainly have to deal with techno-economic issues related to their project, and less with any administrative issues.

As provides by Law 3851/2010, an initial governmental study has been conducted within one month after the law was published, indicating twelve areas, within which offshore wind parks could be site, see Map 2.



Map 2: Proposed locations for offshore wind parks in Greece **(Koronides, et al. 2011)**

This study was only based on a few sitting criteria, which were however not specified and it is unclear whether they include the criteria set by the Special Spatial Framework, of Law 2464/2008, requires. For instance, one of the criteria is the exclusion of obvious sites, where the installation of an offshore wind park is incompatible with other marine elements or uses. But, it does not become clear what these obvious sites are, since they could be military zones, sites with technical infrastructures, shipping lines or cultural elements, marine areas with ecological and/or touristic importance, recreational value etc.

However, this study was not intended to be the final one for indicating the final areas where offshore wind parks could be sited. A strategic environmental impact assessment of these twelve areas should then take place in order for the final areas to be decided and for their licensing procedure to begin. However, such a study has never been implemented due to the country's economic recession and deficiency of state funds. To be more specific, according to an interview with a representative from the Center of Renewable Energy Sources of Greece (CRES), which was the responsible governmental department to complete all the relevant studies, Greece is lacking of a central geographical information system that would provide information about the seabed (morphology, archaeological findings, protected species, etc.), the different sea uses, the Exclusive Economic Zone (EEZ), and any other information that is necessary to be considered for offshore wind development (Rossis 2013). As a result, according again to (Rossis 2013), even the seabed exploration and mapping is an extreme cost, which the government cannot cover at its current economic situation.

As a result, offshore wind development stopped before it even began and it has yet to be decided whether the planned tendering procedure will take place, or the government will postpone offshore wind development, deviating from the target that it has set, until it has the financial capacity to complete the initial plan. In the first case, the investors will have the right to start exploiting these twelve areas, having to complete the required environmental studies and deal with any political and administrative issues, taking the risk that any barrier could hinder the implementation of their project. In the meanwhile, since the provisions of Law 3851/2010 could not been implemented, the Government of 2011 allowed the revision of the applications made during 2007-2010, by private companies, to continue normally and they are still until today under approval for electricity generating license, from RAE.

What is interested is concerns expressed by (Chaviaropoulos 2011), according to whom, a large part of the proposed area indicated by the governmental study might eventually be prohibited for the installation of an offshore wind park due to conflicts with military activities, air traffic control and maritime traffic. Moreover, the capacity of an offshore wind park located within the area that the governmental study indicated, might not be as high as the initial governmental estimations due to the fact that the suitable areas might get smaller after a more detail analysis. As a result, it seems that there might be factors that have not been accounted for, or have not been correctly assessed, when deciding about the offshore wind parks' sitting and micro-sitting.

1.4 Project Proposal and Research Question

Having described the development and the status of offshore wind development in Greece, some of the problems that hinder the further development, as well as concerns about the suitability of the areas indicated by the governmental study, this project is aiming at investigating in more detail one of the twelve areas, identified by the State as the most suitable for offshore wind parks siting. The study will incorporate many criteria that need to be considered for offshore wind parks planning, as indicated by the literature. Such a study could serve, for both the Greek government and the private investors, as a paradigm of how such a study should be approached and implemented, but it could also indicate potential barriers that hamper the completion of the planning process.

The one out of twelve areas that is chosen to serve as the case study is a marine area in Petalioi Gulf, Greece, see Map 2. This area is chosen because according to the governmental study made by CRES, it is an area with great potential for offshore wind development mainly due to its wind potential, grid connection and bathymetry. Besides the wind potential, which needs to be further examined, this area seems indeed to present significant advantages for offshore wind energy exploitation. More specifically, it is an area that although it extends in large distance from the shore, it remains shallow, which is usually not the case for the Greek Sea. This can facilitate the installation of offshore wind turbines without increasing the costs significantly. In addition, this area due to the fact that is very close to the capital of Greece, which has the highest electricity consumption of the country, is of great importance as it could contribute to the capital's electricity mix. Finally, it is an area with environmental, historical and economic interest, offering a lot of factors to be examined and accounted for in this project.

However, since the exact factors that need to be examined are not yet known and will be indicated mainly through a literature review, the main research question is formed based on the concerns expressed by (Chaviaropoulos 2011). Thus, the factors that are relevant to an offshore wind park's sitting and micro-sitting need to be examined, forming the main research question as:

"How different factors affect the sitting and micro-sitting of an offshore wind park in Petalioi Gulf, Greece?"

The sitting of an offshore wind park refers to the investigation of the most suitable location where the park can be located, considering a range of relevant factors.

The micro-sitting of an offshore wind park refers to the investigation of the park's layout, which includes investigating the relevant technological and economic factors.

1.5 Project Delimitations

As also mentioned above, a sitting study has already been conducted for Petalioi Gulf, by a governmental agency. Also, a micro-sitting study has also been conducted by a private company, indicating some of the specific technological and economic aspects of an offshore wind park in

Petalioi Gulf. However, this project seeks to remain uninfluenced by the existing studies, attempting to address the main research question as no study has been made before.

So, this project can serve as an additional study to the already conducted ones, revealing information that might have not been considered by the latter. This is because this study seeks to investigate more sitting criteria than the ones included in the governmental sitting study, and conduct a technical and economic analysis, that may reveal additional useful information to the micro-sitting study conducted by the private company. Either way, due to the fact that both the governmental and the private company's study lacks transparency, meaning that only the results are presented and there is no much knowledge about the specific methods and data used, this study can also contribute towards revealing what are the methods and data needed for these studies.

Of course, wherever that is relevant, the findings of this project will be compared to the findings of the governmental and the private study, since this is among the aims of the project; to investigate what is not correctly done especially by the governmental study which can eventually lead to deviating from the initial plans, as (Chaviaropoulos 2011) explained.

As expected, the analysis is mostly based on the available data. However, as also mention above, Greece lacks of geographical information necessary to be considered for offshore wind development. As a result, the lack of available data can be a serious project delimitation, mostly regarding the sitting study. Although this project seeks to search for data that are not available to the public, the finding of all the missing data is impossible given the limited time for conducting this project and the lack of economic support. For instance, the mapping of seabed's geological and ecological conditions would be an important element to be added in the sitting analysis, but it is a time consuming and expensive procedure, which cannot be materialized by a student as part of a master thesis. Any data delimitations will be highlighted throughout the report.

Then, although the methodology used to address the main research question, as seen in the Methodology Chapter that follows, requires the investigation of the relevant knowledge, technique and organization in order to conclude on what affects offshore wind development, this study only focuses on the first two components and does not examine how organizational changes can affect offshore wind development. The reason for not examining all three components is mainly due to the limited time available for conducting this project and the concerns expressed by (Chaviaropoulos 2011) which seem to be mainly a result of lack of knowledge and technique towards offshore wind development.

Finally, although normally the aim of a micro-sitting study would be the investigation of the most optimum park's layout that will result to a high energy production at the lowest cost, this is beyond the scope of this project. The micro-sitting analysis of this project is a preliminary analysis in order to examine what a reasonable park's layout would be based on the specific characteristics of Petalioi Gulf and if the proposed layout is an economic feasible option.

2. METHODOLOGY

At the beginning of this project and by generally examining the offshore wind energy development in Greece, a range of information that were gathered, which are described in the Introduction, revealed the current situation and the concerns associated with it. More specifically, the status of offshore wind development in Greece was examined along with the national targets and efforts that contributed to this development and the concerns expressed mainly about the effectiveness of the national actions. All this information led to the formation of the project proposal and the main research question. In order for all these background information to be collected two main methods were used; the literature review and an interview with a key stakeholder.

An initial literature review is a very useful method to create a point of departure for a project, allowing the discovery of a variety of published information on a research topic. The findings of the literature review are the foundation based on which the researcher builts her own research, aiming at contributing towards answering questions that have not been answered yet.

The initial literature studied in this project mainly consisted of governmental documents that describe the national targets towards renewable energy development in Greece, including the offshore wind energy, and national legislations that describe the more specific procedures that need to be followed in order for the targets to be successfully achieved. In this way, useful information about the regulatory framework and the national efforts towards offshore wind development were acquired.

The interview was conducted with a representative of the Center for Renewable Energy Sources of Greece, a governmental agency that has the responsibility to promote renewable energy sources. This agency had played a key role towards offshore wind development since it is the agency that prepared the initial studies about offshore wind exploitation in the Greek Sea, according to the requirements set by the national legislations. The main aim of the interview was for the author to figure out what is the current status of offshore wind development on Greece, whether the targets set by the Government were achieved, whether the procedure proposed by the national legislations towards offshore wind development was successfully implemented and if not what were the main issues that hampered this development. In order for all these information to be acquired, a semi-structured interview was chosen as the best type of interview to be used.

The semi-structured interview differentiate from the structured interview in which the interviewer seeks answers to very specific question and does not allow the conversation to deviate from this objective, and the unstructured interview in which the interviewer does not have an initial plan about the course of the conversation and does not seek answers to specific questions, letting the person being interviewed to steer the conversation. In the semi-structured interview, on the other hand, although the interviewer has an initial plan about a set of questions that need to be addressed, she is very flexible on letting the person being interviewed to deviate from these questions, bring new elements to the conversation and reveal information that was completely unknown to the interviewer.

So, this type of interview was proved to be very useful towards acquiring information about offshore wind development in Greece. This is because the author had relatively limited knowledge on the topic and it was the best solution to let the person being interviewed to steer the conversation and reveal important factors surrounding offshore wind development. In this way, the author received answers to specific questions, such as the effectiveness of the national legislations, but she also had to opportunity to collect additional information on the topic that was not part of the initial set of questions. This is because, due to the characteristics of the semi-structured interview, the person being interviewed was free to deviate from the predetermined set of questions and express additional information that ended up very useful.

As a result, the information collected by the initial literature review and the interview both contributed towards revealing the concerns associated with the offshore wind development in Greece, forming the main research question of this project. Figure 3 presents the overall methodological approach to address the main research question, which is also described below along with the more specific methods and tools used.

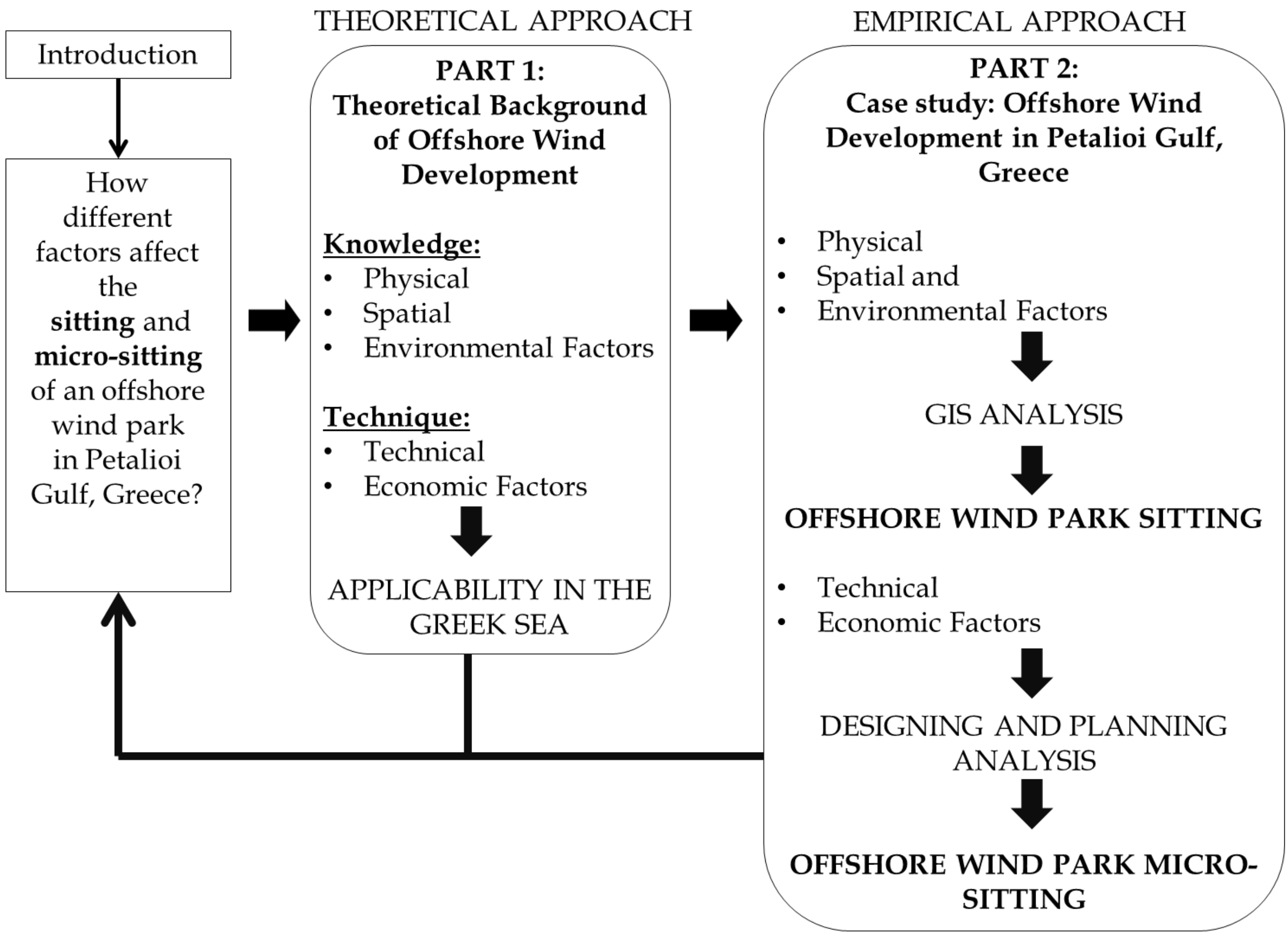


Figure 3: Methodological approach of the main research question

2.1 Theoretical Approach for answering the Research Question

The technology examined in this project is the offshore wind energy, which if implemented to a specific region it will result to technological changes. According to Mueller, Remmen and Christensen, 1984 *in* (Lund 2009), *"technology is a combination of four interrelated components; knowledge, technique, organization and product"*. This is basically their technology theory the basic assumption of which is that any qualitative change in one of the four components can affect the others.

Therefore, considering as the product of offshore wind energy technology the installation of an offshore wind park, this project aims at investigating how its implementation can be affected by changes in any of the other components. The two components chosen to be investigated in this project are the knowledge and the technique, in order to be assessed how they can affect the sitting and micro-sitting of an offshore wind park in a specific region.

Knowledge

The knowledge refers to the information which is necessary to be known when investigating the prospect of offshore wind park sitting in a specific region and it is presented in Chapter 3. The literature review is again a very useful method towards acquiring this information because, mainly based on the experience gained so far from the installed onshore and offshore wind energy development, reveals all these factors that are relevant to an offshore wind park installation.

According to the literature, these factors are found to be physical, spatial and environmental. However, only knowing which these factors are, it is not adequate for an integrated knowledge that will help to understand how they can affect the installation of an offshore wind park, which is the aim of this project. Thus, after identifying the potential factors that can have an impact on offshore wind energy development, it is further analyzed how exactly these factors can have an impact and how they can relate to the specific characteristics of the Greek Sea, which are also identified by a literature review.

Technique

The technique refers to the technical issues associated with the micro-sitting of an offshore wind park, which also need to be known and are presented in Chapter 4. The literature review is again used in order for the technical information to be gathered, again due to the fact that it is in the literature where the experience gained so far from the installed wind parks is recorded.

According to the literature, among the technical issues that need to be investigated for a micro-sitting study are the wind turbines, their support structure and the wind park's layout. Technical choices are very much related and based on economics, so the economic aspects of the installation of an offshore wind park are also investigated and described in Chapter 4.

2.2 Empirical Approach for answering the Research Question

After approaching the research question theoretically, investigating what are the different factors that can generally affect the sitting and micro-sitting of an offshore wind park and in which way, then, the research question is approached empirically. In other words, it is investigated how the factors analyzed in the first part of the report, apply to the study area examined in this project, according to the specific characteristics of it.

In order for the specific characteristics of the study area to be identified, different sources were used. More specifically, some of the required data were provided by governmental agencies, whereas other resulted from the review of scientific papers for the study area or from the study area's nautical chart. Table 2 shows the different characteristics examined for the study area, as well as the data source for each of them.

Table 2: Specific Characteristics examined for Petalioi Gulf and their sources

CATEGORY	SPECIFIC CHARACTERISTICS	DATA SOURCE
Physical Characteristics	Wind Speed Bathymetry	EMD and ConWx Model Data from WindPRO 2.9 Manual Digitization of Nautical Chart
Spatial Characteristics/ Site Obstructions	Wrecks Lighthouses Submarine Cables Shipping Lines	Manual Digitization of Nautical Chart
Environmental Characteristics	National Park Swimming Coastlines Phytobenthos Zoobenthos Fish Marine Mammals Birds	Municipality's Online Documents Special Secretariat for Water Online Data Governmental Online Documents and Scientific Papers

The specific characteristics of the study area are utilized in two ways. Firstly, the initial intention is for all the characteristics to be spatially identified within the study area and after the necessary processing to gradually limit the available areas where an offshore wind park can be located, revealing the final most suitable area. In order for this to be materialized, a Geographical Information System (GIS) is chosen as the most appropriate tool to be used.

2.2.1 Geographical Information System

As seen in Figure 4, Geographical Information System (GIS) is a computer-based package which allows the user to collect data, store and manage them by converting them into an appropriate form, as well as analyzing and modeling them. In addition gives the opportunity to display any geographic data for a wide range of applications (Davis 2001).

GIS is a true integrated technology, which is adopted by a large number of private and public companies "*as a major information and decision-support technology*" (Davis 2001). Among its different areas of application, GIS is a very useful tool for the purpose of site selection of different infrastructures, such as a wind park, a landfill etc., where specific requirements need to be fulfilled, mainly in order to avoid the infrastructure's conflict with other land uses (Despotakis and Economopoulos 2005). Towards this direction, GIS software programs allow the entry of spatial data, their process with various spatial tools, such as buffering and overlaying and their display into a map form, facilitating the decision making and contributing to a comprehensive research (Abdelaziz and Mekhamer 2011).

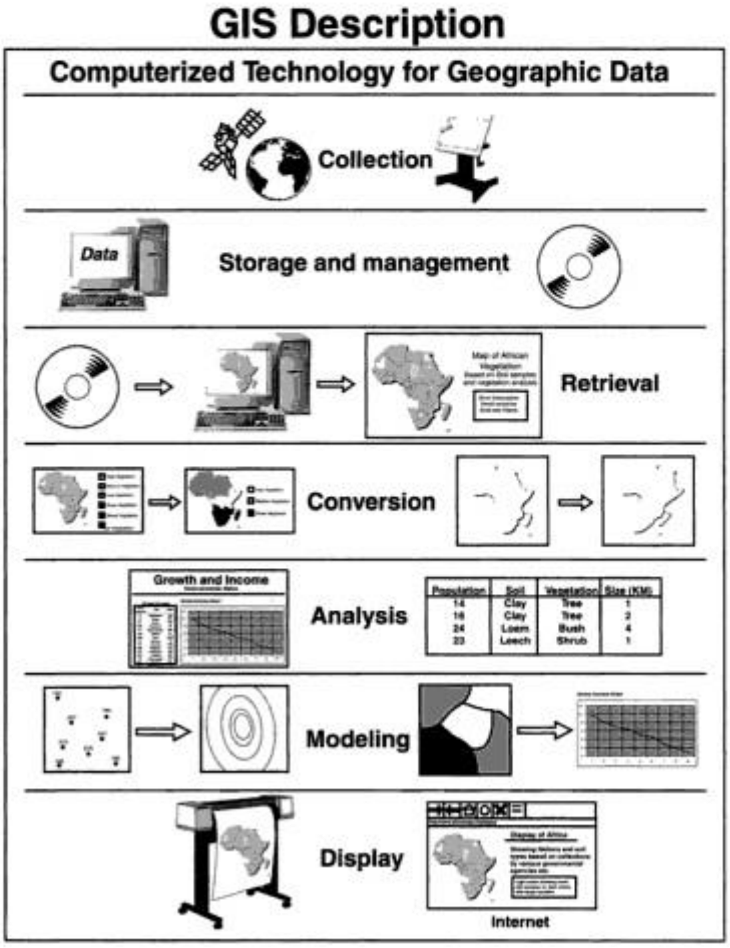


Figure 4: GIS software package description **(Davis 2001)**

For this project, the latest available version of ArcMap, the ArcMap 10.1 is used. All the data, hence the specific characteristics of the study area, are converted into a useful form in order to be imported into the software and be processed. Data that are not available in the appropriate digital form (i.e. shapefiles) or georeferenced according to the Hellenic Geodetic System, are manually digitized and added to the software. It is worth mentioning that all the data are georeferenced to the Hellenic Geodetic Reference System 1987, also known as EGSA 1987.

According to the theory, as described in Chapter 3, Greece has set very specific criteria for offshore wind park sitting, specifying the minimum distance that needs to be applied from different marine uses and marine elements, in order for a smooth functionality and performance of offshore wind installations to be ensured, as well as a smooth incorporation of the installation to the environment. These sitting criteria are specified in the Special Spatial Framework of Law 2464/ 2008 and the spatial characteristics of the study area are processed based on them, becoming the key criteria for assessing the most suitable location for an offshore wind park in Petalioi Gulf.

Table 3 shows all the different characteristics of the study area that are imported to ArcMap (in the form of different layers) and the sitting criteria that are applied to them in order to prohibit the installation of an offshore wind park within a specific distance from them, according to the requirements of the Special Spatial Framework. The resulting layers are then overlayed, indicating the final suitable area for an offshore wind park.

Table 3: GIS layers considered for the offshore wind park sitting in Petalioi Gulf

Initial Layer	Topology	Sitting Criterion	Topology
Bathymetry	Polyline	Prohibited Zone >50 m	Polygon
Wrecks	Point	Prohibited Zone 7d = 882 m	Polygon
Lighthouses	Point	Prohibited Zone 1.5d = 189 m	Polygon
Submarine Cables	Polyline	Prohibited Zone 1.5d = 189 m	Polygon
Shipping Lines	Polyline	Prohibited Zone 1.5d = 189 m	Polygon
National Park	Polygon	Prohibited Zone 200 m	Polygon
Swimming Coastlines	Polyline	Prohibited Zone 1500 m	Polygon

The specific characteristics of the study area are however not necessarily utilized through spatial analysis, due to the fact that some of them cannot be spatially identified within the study area due to data unavailability. As a result, some of the characteristics are discussed separately in terms of their general existence within the study area and relevancy to the installation of an offshore wind park, in order to be taken into consideration in future studies. These characteristics are the wind speed, the phytobenthos, the zoobenthos, the fish, the marine mammals and the birds. As a result, the final area indicated by this project as the most suitable for the installation of an offshore wind park does not include any spatial restrictions that the above mentioned characteristics could create.

2.2.2 Offshore wind park design and planning

The GIS analysis revealed the most suitable area for the installation of an offshore wind park, based on the physical, spatial and environmental characteristics of Petalioi Gulf. The last step of this project is to make a preliminary assessment of the park's micro-sitting, based on the specific characteristics of the study area and the technical aspects that can affect an offshore wind park. The aspects chosen to be investigated are determined by the literature review and are the wind turbines' size, their distance and their support structures. After defining these, the preliminary assessment of the park's micro-sitting is achieved based on which an energy and economic analysis are conducted.

For the energy analysis, WindPRO 2.9 is used. WindPRO is a software package, similar to a GIS environment that allows a wind project designer to insert or download data, store, analyze and use them for conducting different studies, technical, environmental or economic. The main purpose for using this software is because it facilitates energy calculations due to its main advantages.

Among the advantages of WindPRO is the provision of online wind data. This is a very important and useful element for the technical analysis of the offshore wind park in Petalioi is, as it solves the problem with unavailable wind data for this area, a primary element for accurate energy calculations. A more detail explanation about the wind data used for the energy calculations is given in the following chapters. In the same direction, WindPRO has a database for climatic conditions from different climate stations all over the world, providing useful information which is also important for accurate energy calculations.

Another strong advantage of WindPRO is its default parameters that can be set when calculating the offshore wind park's annual energy production. For instance, the Wake Decay Constant can be set in order for the software to make all the relevant calculations based on the correct terrain type of the wind park. This is very important since wake losses are a very crucial part when designing a wind park.

So, after setting all the necessary parameters the annual energy production is calculated, based on wind data, a wide range of climatic data, wake losses and other losses, which are analyzed in Chapter 6.

Finally, based on the park's energy production, an economic analysis is conducted. The specific installed capacity costs used for the calculation are either based on estimations derived from the literature or are calculated based on the specific characteristics of Petalioi Gulf. More detail information is provided in Chapter 6. The results of the economic analysis show the park's economic feasibility considering different interest rates and thus contributing towards the final decision making about the installation of an offshore wind park in Petalioi Gulf.

3. OFFSHORE WIND PARK SITTING FACTORS

Based on the methodology used to address the main research question of this project, general theoretical knowledge about what may affect the installation of an offshore wind park needs to be acquired. Towards this direction, this Chapter aims at investigating what are the relevant factors that may affect and need to be considered when investigating the prospect of an offshore wind park sitting in a region.

3.1 Physical Characteristics

One of the most crucial factors for the establishment of an offshore wind park planning is the existence of sufficient exploitable wind potential, which is a factor that can initially limit potential sites of offshore wind installation.

The wind data of a region can derive from ground stations like wind stations located in airports or permanent weather observation stations. The problem with using wind data from such stations for an offshore wind park development is that these stations are usually located onshore, not providing information for sea wind and can often give inaccurate information due to the stations' malfunctions. On the other hand, wind speeds can also be modeled mainly by taking into consideration a wide range of climatic data for a region, including temperature, surface and sea level pressure, solar radiation, humidity, cloud cover etc. Modeled wind data can then be a lot more accurate since they are calculated based a range of different parameters.

According to (European Environment Agency 2009) offshore wind speeds lower than 5 m/s might not be acceptable as they are considered as non-economically exploitable. With a first assessment and based on Map 1 of the Introduction, Greece has wind speeds that range between 7.5 to 10 m/s at a height of 100 m, thus it has an acceptable range of wind speed for the consideration of an offshore wind park development.

After ensuring the good wind potential of a region, it is equally important to know the joint wind speed and direction distribution. In this direction, a wind rose is a very useful tool when designing a wind park, since it indicates the frequency of winds blowing from different directions which can determine the orientation of the wind turbines, but this is a micro-sitting consideration and is examined at a second phase.

Then, the next important physical characteristic that needs to be assessed is the bathymetry of the marine area where the development of an offshore wind park is considered.

Although technological advances allow the installation of offshore wind parks in water depth of 200 m and higher, the majority of online offshore wind parks is installed in shallow waters, in 22 m average water depth and within an average of 29 km distance from the shore (The European Wind Energy Association 2013a). This means that the experience gained so far is mainly on offshore wind installations in shallow waters (less than 50 m depth) and especially for countries like Greece with no previous experience on offshore wind development, the installation of an offshore wind park should not be considered in depths higher than 50 m.

However, it needs to be ensured that there is enough space from shore and up to 50 m depth in order for an offshore wind park to be located. This is because there are marine areas, including areas in the Greek Sea that are characterized by abrupt increasing water depth, reaching a depth of 50 m even with 1 km from shore. In this case, there would not be adequate space for an offshore wind park installation and that is why bathymetry is among the primary factors that need to be examined together with the wind potential.

After ensuring that the wind and bathymetrical conditions are favorable for offshore wind development in a region, there are several other important factors that need to be considered during offshore wind park planning, in order for a smooth and harmonious incorporation of the project to the environment and compatibility with other marine uses to be achieved.

Offshore wind parks can conflict with other marine uses and can be also associated with several environmental impacts on the marine environment and sea life. More specifically, offshore wind parks installation could conflict with fisheries, elements of cultural heritage (archaeological findings, historical places), tourism, military, shipping lanes etc. and have an impact on benthos, fish, marine mammals and birds (Manwell, Mcgowan and Rogers 2009).

In order for all potential conflicts to be addressed and any potential social and environmental impacts to be avoided, appropriate offshore wind park sites must be selected. Below, there is a brief description of what the potential conflicted marine uses could be, as well as what the impacts of an offshore wind park to the marine environment and sea life could be, impacts which need to be considered at the second part of this paper, the case study.

3.2 Spatial Characteristics

Marine areas cannot be individually seen as natural, recreational, industrial, fishing or shipping spaces, because they simultaneously accommodate multiple sea uses, by providing the space and the appropriate conditions for a great variety of anthropogenic uses to be developed (Lange , et al. 2010).

The list that follows indicates the most common uses that can be met in marine areas, as described by (Lange , et al. 2010) for a specific German case study they examined:

- Military zones
- Ecologically-important protected areas
- Fishery areas
- Shipping routes
- Coastal protection structures
- Raw materials exploration zones
- Tourist areas/zones

- Cable and pipelines network
- Mariculture zones
- Miscellaneous Infrastructure

Although this list refers to the marine uses met in the German coastal zone, it seems a quite extensive list that could be used as a guideline for the potential marine uses in other European countries as well. It is worth mentioning that an additional marine use that is missing from this list, is the existence of archaeologically-important areas that also need to be considered while sitting an offshore wind park.

The way that each marine use may interfere with an offshore wind park is seen in figure 5, where the different colors indicate the possibility of two marine uses to co-exist, while the arrow indicates the marine use that typically takes precedence over the other. Thus, as it is seen, there is no or limited possibility for shipping, oil and gas industry and cables and pipelines to co-exist with an offshore wind park and they typically take precedence over it. Also, for military, fishery and sand extraction areas there is no or limited possibility to co-exist with an offshore wind park but it seems that the latter can typically take precedence over fisheries and sand extraction activities. Finally, there is possible co-existence between nature conservation and an offshore wind park, but of course a very careful environmental impact assessment needs to take place, ensuring that the park will not adversely affect nature.

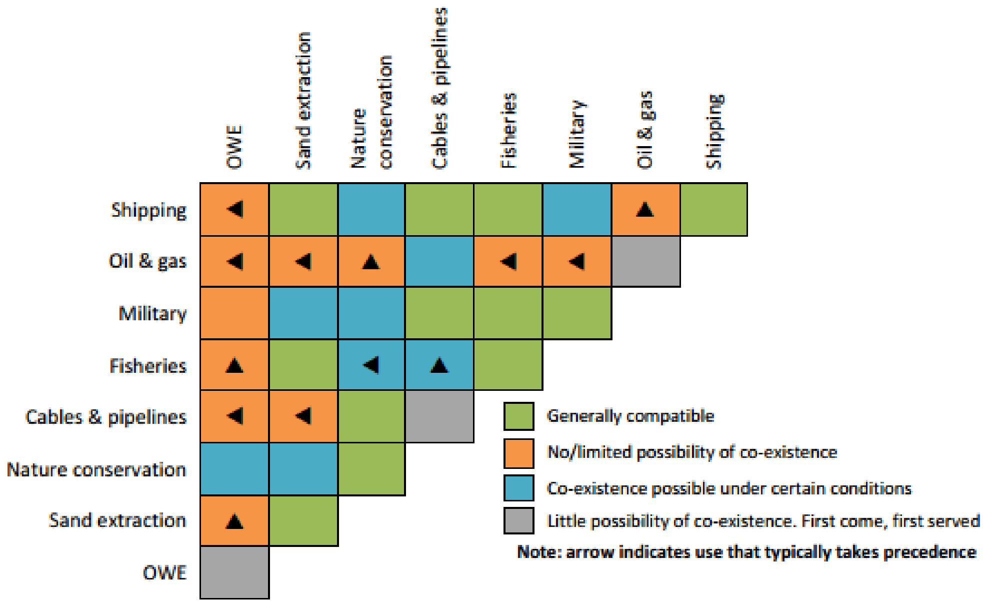


Figure 5: Interaction between marine uses and offshore wind development **(Verum, et al. 2011)**

Due to the fact that the majority of these marine uses can be easily detectable (excluding nature conservation), their existence and their exact location need to be identified within a specific study area and if necessary the installation of an offshore wind park shall be restricted within a specific distance from them, according to national regulations.

3.3 Environmental Characteristics

Besides the very obvious marine uses, there are marine environmental elements that require a more detail investigation about how they can be detected, or how they can interfere with an offshore wind park. The reason is that due to the fact that they are not easily detectable elements, like the benthos, the fish or the birds of a marine environment, and there might be no available data indicating their existence and their exact location within a study area, they can be easily disregarded leading to environmental degradation.

During planning an offshore wind park, it is very important to examine the impact that such an infrastructure can have to the marine environment and sea life. Since different locations are characterized by different ecological status, we need to be aware of the ecological status of the potential areas where the offshore wind park could be located in order to be determined whether these locations are suitable from an environmental perspective. Thus, in this section, it is briefly presented the way that an offshore wind park could affect different species categories of the marine environment, as well as indices that can be used to determine the ecological status of a marine area, which can then serve as a decision tool for the final location of an offshore wind park.

<u>Impacts on Benthos</u>

Starting off with benthos, which is the base of the marine food chain, is a community of organisms (plants, animals, bacteria) that live on or in the seabed. Benthos can be either directly or indirectly affected by the installation of an offshore wind park in the marine environment. Directly, it is very likely that phytobenthic and zoobenthic habitats are destroyed with the placement of wind turbine’s support structures, especially gravity-based support structures, which cover a larger part of marine bottom. Then, indirectly, the disturbance created during the installation of the park can cause sediment transport, covering and thus destroying phytobenthic and zoobenthic habitats and/or water turbidity, blocking solar radiation, hindering photosynthesis and thus affecting negatively the phytobenthos and zoobenthos.

As a result, offshore wind park installation shall be restricted in marine areas with high ecological status, in order to avoid creating changes in healthy benthic communities’ composition and structure. However, in Greece there are no available data indicating the specific areas with high ecological status that need to be protected, thus this needs to be examined by careful examination of the seabed and the use of phytobenthic and zoobenthic indices.

Phytobenthic Indices

There are specific marine plants than can serve as indices for water quality. More specifically, monitoring of algae and Posidonia Oceanica can be a valuable tool for assessing the quality of the Mediterranean marine environments (Tsiamis, Orphanidis and Aligizaki 2011).

Algae occurs in rocky bottoms and specific types of algae, such as the Cystoseira, are used by scientists in order to assess the quality of water, as they only grow in clean waters (Tsiamis, Orphanidis and Aligizaki 2011). On the other hand, Posidonia oceanica is a plant that mainly occurs in sandy bottoms, in depths up to 45 m and solely in clean waters, hosting a great variety of marine fauna (Marathon Municipality 2005) and (Pergent, et al. 2010). Besides the importance of Posidonia oceanica for the marine ecosystem, it also plays an important role in diminishing shore erosion, because the plants' movement decreases the waves' intension and thus their impact on the shore (Ljubljana University 2013).

Despite the important role of Posidonia oceanica, it has declined in many areas of the Mediterranean Sea mainly due to human activity in coastal areas, including trawling, boat anchoring and turbidity (Pergent, et al. 2010). That is the reason why since 1992 Posidonia is included among the natural habitats that require conservation, under the European Union's Habitats Directive (92/43/EEC), thus limiting human activity wherever they occur. However, according to (Lazou and Issaris 2009), the protection of the Posidonia cannot be easily achieved due to the lack of maps indicating the exact location of the Posidonia meadows. In this way, although they require protection, they can be easily overlooked and destroyed.

Zoobenthic Indices

In Europe there are several EU directives requiring the development of biological indicators suitable to monitor the marine environment and assess its biodiversity. In this direction, different indices have been developed in order to assess the Ecological Quality Status of zoobenthic ecosystems. Among the indices used in Greece, there is the Shannon-Wiener Diversity (H'), the Species Richness (S) and a newer one called the BENTIX index.

The Shannon-Wiener Diversity (H') index measures a community's biodiversity, taking into consideration both the species richness within a community and the species evenness, hence how evenly individuals are distributed among these species (Simboura and Zenetos 2002). This is also the reason why this index has been very popular among marine ecologists. Table 4 shows the different types of ecological quality status based on the H' index, with the highest values indicating the most pristine environments.

Table 4: Ecological Quality Status based on Shannon-Wiener Diversity (H') Index

H' Index	Ecological Quality Status (ECoQ)	Pollution Classification
0 – 1.5	Bad	Azoic to very highly polluted
1.5 – 3	Poor	Highly Polluted
3 – 4	Moderate	Moderately Polluted
4 – 5	Good	Slightly Polluted (Transitional Zone)
>5	High	Normal (Reference Sites)

Source: (Simboura and Zenetos 2002)

A study made for Greek waters indicated that community diversity is lower in transitional waters; midlittoral sands, deltas and lagoons and higher in coarser sediments; mixed sands, coarse sands and coralligenous bottoms (Simboura and Zenetos 2002). Examples of two of the areas with the highest H' value and thus the highest Ecological Quality Status are Itea in muddy sands with an index value of 6.68 in 0.5 m^2 sample surface and Petalioi Gulf again in muddy sands with an index of 5.67 in 0.1 m^2 sample surface (Simboura and Zenetos 2002).

Then, the Species Richness (S) index measures the number of different species within a community. The main drawback of this index is that it does not take into consideration the abundance of the species, as the first index does, but it is useful when abundance data are not available (Simboura and Zenetos 2002). (Simboura and Zenetos 2002) cited an example about the shallow muddy sands of South Evoikos, showing the correlation between the species richness and the ecological quality status of the area, see Figure 6. As it can be seen from the figure, the increase of species richness coincides with an increase in the ecological quality of the area.

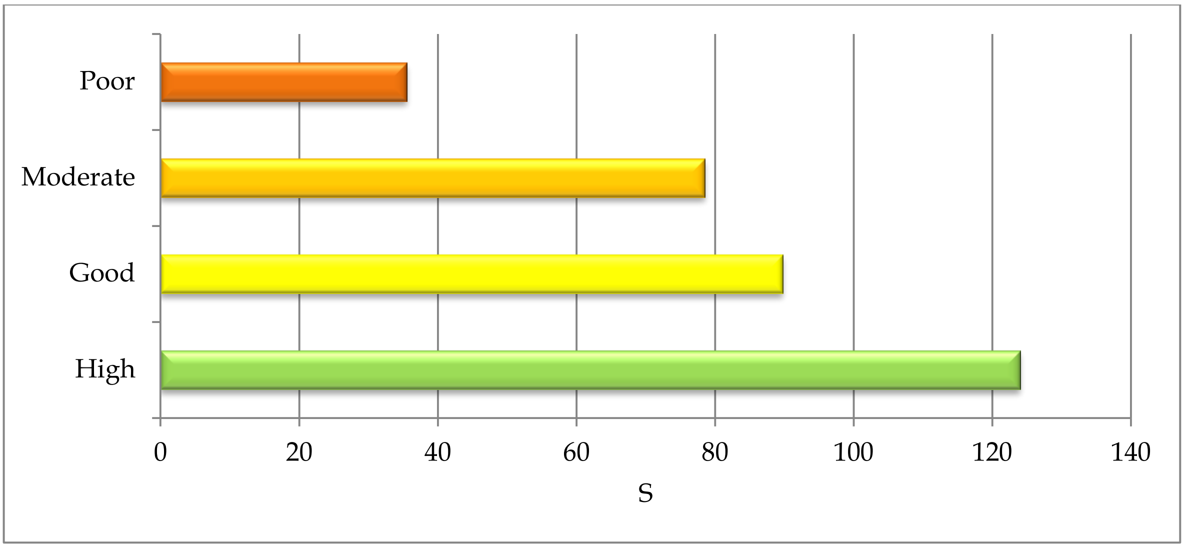


Figure 6: Species Richness (S) and Ecological Status (EcoQ) in South Evoikos (0.2 m^2 sample surface) **(Simboura and Zenetos 2002)**

Finally, the BENTIX index defines the Ecological Quality Status, by taking into consideration the relevant percentage of different species within a sample, species with different levels of sensitivity or tolerance to stress factors (Simboura and Reizopoulou 2007). More specifically, marine species are divided in two major groups, with Group I being the sensitive species that are less tolerant in any disturbance and Group II and III the tolerant, which are obviously tolerant species to most of disturbance or stress factors (Simboura and Reizopoulou 2007). The abundance of sensitive species is what defines the habitat type of the marine ecosystem. Moreover, as shown in Figure 7 from an application of the BENTIX index to numerous locations in Greek marine ecosystem, high abundance of sensitive species is also associated with high ecological status of an area. This is because the existence of sensitive species indicates the existence of cleaner waters without human intervention and disturbances, suitable for the sensitive species to survive.

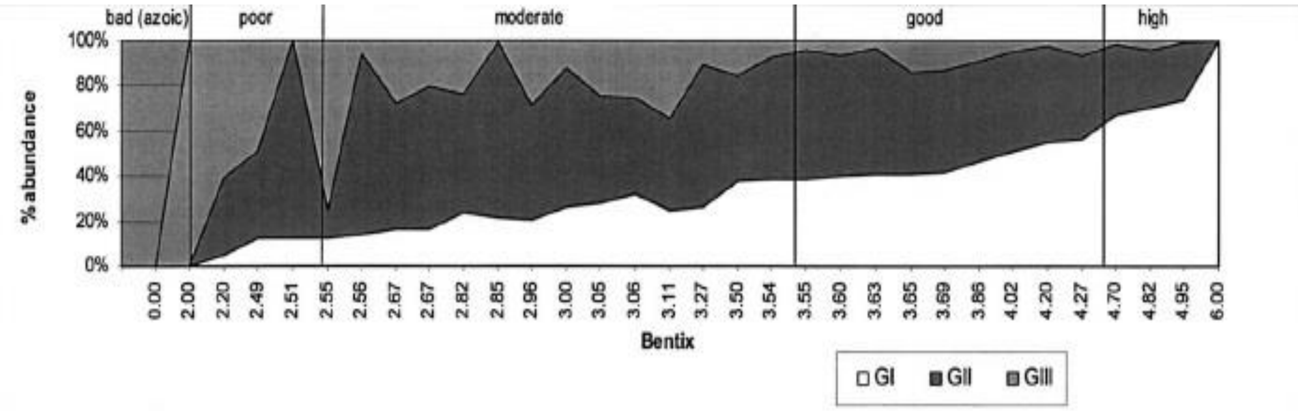


Figure 7: Degradation model of benthic communities health; illustrating percentages of ecological groups and BENTIX index values **(Simboura and Zenetos 2002)**

Table 5 shows the different types of ecological quality status based on the BENTIX index, with the highest values indicating the most pristine environments.

Table 5: Ecological Quality Status based on BENTIX Index

BENTIX Index	Ecological Quality Status (ECoQ)	Pollution Classification
0	Bad	Azoic to very highly polluted
2 – 2.5	Poor	Highly Polluted
2.5 – 3.5	Moderate	Moderately Polluted
3.5 – 4.5	Good	Slightly Polluted (Transitional Zone)
>4.5	High	Normal/Pristine

Source: (Simboura and Zenetos 2002)

It is worth mentioning that muddy bottoms host more tolerant species because the bottoms' morphological conditions favor nutrients concentration, increasing species tolerance (Simboura and Zenetos 2002). As a result for this habitat types the BENTIX index is reduced, as seen in Table 6, with again the highest values showing the most pristine environments.

Table 6: Ecological Quality Status of muddy bottoms based on BENTIX index

BENTIX Index	Ecological Quality Status (ECoQ)	Pollution Classification
0	Bad	Azoic to very highly polluted
2.5 – 3	Moderate	Moderately Polluted
3 – 4	Good	Slightly Polluted (Transitional Zone)
>4	High	Normal/Pristine

Source: (Simboura and Zenetos 2002)

Unfortunately, there are no available zoobenthic indices for the whole Greece showing the general picture of the ecological quality status of Greek waters, but only individual studies for different sites within the Greek Sea are available. Thus, in order for the ecological quality status of a specific area to be assessed, indicating the ecological importance and the level of protection that is required, data from existing studies shall be used or new studies for the individual study area shall be conducted.

Concluding, a careful monitoring of benthic fauna and flora shall take place in the potential areas for an offshore wind park installation in order to be determined whether the ecological status of the marine area is high, restricting the installation of an offshore wind park in order for the benthic ecosystems to be protected.

Impacts on fish

According to several studies that have been described by (Snyder and Kaiser 2009), fish could be affected during the construction phase of an offshore wind park, especially when support structures are embedded into the seabed. The degree of this effect is not clear and varies from temporal abandonment of the area, where the construction takes place, to mortality (Snyder and Kaiser 2009).

Furthermore, fish could be affected by electric and magnetic fields created by the underwater cables. In this case fish can be disoriented, losing their ability to detect their prey or migrate to other areas, a case that could threaten the viability of fish population (Snyder and Kaiser 2009).

On the other hand, the installation of offshore wind parks, and especially the turbines' support structure can function as new fish habitats, attracting new species. This can contribute to the benthic biodiversity, as well as enhance the local fishery. Of course, this might not always be the case because the existence of offshore wind installations may completely prohibit local fishery.

Greece has a large tradition in fishing- it is part of its culture and economy, as the country's morphological and climatic conditions favor aquaculture. However, fishery has become a crucial issue of concern for Greece due to overfishing and the rapid decrease of fish in the Greek Sea. As a result it is very important to ensure that the installation of an offshore wind park will not enlarge the problem. However, the fact that support structures may host new fishes and that fishing might be prohibited within and close to the offshore wind park, can actually contribute positively to fishes' diversity and protection. Obviously, the first possible solution to avoid overfishing is not the installation of an offshore wind park, but it is worth noting that such an infrastructure could also serve this purpose, under the condition that is proved not to be s threat for the rest of the marine environment.

Impacts on marine mammals

The impact that an offshore wind park can have on marine mammals is mainly due to noise creation during construction and operation. During the construction phase it is possible that marine mammals loss their hearing ability, especially when support structures are embedded into the seabed, generating high levels of noise. The noise of the construction phase can be audible to marine mammals for at least 80 km and can cause behavioral responses to marine mammals up to 20 km away (Snyder and Kaiser 2009).

During the operation phase, the noise made by the turbines can be audible to a distance up to 1 km and can affect marine mammals that use their hearing abilities in order to find food, or mammals that send and receive acoustic signals in order to communicate (Snyder and Kaiser 2009).

Greek Seas host six species of marine mammals, most of which are characterized as endangered species, requiring protection. More specifically, according to (Legakis and Maragkou 2009) these species are the following:

- Mediterranean Monk Seal Monachus-Monachus; a critically endangered species, widely spread throughout coastal Greece
- Common Dolphin; an endangered species that mostly occur in water depths up to 200 m
- Sperm Whale; an endangered species that mainly occurs in very deep waters all over Greece
- Risso's Dolphin; a vulnerable species that occurs in depths from 200m to 1700m
- Striped Dolphin; a vulnerable species that occurs in deep waters and is the most common of the Greek sea
- Common Bottlenose Dolphin; a vulnerable species that occurs around most of the Greek islands, as well as within straits and gulfs

The existence of these endangered species in Greek waters requires that a careful study is conducted before the installation of an offshore wind park, monitoring the existence of marine mammals, which will assess the suitability of the potential location for the park.

Bird interaction with wind turbines

Bird population can be affected from offshore wind turbines both directly and indirectly. The most obvious direct effect is the avian mortality through collisions. Studies have estimated that the death rate could range between 0.95 to 11.67 deaths per MW per year (Strickland and Johnson, 2006 *in* Snyder & Kaiser, 2009).

The main indirect effect of offshore wind parks to birds is their potential ousting from feeding and roosting habitats. This happens in the case that the parks are installed in rookeries and feeding areas, which might no longer be accessible to birds, due to their effort to avoid passing through the wind park (Hederson, 2003, Drewitt & Langston, 2006 *in* Snyder & Kaiser, 2009). This can be considered as a fairly important problem as many birds are habitat-specific and often susceptible to habitat changes (Manwell, Mcgowan and Rogers 2009). Any displacement of birds from the areas where the offshore wind park is installed is equivalent to bird habitat loss.

A second indirect effect is on migrating birds, as offshore wind parks might be installed in zones with bird migration corridors. In this case birds need to alternate their migration paths and habitats, with the possibility of being disoriented.

In Greece an effort has started since 2007 in order for important bird areas to be identified and especially areas for the Mediterranean Shag and the Audoin's Gull, which are two of the priority endemic species which are present in Greece during the breeding season (Hellenic Ornithological Society 2013). Until now, 17 marine areas have been identified as having the largest population of these two species, thus the installation of an offshore wind park within one of these areas shall be examined carefully in order to be ensured that it will not affect these vulnerable species.

3.4 Offshore Wind Park Sitting Criteria in Greece

As briefly mentioned in the Introduction, Greece has only made a few initial steps towards offshore wind development. These first steps have been taken in 2010 with the passing of Law 3851/2010, which is aiming at facilitating the development of many renewable energy sources, including the offshore wind energy. Based on this Law, the Greek government conducted an initial study indicating twelve areas which were considered as the most suitable for offshore wind park installation, but as mentioned in the Introduction, this study was based on very limited criteria, even less that what the Special Spatial Framework, of Law 2464/2008, requires. So, at this point it is useful to present the criteria used in the initial study made by the Greek government, as well as the criteria that have been set by Law 2464/2008.

The initial study made by the Greek government was first presented in the 6th of July 2010, at energy agencies, companies, representatives of ministries and NGOs. The criteria that have been used for the implementation of this study, as presented, are the following:

- Exclude obvious areas, where the development of offshore wind parks is incompatible with other sea use
- Remain within the borders of the territorial waters, i.e. within 6 nautical miles from shore for any offshore wind project
- Ensure technical feasibility of installing offshore wind turbines in the specific areas chosen (mainly ensure a maximum of 50 m of sea depth)
- Avoid areas with important consequences for the environment (mainly avoiding NATURA 2000 areas or other well-known protected areas)
- Minimize the visual impact

While these criteria are quite few and somewhat unspecified, the Special Spatial Framework, of Law 2464/2008, defines specific site selection criteria for offshore wind parks by indicting incompatibility and exclusion zones, within which offshore wind parks sitting is prohibited; determining specific distances to ensure the smooth functionality and performance of offshore wind installations, as well as the smooth incorporation of the installation to the environment; and determining the maximum allowable density of offshore wind park installation, in order to avoid their dominance over other marine uses.

Incompatibility and exclusion zones

According to the Special Spatial Framework, of Law 2464/2008, the sitting of an offshore wind park shall be prohibited within specific zones, for different reasons such as technical, social or environmental incompatibilities. The purpose of this prohibition is the harmonious integration of an activity to the natural and human environment by avoiding conflicts with other marine uses and to prevent negative effects, such as visual disturbance. Thus, the sitting of an offshore wind park is prohibited within a certain distance from:

- Declared monuments of world cultural heritage and other monuments of major importance, as well as archaeological zones, which are defined from the existing provisions
- Sites of nature conservation
- National parks, declared monuments of nature and aesthetic forests
- Protected areas of NATURA 2000 network
- Zones of organized tourism development, productive activities of the tertiary sector development, theme parks and ports
- Sandy shores and established swimming coastlines
- Established passenger shipping lines

Distances from incompatible marine uses

The specific site of an offshore wind park installation requires compliance with the minimum distances from neighboring marine uses, activities and technical infrastructure networks. These distances result from the existing institutional framework, technical specifications of the wind turbines and the relevant international experience, adjusted to the specific characteristics of the Greek seas. These distances aim at ensuring a smooth operation and maximum efficiency of the installed wind park and minimizing any impacts on neighboring incompatible marine uses, activities and infrastructure networks.

In Greece, due to the specific characteristics of marine areas, the determination of distances from incompatible marine uses shall be based on the sea's morphology, the density of marine uses and the range of areas of environmental and cultural interest. More specifically:

Table 7: Minimum distance of an offshore wind park from other marine or land uses

Incompatible marine use	**Minimum distance of offshore wind park from the incompatible marine use**
Distances from areas of environmental interest	
National parks, declared monuments of nature and aesthetic forests	200 m
Swimming coastlines, included in the monitoring program of bathing waters quality	1500 m
Distances from cultural heritage sites	
Declared monuments of world cultural heritage and other monuments of major importance, archaeological sites and historic places, subject under the law 3028/2002	3000 m
Absolute protection zone of other archaeological sites	7d, where *d* is the diameter of the wind turbine's rotor, minimum distance 500 m
Other cultural monuments and historic places	7d, where *d* is the diameter of the wind

	turbine's rotor, minimum distance 500 m
Distances from residential activities	
Towns and settlements of >2000 inhabitants and settlements of <2000 inhabitants, characterized as touristic	1000 m from the settlement's border
Settlements of <2000 inhabitants, not characterized as touristic	500 m from the settlement's border
Traditional settlements	1500 m from the settlement's border
Monastery	500 m from the monastery's border
Distances from technical infrastructure networks	
Roadway, roads and railway lines	Safety distance 1.5 d from the borders of the expropriation zone
High voltage lines	Safety distance 1.5 d from the borders of the lines
Telecommunication infrastructures (antennas), RADAR	Not specified
Aviation installations and activities	Not specified
Distances from production activities	
Fish-farming	Safety distance 1.5 d
Areas of organized tourism development, production activities of the tertiary sector development, theme parks, ports and tourist accommodations and infrastructures	1000

4. OFFSHORE WIND PARK MICROSITTING FACTORS

After acquiring the knowledge about the relevant factors that can affect the installation of an offshore wind park in a region, based again on the methodology used to address the main research question, it is useful to also investigate the relevant technical issues that can affect the final installation of the park and this the aim of this Chapter. However, due to the fact that technical choices are very much based on economics, the economic aspects of the installation of an offshore wind park are also investigated.

4.1 Wind Turbines and Optimum Distance

The decision about the exact size of the wind turbines that should be used for an offshore wind park depends on the particular wind and bathymetrical conditions that occur in each study area. However, as mentioned in the Introduction, it is worth noting that with the development of offshore wind park projects, the relevant technology has been developed as well, allowing bigger offshore wind turbines to be installed even in deeper waters.

Starting in the 90s, offshore wind turbines of just 1 MW average capacity were installed, followed by 2MW in 2003 and 3 MW in 2005. Today offshore wind turbines of up to 5 MW capacity are installed, while prototypes of 7 MW and higher are also tested (Kaldellis and Kapsali 2013).

The high water depth that occurs in the Greek Sea favors the installation of support structures able to support larger wind turbines. In combination with the good wind potential of the country, the installation of bigger wind turbines, of 5 MW, can be considered very favorable, thus allowing higher energy outcome.

After defining the size of the wind turbines, it is very important to set the distance between them in order to achieve the highest energy production and still remain within the area found as the most suitable for an offshore wind park installation. Typically, the distance between offshore wind turbines ranges among 6D and 10D (where D the rotor diameter). However, this is not a fixed distance and needs to be adapted based on the specific characteristics of each offshore wind park. For instance, an informal standard distance applied to offshore wind parks in the North Sea is 6DX8D, in order to reduce wake effects and thus achieve higher park efficiency (Jacques, Kreutzkamp and Joseph 2011).

The wake effect is the result of the wake that is left behind a wind turbine. Specifically, when a wind turbine extracts energy from the wind, it leaves behind a wake by reduced wind speed, which is utilized by the downstream wind turbines, producing less energy than what they would produce individually in a free stream. The wake behind the wind turbines is illustrated as a cone in Figure 8.

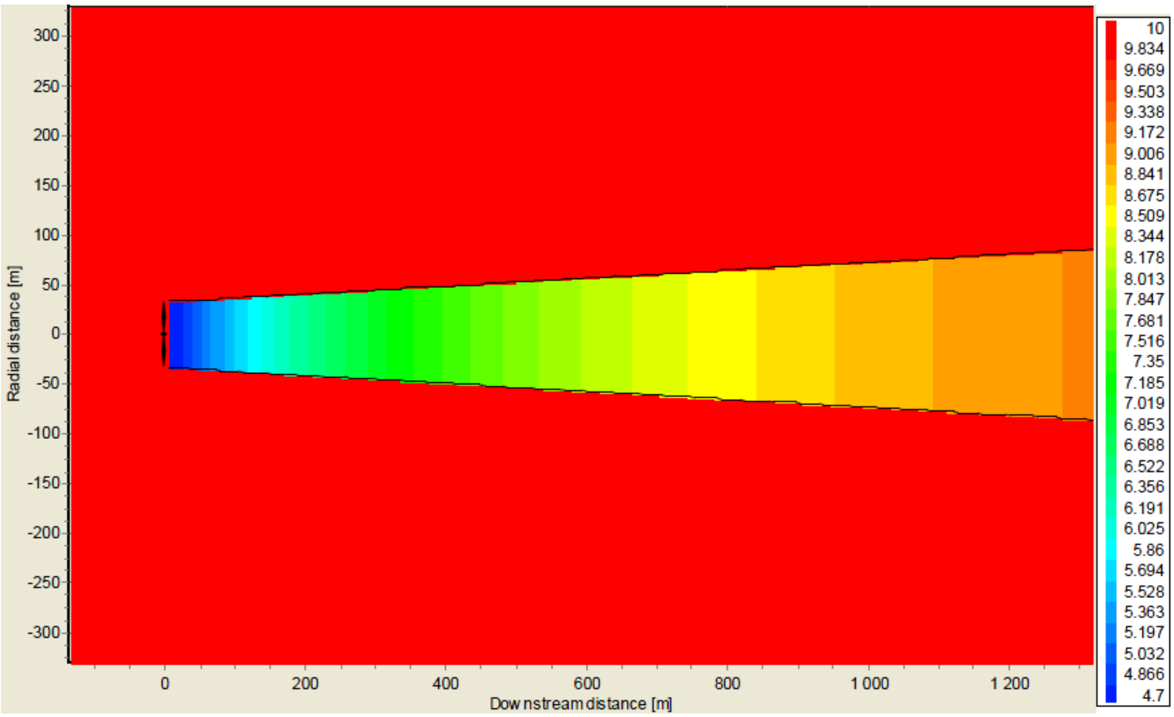


Figure 8: Wake effect behind a wind turbine **(EMD 2010)**

As it can be seen in the figure, although the wind speed of the area is 10 m/s, due to the wake effect, the wind speed behind the wind turbine is reduced to 4.7 m/s and it returns back to normal at higher than 1.5 km away from the wind turbine, which would correspond to 12D distance between offshore wind turbines with rotor diameter 126 m. However, such a distance between the wind turbines might not be the most efficient solution, especially when working within a limited area, as it limits the number of wind turbines that can be located.

Knowing the wind direction it can facilitate the decision about what distance to be applied between the wind turbines, with the ultimate target to reduce wake effects and achieve high park efficiency. Normally, a higher distance between the turbines should be applied to those located horizontally to the wind direction, as they will have higher wake effect, and a lower distance to those located vertically to the wind direction.

4.2 Support structures

For the installation of offshore wind turbines in different depths and distance from the shore, a key role plays the support structure that is used, the main infrastructure that differentiate from onshore wind parks.

Besides the water depth and the shore distance, there are also other criteria that need to be considered when deciding on the most appropriate type of support structure to be used for offshore wind turbines in a specific area. These criteria are the wave conditions, the specific characteristics of the seabed, the potential consequences on the marine environment, the turbine characteristics, the technical and commercial risk factors and the proximity in the electricity grid

(The European Wind Energy Association 2011). Figure 9 shows the different structures currently available, in relation to the depth in which they can be employed.

Figure 9: Different support structures for offshore wind turbines in relation to maturity and water depth **(Kaldellis and Kapsali 2013)**

As it can be seen from the figure, several support structures for offshore wind turbines have been developed, which however are currently in different technological status. Generally, the support structures are divided into the ones for shallow water, transitional water and deep water, which are further described below.

Until now, many different support structures have been used, with the most prominent being the monopile in water depths of less than 20 – 25 m, due to the fact that this type of foundation has an easier production and installation phase and lower cost (The European Wind Energy Association 2011). Then, gravity-based structures have also been used in many offshore wind projects because they are also appropriate for shallow waters and are quite easy to produce (Kaldellis and Kapsali 2013) and (The European Wind Energy Association 2011). Finally, the so-called space-frame structures (jackets, tripods and tripiles) have also been used so far, but in a much smaller quantity than the others.

Monopiles

Starting off with the most popular support structure of shallow water (up to 30 m), the monopiles are tubes made of steel, with a diameter of 2.5 to 4.5 m (Manwell, Mcgowan and Rogers 2009). Depending on the soil conditions, monopiles are embedded from 3.5D to 8D (where *D* is the diameter of the monopile) into the bottom of the sea; 3.5D to 4.5D in stiff clay, 6D in average soil and 7D to 8D in soft silt (Lehmann 2007). Normally, no seabed preparation is required for monopiles to be installed, but locations with large boulders are usually not appropriate (Manwell, Mcgowan and Rogers 2009).

The main drawback of this support structure is the high noise level during installation, than can affect fish and marine mammals, but on the other hand, it is an easy and simple to construct support structure, for which there is already high technological experience (Chaviaropoulos και Rossis 2009).

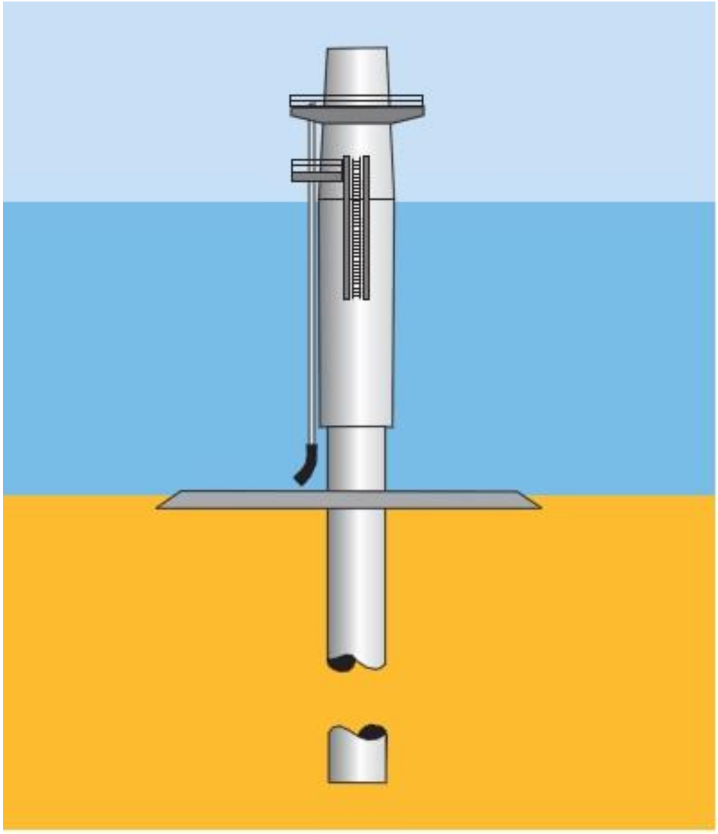


Figure 10: Monopile support structure **(The European Wind Energy Association 2011)**

<u>Gravity-based structures</u>

These support structures are stable in all environmental conditions, but only appropriate for water depths up to 40 m. They are based on gravity, and that is why they utilize a heavy base with a diameter of 12 to 18 m, which is filled by reinforced concrete, steel, rock or pumped-in sand (Manwell, Mcgowan και Rogers 2009) and (The European Wind Energy Association 2011).

In order for these structures to be installed, seabed preparation is necessary in order for the ground to become uniform and level, which is one of the main drawbacks. Also, it is a heavy equipment to transport. However, this type of support structure cause low noise level during installation and it is quite affordable in comparison with other support structures (Chaviaropoulos and Rossis 2009).

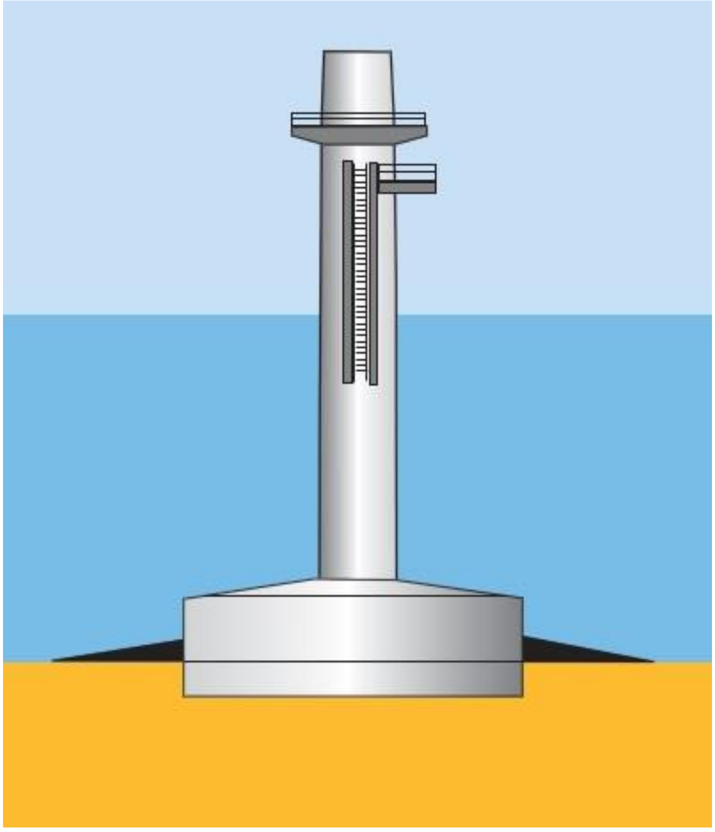


Figure 11: Gravity-based support structure **(The European Wind Energy Association 2011)**

Moving on with the space-frame structures (tripods and jackets), are type of foundations suitable for deeper waters of 30 to 60 m (Wilhelmsson, et al. 2010) and they usually require minimal seabed preparation (Manwell, Mcgowan and Rogers 2009). As with the monopiles, this type of structure is not recommended for areas with large boulders (Lehmann 2007).

Tripods

They are three-legged support structures of cylindrical steel tubes (The European Wind Energy Association 2011), which are appropriate for water depths from 20 to 50 m. As with the monopiles, tripods are also embeeded into the bottom of the sea, but the penetration depth and the width of the base depend on the environmental and seabed conditions (The European Wind Energy Association 2011). Since they require to be embeeded into the bottom, may cause high noise levels affecting fish and marine mammals. They are also quite difficult to be constructed and transported on site (Chaviaropoulos and Rossis 2009). However, these support structures are very durable and appropriate for big and heavy wind turbines (Chaviaropoulos and Rossis 2009).

Jackets

These support structures are appropriate for water depths of 30 m and more, and they also require to be embeeded into the seabed (Chaviaropoulos and Rossis 2009). Despite the fact that they need to penetrate the seabed, according to (Chaviaropoulos and Rossis 2009), they do not cause high noise levels during installation and as with tripods, they are appropriate for big heavy wind turbines. On the other hand, they are quite expensive structures, require a long tme for installation and can be affected by extreme wave conditions (Chaviaropoulos and Rossis 2009).

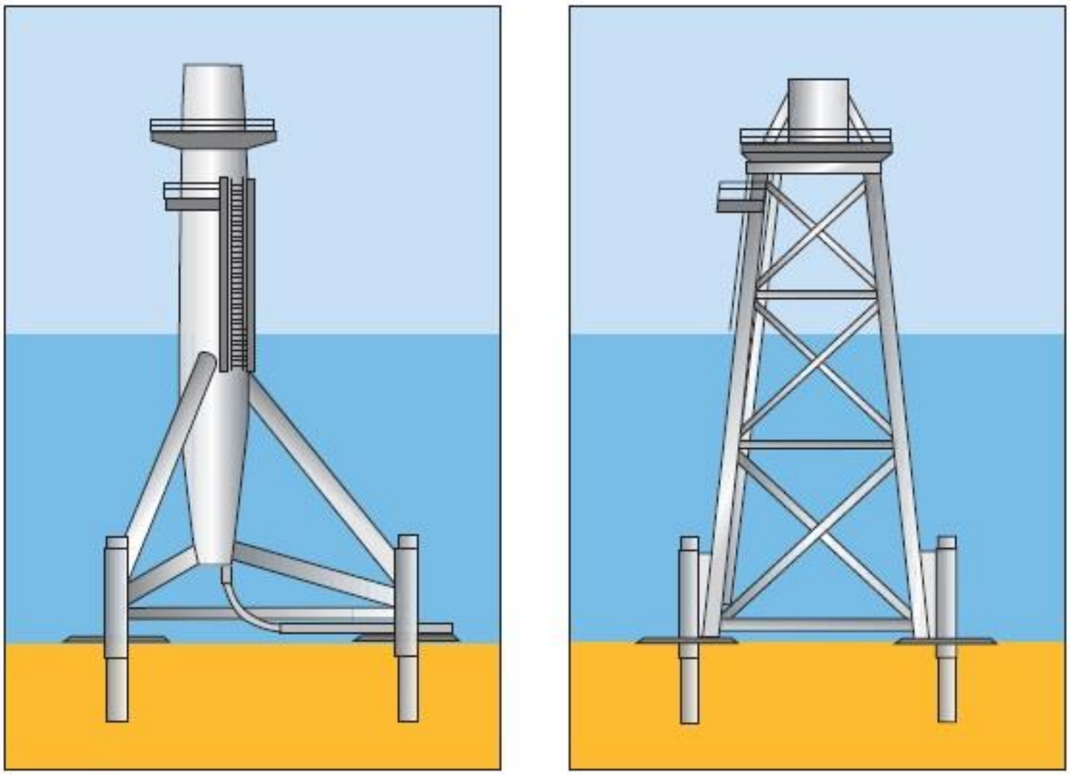


Figure 12: From left to right: Tripod and Jacket **(The European Wind Energy Association 2011)**

As mentioned in the previous Chapter, Greek Sea is characterized by an abrupt increase in water depth, which starts very close to the shoreline. Thus, the installation of an offshore wind park that coincides with the average water depth and distance from shore of European offshore wind parks, is not an option in Greece.

As a result, based on the special characteristics of Greek Sea and the technological review, conducted above, it seems that the most appropriate support structure for the wind turbines of an offshore park in Greece is the Tripods and Jackets, which are suitable for waters of 30 m and more. However they are quite expensive structures and require a long tme for installation, characteristics that need to be considered in a techno-economic analysis. Tripods compared to Jackets may cause high noise level, negatively affecting fish and marine mammals. Jackets can be affected by extreme wave conditions, but this is not an issue of concern for Greece, since the wave conditions are not so extreme in Greek Seas, compared to the North Sea for exmaple (Athanasopoulos 2013). This can also contribute positively to the operation and maintenca costs, which can be very high especially during winter in places with extreme wave conditions.

4.3 Economics

According to (Hederson, et al. 2003), offshore wind energy projects require significantly higher capital cost compared to onshore projects, mainly due to turbine support structures and electric infrastructures. According to the same source, the capital cost of an offshore wind energy project is usually divided into the following shares:

- Wind turbines 45%
- Support structures 25%
- Electric infrastructure 21%
- Installation and engineering costs 7%
- Project management 2%

Although the investment costs have been reduced since the beginning of offshore wind activity, they are still high compared to onshore projects. Thus, the capital cost of offshore wind energy projects is estimated to be between 1300-3700 €/kW, while the capital cost for onshore projects is lower and ranges between 1100-1500 €/kW, although it can be even lower due to cheap labor, grid connection, upgrade issues etc. (Kaldellis and Kapsali 2013).

Table 8 shows the potential costs of an offshore wind park, as estimated by EWEA, the accounting firm Ernst & Young and according to the actual costs of the 207 MW offshore wind park "Rødsand II" in Denmark.

Table 8: Estimated costs for offshore wind parks (€/kW)

	EWEA	Ernst & Young	Rødsand II
Wind Turbines	815	1725	1329
Support Structures	350	805	400
Electric Infrastructures	355	690	-
Other	160	40	-
TOTAL	1680	3680	2077

Source: (Chaviaropoulos and Rossis 2009)

Regarding the operation and maintenance (O&M) costs, these vary among different locations and as a result different depths, distance to shore, wave conditions, wind speeds, salinity etc., but according to some rough estimations is double than the O&M cost of an onshore wind park and is about 34 €/MWh, see Table 9.

Table 9: Estimated operation and maintenance cost of offshore wind parks (€/MWh)

	Onshore	Offshore
Wind Turbines Maintenance	7	19
Network Cost	2	3
Insurance	3	4
Land/Sea Leasing	2	2
Decommission	1	6
TOTAL	16	34

Source: (Chaviaropoulos and Rossis 2009)

Besides the average potential costs, presented above, which are roughly estimated by different organizations, such as the EWEA or the Ernst & Young, there are also cost functions derived from various sources, which can be used to calculate the cost of the support structures, the installation, the operation and maintenance. The costs resulted from these functions are more accurate than the estimations because they are based on the characteristics of each offshore wind project, including the distance from shore and the water depth. These cost functions are presented below, as derived from (Möller , et al. 2012).

Support Structure Cost (C_f): The foundation cost in €/MW as linear function of the water depth (d) in negative meter values.

$$\mathbf{C_f = -14557 * d + 270667} \quad (1)$$

Installation Cost (C_{ins}): The cost for installing a wind turbine in €, including the cost for renting an installation vessel daily, and the distance (d) from a major supply harbor in meters.

$$\mathbf{C_{ins} = 0.114 * d + 25000} \quad (2)$$

Operation and Maintenance Cost (C_{om}): The operation and maintenance cost in €/MWh net electricity production, as linear function of the distance (d) from shore in meters.

$$\mathbf{C_{om} = 0.00026 * d + 17}, \textit{ if } d < 50000 \; m \quad (3)$$

$$\mathbf{C_{om} = 0.0001 * d + 25}, \textit{ if } d \geq 50000 \; m \quad (4)$$

Finally, additionally to calculate the individual costs of an offshore wind park, it is also useful to calculate the Net Present Value (NPV) of the overall investment in order to assess the economic feasibility of the offshore wind energy project. The NPV takes into consideration all payments relating to the investment, both the positive and negative cash flows, as well as the discount rate to the temporal distribution of the payments (Lund and Østergaard 2010) and it can be calculated with the following expression:

$$\mathbf{NPV = NP * \{ [1 - (1 + i)^{-n}] / i \} + I} \quad (5)$$

Where
NP: the annual net payments (positive and negative cash flows)
n: the project's lifetime in years, which is assumed to be 20 year for offshore wind parks (RWE 2013)
i: the discount rate
I: the initial investment payment (wind turbine, support structure, installation and electric infrastructure cost)

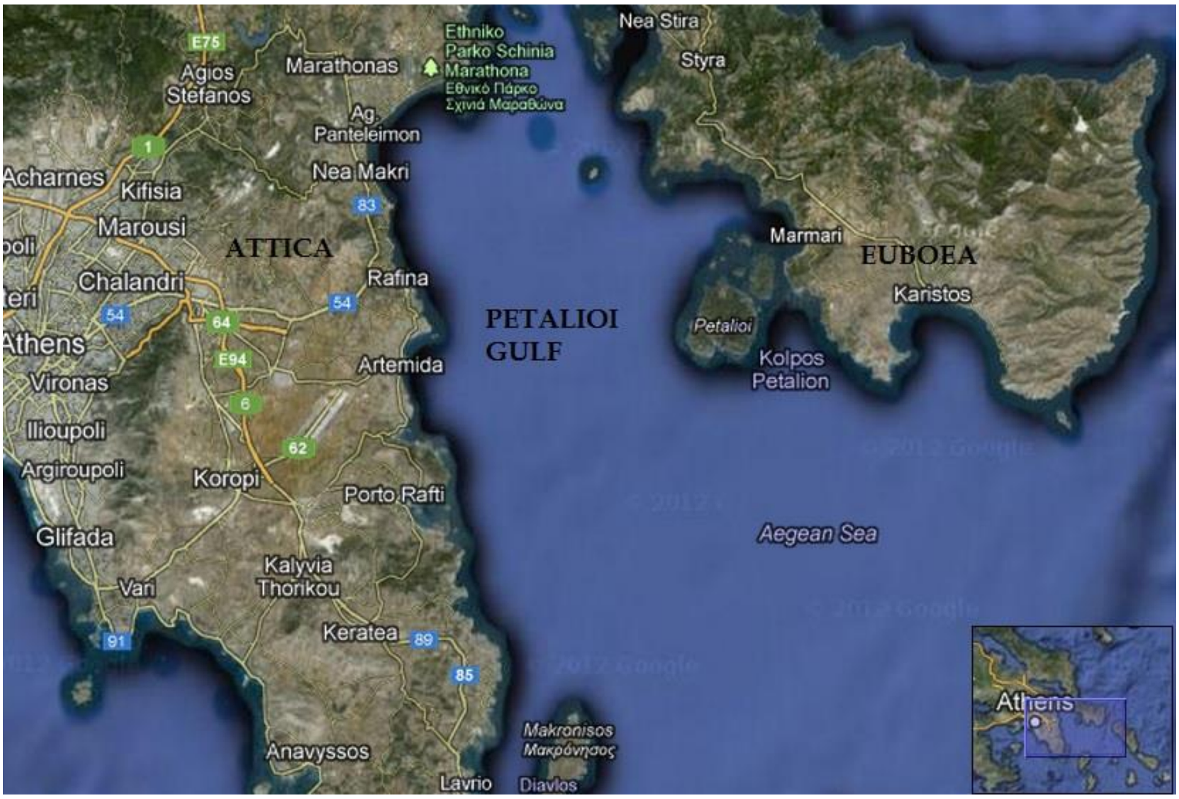
Part 2
Case Study: Offshore Wind Development in Petalioi Gulf, Greece

5. OFFSHORE WIND PARK SITTING IN PETALIOI GULF

After theoretically examining the relevant factors that can affect offshore wind park sitting, i.e. physical, spatial and environmental, this chapter is aiming at approaching the research question empirically. More specifically, it aims at investigating what are the physical, spatial and environment characteristics of Petalioi Gulf and how they can affect the sitting of an offshore wind park in this region. This means that the different characteristics of Petalioi Gulf have to be spatially identified, wherever that possible, in order for the appropriate sitting criteria to be applied to them. The sitting criteria are either based on the requirements set by the Greek Special Spatial Framework of Law 2464/ 2008, or based on the knowledge gained by an extensive literature review, which is presented in Chapter 3.

5.1 Study Area: The Petalioi Gulf

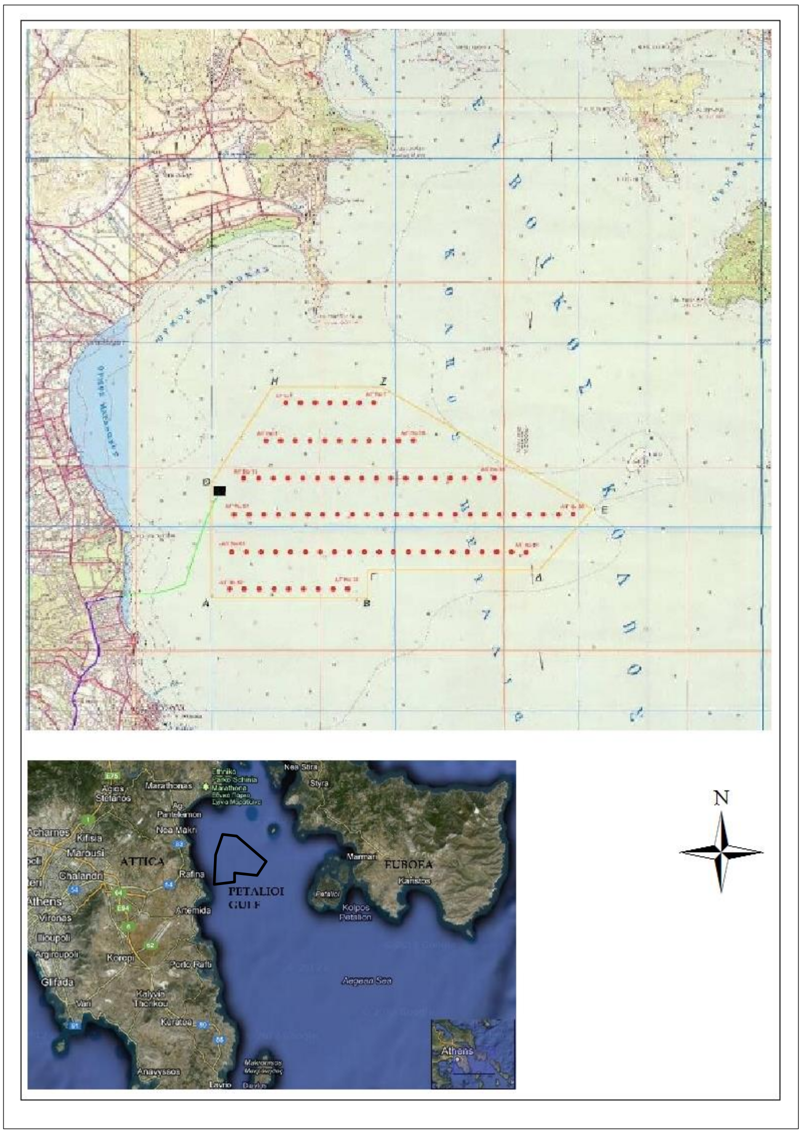
Petalioi Gulf is located in the Aegean Sea of Greece, extending from the east coast of Attica to the southwestern part of Euboea, see map 3. The length of the Gulf is approximately 50 km from North to South and its width is approximately 5 km in the North and 50 km in the South.



Map 3: Petalioi Gulf location in Greece **(Google Maps 2013)**

The Petalioi Gulf is one out of the twelve areas identified by CRES as one of the most appropriate areas for offshore wind development, due to its good wind potential, bathymetry and grid connection to the mainland.

Besides the governmental study that revealed Petalioi Gulf as an area with good potential for an offshore wind park installation, the same area was identified by the private company "TERNA-Energy", which proposed the installation of an offshore wind park of 450 MW capacity, consisting of 90 wind turbines with 5 MW rated power each, located at a maximum distance of 12 km from the Attica's shoreline. The proposed park was calculated to produce about 1226 GWh electricity per year and its cost was calculated to be 1.6 billion € (3.5 million €/MW), a cost that coincides with the cost estimations of the accounting firm Ernst & Young, as seen in Table 8. The Map that follows indicates the location where TERNA-Energy proposed the installation of an offshore wind park.



Map 4: Proposed location for an offshore wind park in Petalioi Gulf, from TERNA Energy

Although Petalioi Gulf is an area for which two studies for an offshore wind park sitting have already been taken place, both the governmental study the one made by TERNA-Energy were based on limited sitting criteria, mainly techno-economic. However, this study seeks to remain uninfluenced by the existing studies, attempting to use more sitting criteria than the already used ones, wherever that is possible.

5.2 Physical Characteristics

To begin with, examining the wind potential of Petalioi Gulf, it seems that it is as high as presented in map 1. As described in Chapter 3, wind data can either derive directly from wind masts or can be modeled based on a range of climatic data for a region. For Petalioi Gulf, since there was not available data from wind masts, modeled data were used. The data used are Meso scale data, modeled by EMD and ConWx based on interim data from ECMWF, the European Center for Medium Range Weather Forecasts. The EMD-ConWx Meso data are calculated with hourly temporal resolution.

Based on the Meso scale data for 2012, the mean wind speed at a height of 100 m is found to be about 8.2 m/s. Table 11 shows the monthly mean wind speed of this year.

Table 10: Monthly Mean Wind Speed in Petalioi Gulf in 2012

MONTH	MEAN WIND SPEED (m/s)
January	8.92
February	8.22
March	7.93
April	7.55
May	6.10
June	9.70
July	9.44
August	8.98
September	8.51
October	7.26
November	8.64
December	7.27

Data Source: (EMD and ConWx 2013)

In addition to knowing the large wind potential of the study area, it is equally important to know the joint wind speed and direction distribution. Figure 13 indicates the wind speeds and direction distribution for Petalioi Gulf, revealing the dominance of north and north-northeast winds.

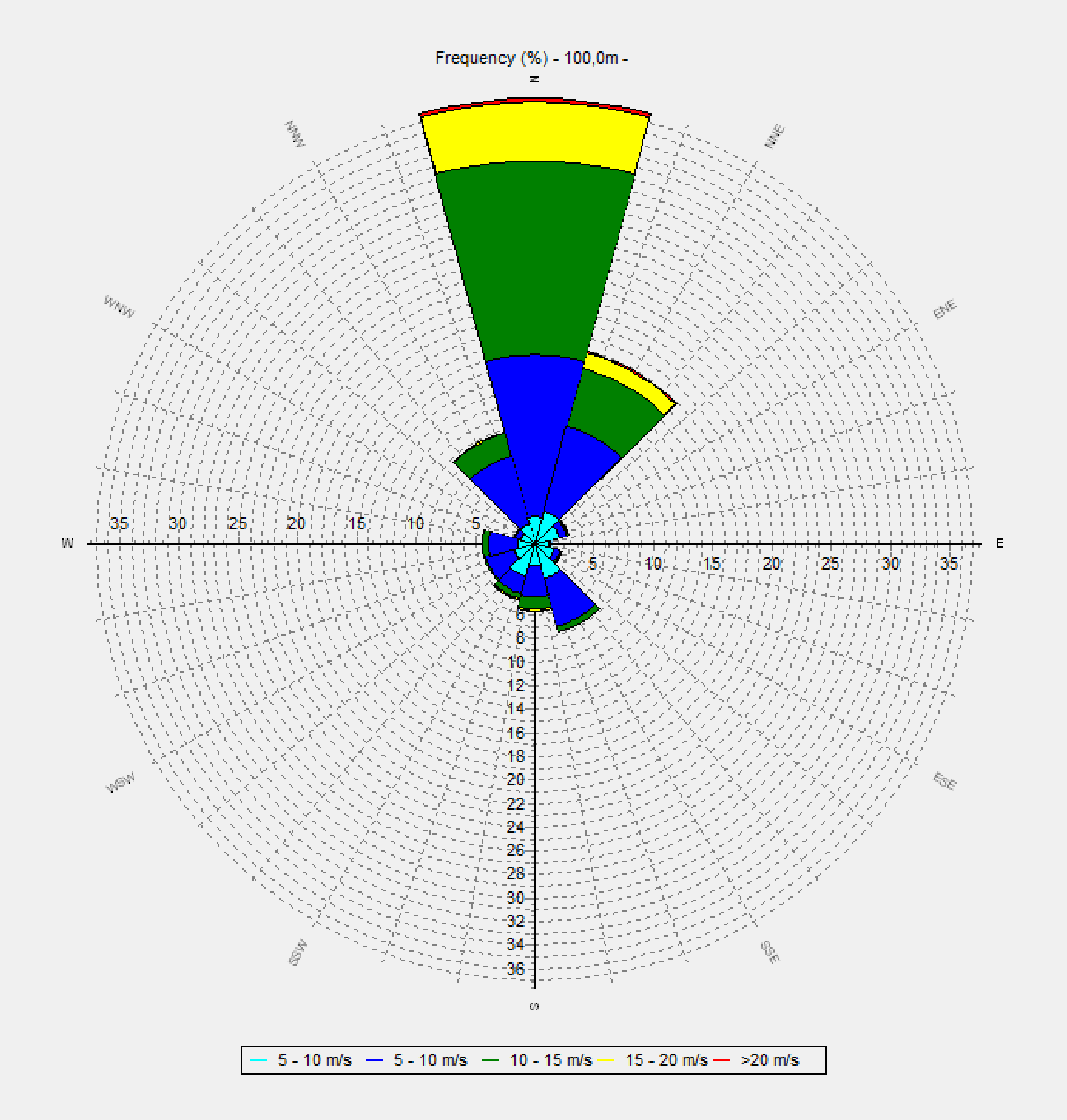


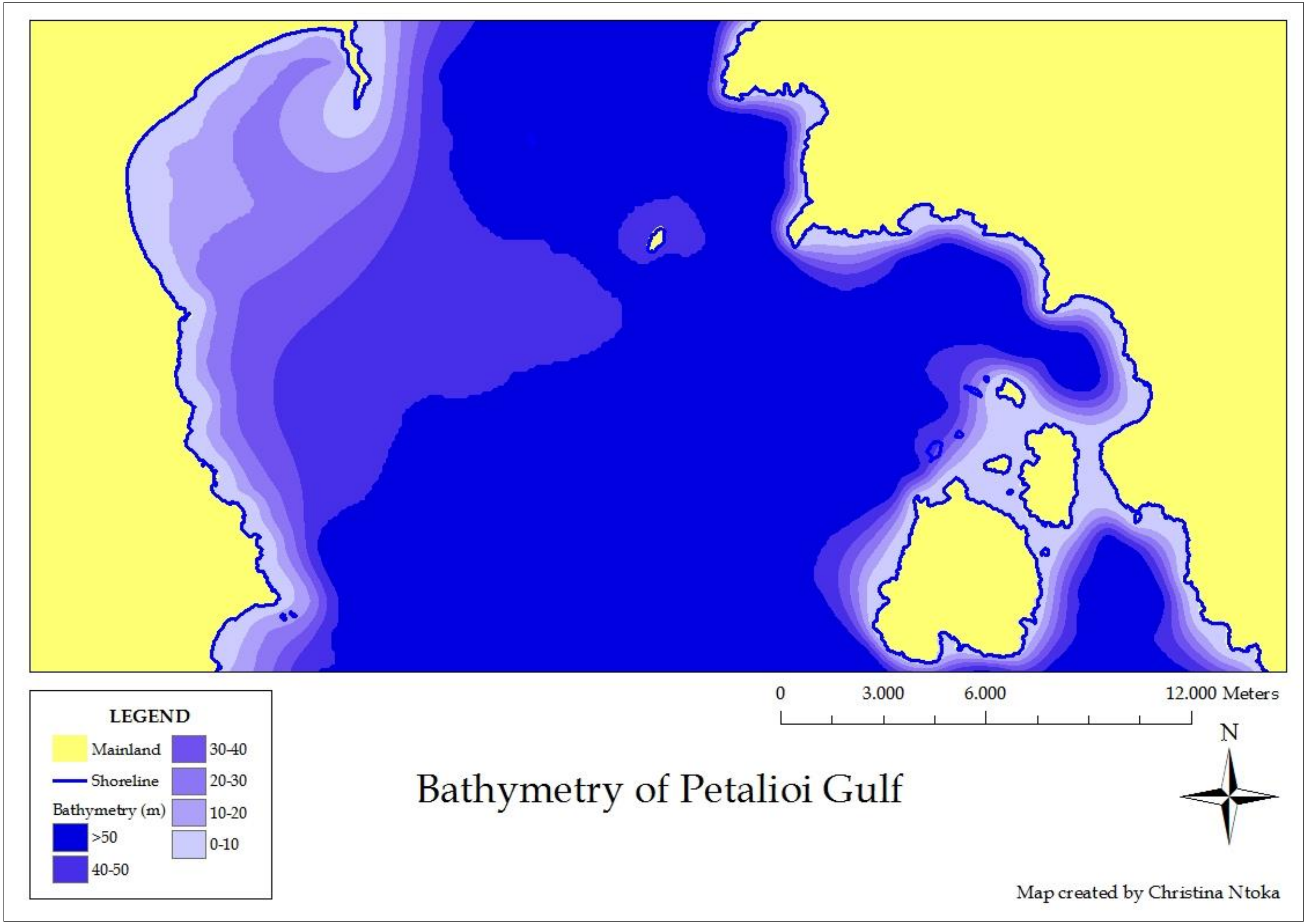
Figure 13: Wind rose for Petalioi Gulf **(EMD and ConWx 2013)**

Since the wind potential is indeed very favorable for the installation of an offshore wind park, the next physical characteristic that needs to be examined is the bathymetry. The western part of Petalioi Gulf is characterized by low depth at a large distance from shore. Specifically, as seen in map 3, a depth of 50 m can be found at a maximum distance of about 12 km. However, there are also parts of the western part of the Gulf where a depth of 50 m exists at a distance of just 1.5 km from shore, but this is not the case in most of the western part of the Gulf. On the other hand, the eastern part of the Gulf is characterized by high depth at a relatively small distance from shore. More specifically, a depth of 50 m can be found at a maximum distance of about 3.5 km from the shoreline, limiting the potential for an offshore wind park installation in this part of the Gulf, since the maximum depth is set at 50 m from shore, as also described below.

<u>Sitting Criterion</u>

Due to the fact that the study area is a marine area with no physical obstacles, it is assumed that the wind conditions are very similar in each location of the study area. Thus, at this point, there is no spatial sitting criterion to be applied for the wind speed and it is assumed that the Meso scale point wind data that were examined for Petalioi Gulf, apply to the whole study area.

Regarding the sitting criterion for the water depth, this study is limited on water depths up to 50 m for the installation of an offshore wind park. Although the installation to water depths less than 30 m could be considered as a more feasible solution from a techno-economic perspective compared to the installation in deeper waters, the morphology of Greek sea with the abrupt increasing water depth significantly limits the areas with shallow waters, which anyway are located very close to the shore, restricting the installation of an offshore wind park in order for any conflict with other land or marine uses to be avoided. As a result, inevitably the installation of an offshore wind park has to be considered in water depths higher than 30 m, but not higher than 50 m, since, as also mentioned in Chapter 3, the technical experience for such depths is in a very early stage and the installation is associated with very high costs. The dark blue area in Map 5 indicates the area where the water depth is greater than 50 m, thus the area where the installation of an offshore wind park shall be restricted.



Map 5: Bathymetry of Petalioi Gulf

5.3 Spatial Characteristics

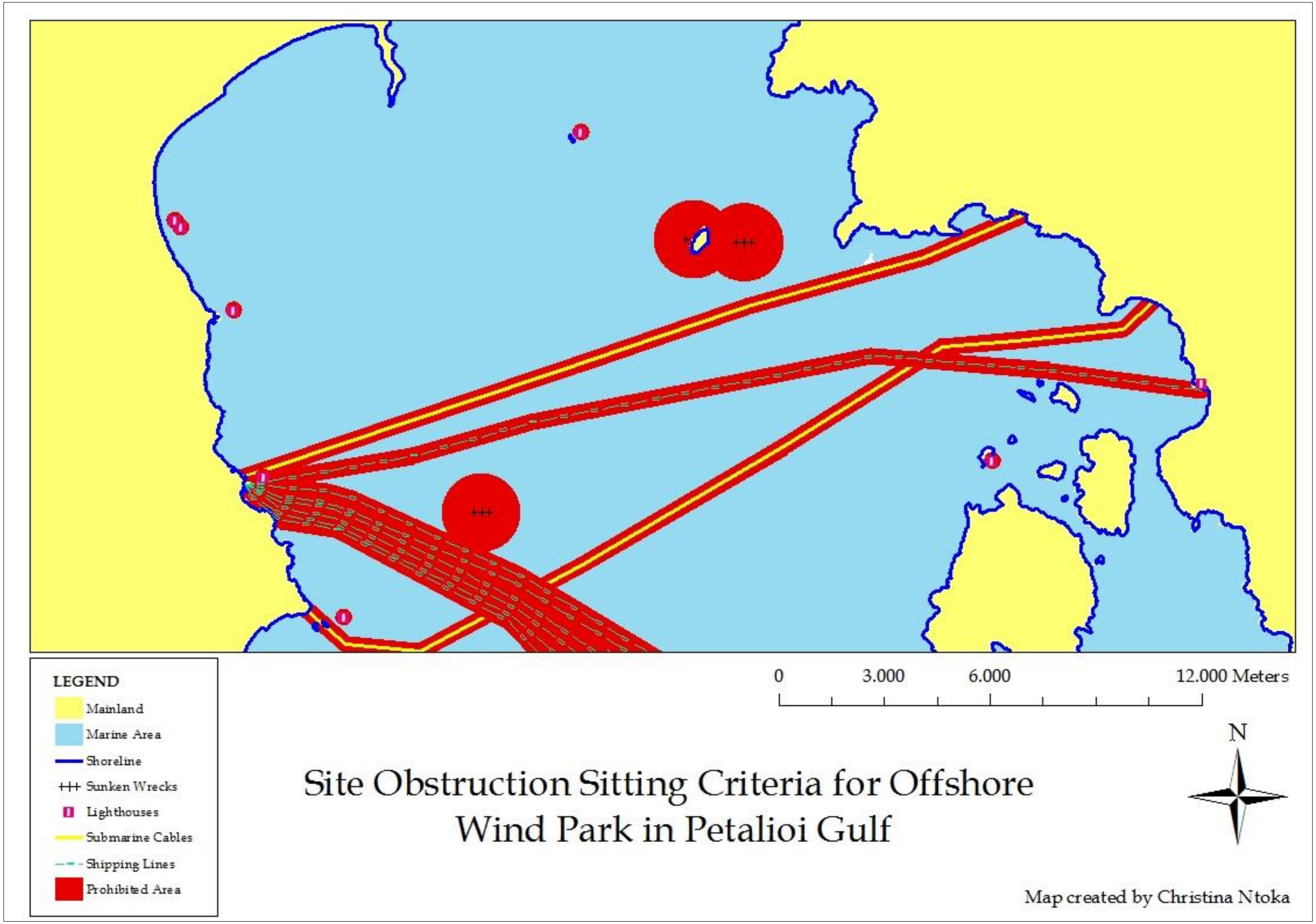
Studying the nautical chart of Petalioi Gulf, a moderate amount of site obstructions occurs, restricting the installation of an offshore wind park, within a specific distance from them.

First of all, three wrecks are identified within the study area, which shall be protected as they may have historical importance and be part of Greece's cultural heritage. Then, eight lighthouses are identified in the study area, prohibiting the installation of an offshore wind park very close to these infrastructures. Then, two submarine cables extending from Attica to Euboea are also identified. Finally, in the southern part of the study area the port of Rafina is located, which is the second biggest port of Attica after Piraeus. From Rafina port seven shipping lines connect the capital with four island destinations.

<u>Sitting Criterion</u>

Based on the Special Spatial Framework, a distance criterion of 7d from the wreck shall be applied, creating a zone within which the installation of an offshore wind park shall be prohibited. Due to the fact that it is not known what type of an offshore wind turbine could be suitable for the study area, since the study is not yet finished, the turbine's rotor diameter (*d*) is not known either and as a result the distance needed for this criterion cannot be specified. However, based on the literature, offshore wind turbines that are suitable for the good wind speed potential of the study area and the high water depth have a rotor diameter of about 130 m. So, the rotor diameter is assumed to be 130 m, in order for a specific distance from site obstructions to be specified.

Having assumed the turbine's rotor diameter, and based on the sitting requirements specified in Table 7 a distance of 910 m from the sunken wrecks and 195 m (*1,5d*) from lighthouses, submarine cables and shipping lines shall be applied, which is the minimum safety distance within which the installation of an offshore wind park is prohibited. Map 6 shows the obstructions occur within the study area, as well as the area around them where the installation of an offshore shall be prohibited.

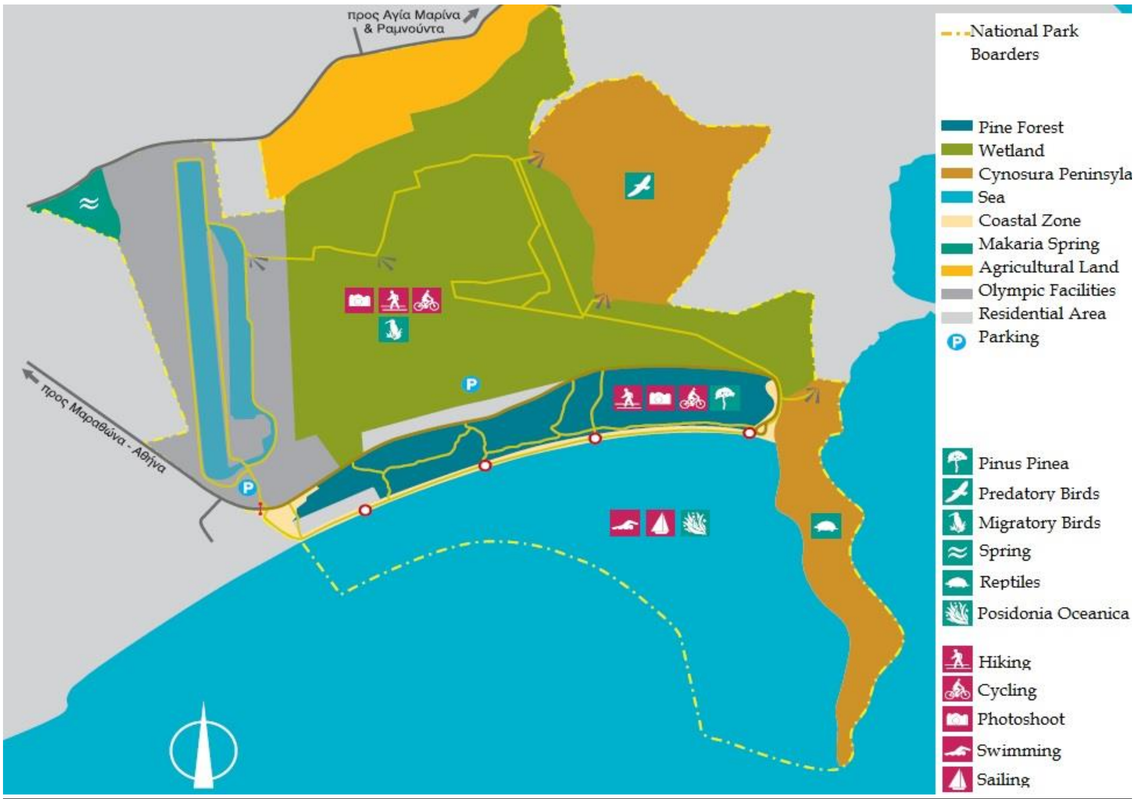


Map 6: Site obstruction criteria in Petalioi Gulf

5.4 Environmental Characteristics

Petalioi Gulf is an area with high environmental interest and needs to be carefully examined before the installation of an offshore wind park.

Starting off with the northwest part of Petalioi Gulf lies the National Park of Schinias, a coastal ecosystem that belongs to the municipality of Marathonas, see Map 3, occupying an area of 1.84 km^2 and having a strong environmental, aesthetic and recreational value. Map 7 shows all the different activities that take place in the park.



Map 7: Land and marine activities in the National Park of Schinias **(Marathon Municipality 2005)**

The park's landscape and geology allow the existence of many different habitat types, including a wetland, a coastal pine forest, a freshwater spring, a peninsula, a hill and a bay. All these different habitats are able to host numerous species of animals, birds, reptiles, freshwater fish and amphibians (Visit Marathon 2011). Due to its ecological importance the park has been added to the European network of protected sites NATURA 2000 and CORINE-Biotopes.

Focusing on the marine area of the park also presents a strong recreational and environmental value. More specifically, it is an area with sandy beaches suitable for swimming and water sports, attracting thousands of tourists every year. From an environmental perspective, as seen in Map 7, the marine area of the park hosts the Posidonia oceanica, a protected natural habitat which can also serve as an index for the ecological status of a marine environment. More specifically, the existence of such a species is associated with high ecological quality since it is a species that only survives in pristine environments. According to hardcopy data provided by the Hellenic Marine Research Canter, Posidonia oceanica does not only exist within the borders of the National Park of Schinias, but in the wider northern part of Petalioi Gulf in water depths up to 20 m.

Besides the benthic flora of the study area that indicates a good ecological status, also the benthic fauna of Petalioi Gulf indicates a good ecological status of the marine environment. Specifically, (Simboura and Reizopoulou 2007) calculated three biotic indices for a sample collected from the muddy bottom of South Evoikos and in a water depth of 34 m, hence within the study area examined in this project. The values of the indices can help in order to assess the ecological quality status of the area. However, the samples were collected in 2006, thus they may differentiate from the current situation. The value of the three indices are presented together with the assessment of the ecological status according to the theory presented in Chapter 3; Shannon-Wiener Diversity (H'): 5.84 – HIGH, Species Richness (S): 87 – GOOD, BENTIX: 3.36 – GOOD

Although according to these indices the study area seems to have a high ecological status, meaning it is a pristine environment or good ecological status meaning it is a slightly polluted area, compared to the indices of other samples collected from other stations in the periphery of Attica, is among the areas with the lowest ecological status mainly due to the high density of more tolerant species compared to sensitive species, although diversity and species richness are relatively high (Simboura and Reizopoulou 2007).

Since the ecological status of Petalioi Gulf is ambiguous, based on phytobenthic and zoobenthic indices and characterized as either a pristine environment or a slightly polluted one, a more detailed and up-to-date analysis is required before any human intervention to the Gulf. So, given that a more detailed benthic study is required in order to conclude on how an offshore wind park installation affects benthos and being affected by it, it is then examined how the rest of the environmental characteristics of Petalioi Gulf affect and being affected by an offshore wind park.

According to the literature, the installation of an offshore wind park can also affect fish either negatively due to high noise level and electric and magnetic fields, or positively due to the attraction of new species in the turbines' foundation structures and protection of fish, since fishing might be prohibited. As in whole Greece, overfishing is also a crucial problem within the study area, especially due to the use of trawlers, however efforts are made to mitigate this problem through regulation that restrict the use of such fishing gear. Although this is an unfounded assumption, it might be worth mentioning that the installation of an offshore wind park could contribute to the efforts of decreasing fishing within the study area, therefore contributing positively to fish diversity and protection. This of course can only work positively if proved that the installation of the park will not adversely affect fish or any other marine living organism.

Then, again according to the literature, an offshore wind park can affect marine mammals. According to (Legakis and Maragkou 2009) three out of six of the marine mammals occurring in Greek Seas, also occur in Petalioi Gulf. More specifically, in the northern part of Petalioi the Mediterranean Monk Seal Monachus-Monachus occurs, a critically endangered species. Then, the Common Dolphin, an endangered species and the Common Bottlenose Dolphin, a vulnerable species also exist in the wider area of Petalioi Gulf. As a result, a careful examination of these mammals' specific location needs to be conducted in order for the installation to be restricted within their habitats, if that necessary.

Finally, regarding the seabirds that might exist within the study area and can be affected by an offshore wind park, Petalioi Gulf is not among the marine areas that host the two priority endemic species of Greece. Thus, since no endangered species are identified within the study area and no available data for any other avian species exist, the installation of an offshore wind park does not seem to be a threat for the avian population of the study area.

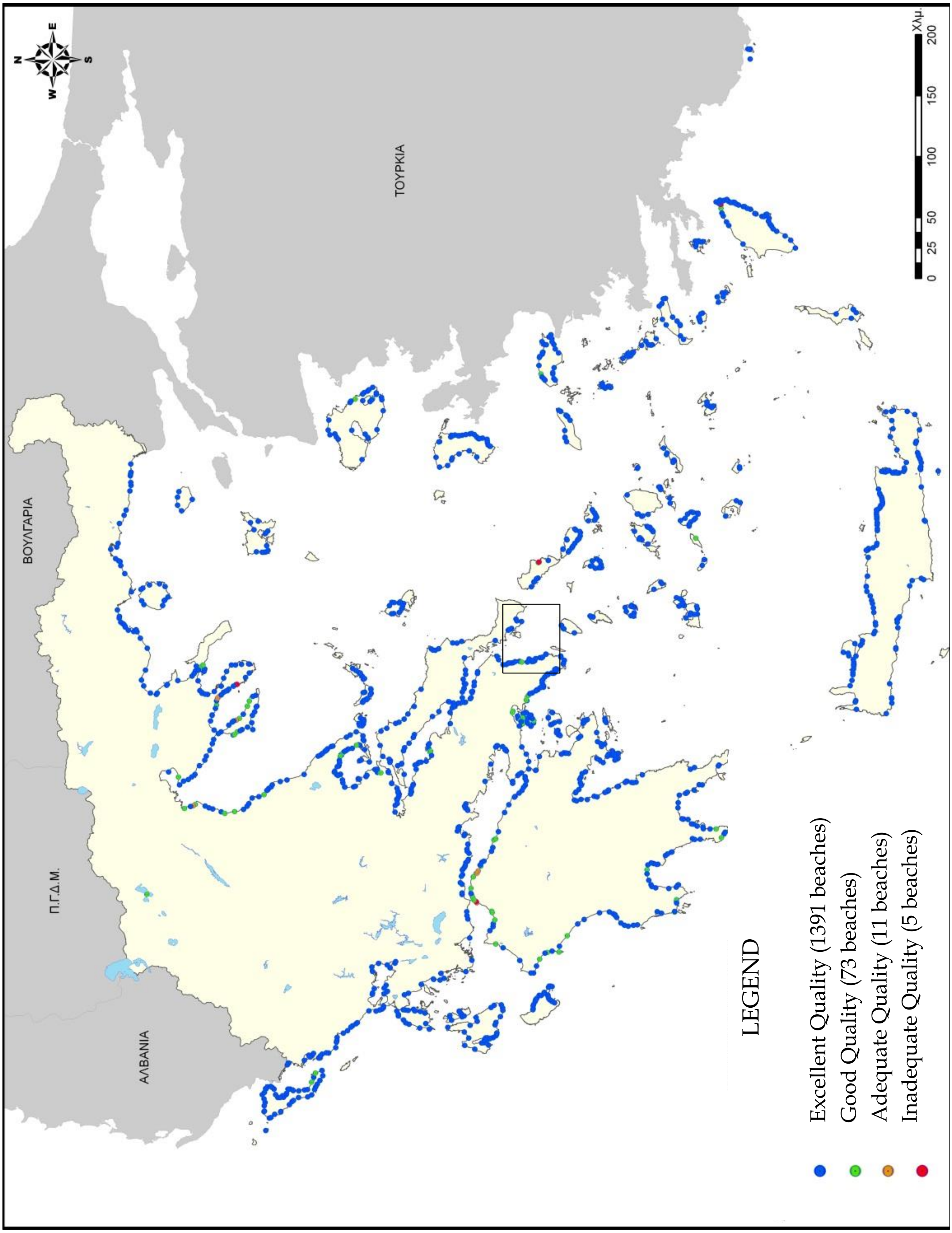
Sitting Criterion

Based on the criteria set by the Greek Special Spatial Framework, since the National Park of Schinias is an area of environmental interest, declared among the NATURA 2000 and CORINE-biotopes European network, a minimum distance of 200 m from the National Park's boarders shall be applied, indicating the area where the installation of an offshore wind park is prohibited.

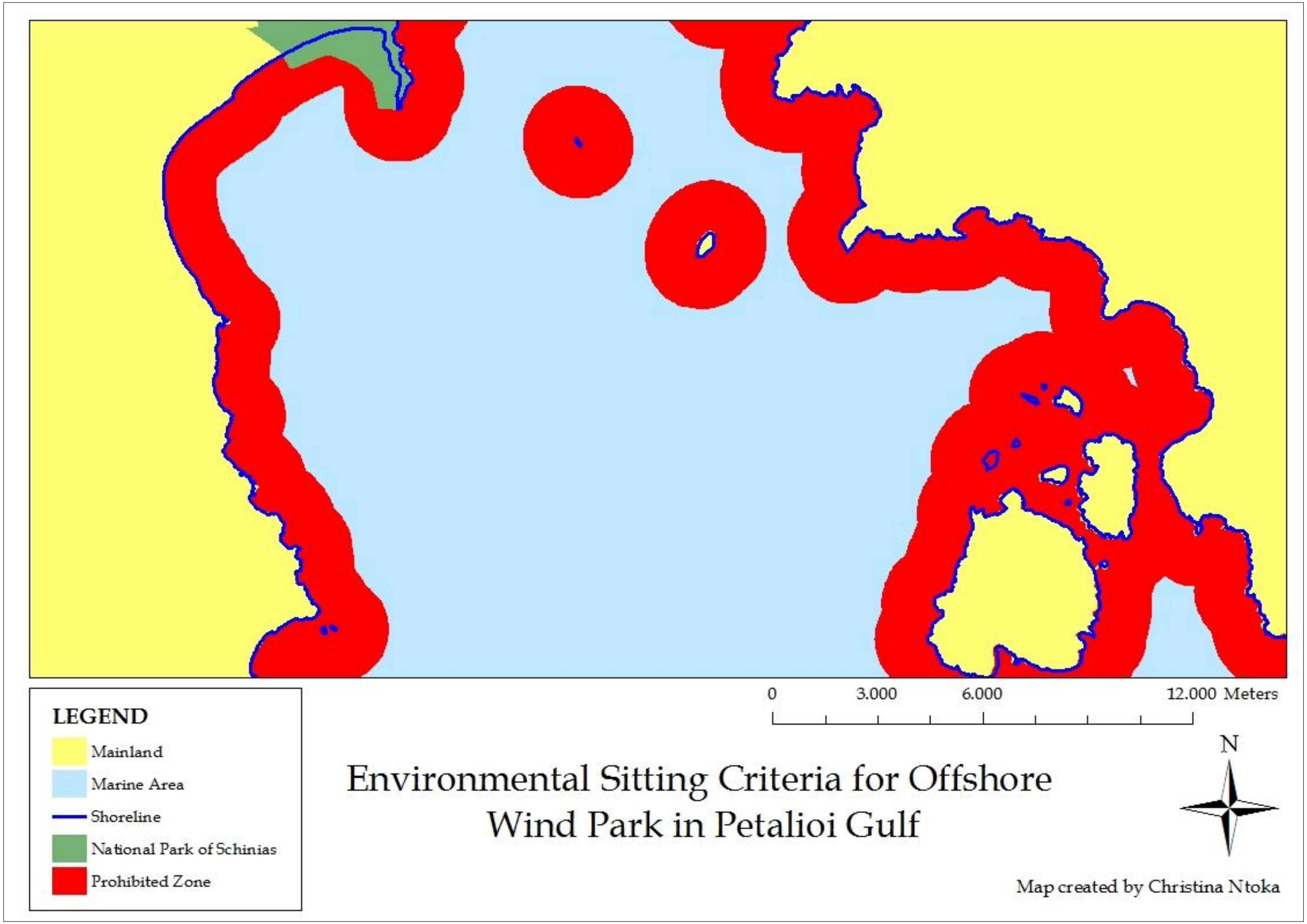
The installation of an offshore wind park is also prohibited within a distance of 1500 m from shoreline, since the coastal area of the park is suitable for swimming and this distance is the minimum distance that shall be applied from swimming coastlines. This sitting criterion is also applied along the coastline of the whole study area, since based on studies for the quality of swimming waters in Greece, the coastline of the study area, especially the western coastline is characterized by waters of excellent quality, see Map 8. This means that even if it is not currently a swimming coastline, it has the potential to becoming a zone of touristic development with recreational and economic value. Applying this minimum distance from the shoreline can also contribute towards decreasing visual impact, although it is still a very low distance in order for the park not to be a major focus of visual attention, something that would be possible at a larger distance than 25 km from the shoreline (Sullivan, et al. 2010).

Then, the installation of an offshore wind park shall also be prohibited wherever the Posidonia oceanica occurs, as it is a protected habitat. However, since there is no available data indicating the exact location of Posidonia, the prohibited area is defined as indicated in Map 7, thus avoiding the installation of an offshore wind park within 1.5 km from the coastline of the National Park of Schinias, an area that recreational activities also take place. Map 9 shows the environmental sitting criteria as applied in the study area, revealing the areas where the installation of an offshore wind park is prohibited.

It is worth mentioning that although the study area presents a high ecological interest by having a rich phytobenthos and zoobenthos and endangered marine mammals, due to the fact that no specific spatial information exist for them, they cannot be included in the map and thus a minimum distance from them cannot be applied in order for these species to be protected and undisturbed by the installation of an offshore wind park. As a result it is definitely a necessity that a detail examination of the marine ecology needs to take place in order for the final site of an offshore wind park to be decided.



Map 8: Bathing waters quality for 2012 (Special Secretariate for Water, 2012)



Map 9: Environmental sitting criteria in Petalioi Gulf

5.5 Results and Discussion

After examining the physical characteristics, the site obstructions and the environmental restrictions of Petalioi Gulf, an area of about 70 km^2 is found as the most appropriate for an offshore wind park installation. The area is located at a minimum distance of 1.5 km from shore and lies in water depths from 20 to 50 m. It is worth mentioning that the area found by the spatial analysis, described in this chapter, almost coincides with the areas that the initial governmental study and the investment company TERNA Energy have indicated.

The area indicated by the governmental study is however much smaller, as it is about 25 km^2, and is located about 5 km away from the shoreline, most likely in order to minimize the visual impact and conflicting marine uses. On the other hand, the area indicated by the investment company coincides more with the area found in this project, with the only difference that is located at a larger distance from the shoreline of Marathonas Gulf, possibly in order to avoid technical difficulties of installing a wind park in multiple waters depths from 10 to 50 m and/or avoiding potential conflicting marine uses and high visual impact with the most touristic area of Western Attica, the National Park of Schinias.

For the same reasons that TERNA-Energy might have moved the wind park at a larger distance from the shoreline, so the final area that is most suitable for the installation of an offshore wind park is limited to water depths from 30 to 50 m, covering an area of about 55 km^2, at a minimum distance of 1.5 km from shoreline and a maximum distance of about 7 km from the shoreline of Marathonas Gulf, as seen in Map 10.

The fact that the results of the spatial analysis of this project almost coincide with the results of the pre-existing studies it is most likely due to the fact that in all of them only information provided by the nautical chart of the study area is used. However, since it was very unclear what were the specific criteria used in both of the pre-existing studies in order for the most suitable area for an offshore wind park to be indicated, this study contributed towards identifying these criteria, specifying them spatially and discussing their rationality and relevancy to the installation of an offshore wind park.

Of course, the limited information that the nautical chart can provide is not adequate for a careful analysis of an area in order to be decided where an offshore wind park shall be located achieving technical and economic feasibility, avoiding any conflict with existing marine uses and avoiding environmental degradation. However, this is something that both the governmental agency and TERNA-Energy recognize, claiming that further analysis shall take place. In this direction, this study managed to specify some more characteristics of the study area, mainly physical and ecological which need to be taken into consideration in order to contribute towards deciding the area's suitability for offshore wind exploitation.

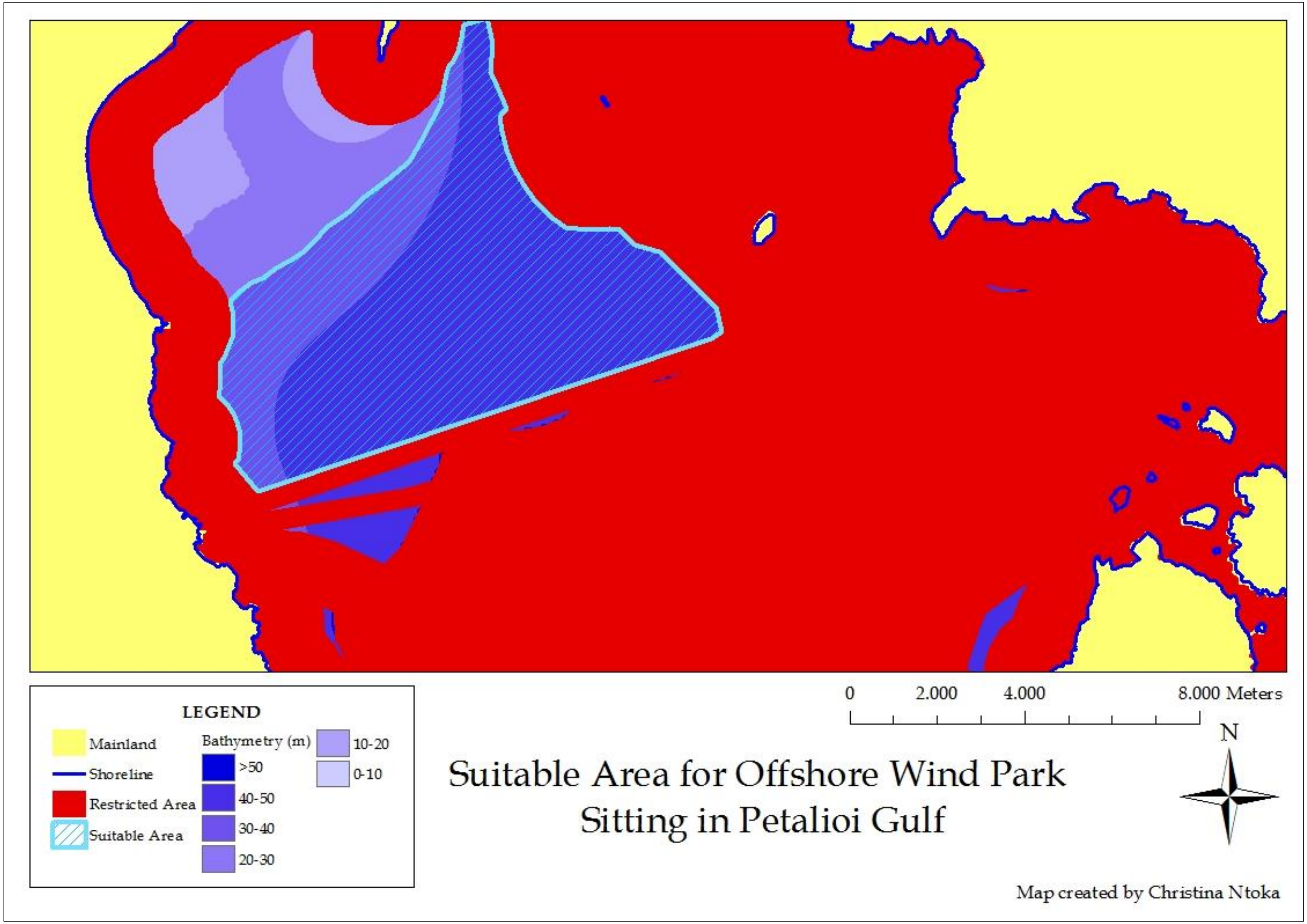
Analyzing the wind potential of Petalioi Gulf and based on modeled wind data from within the study area, it seems that the wind potential is actually as high as it was initially estimated to be.

More specifically, the average wind speed found to be 8.2 m/s in 2012 and at a height of 100 m, while the predominant wind direction for the same year was north and north-northeast.

Then, finding information about the quality status of the beaches along the shoreline of the study area, their touristic importance revealed and it has been incorporated into the spatial analysis. In this way, offshore wind park has moved a little further from the shoreline, also decreasing the visual impact, which is not regulate by the national regulations.

Furthermore, examining the ecological characteristics of the study area, it has been found that Petalioi Gulf is an area with high ecological interest, hosting the protected species Posidonia oceanica in water depth up to 20 m in the northern part of Petalioi Gulf. It is also an area with high richness and diversity of fauna species, characterizing it as an area with high to good environmental quality status, meaning an area which is either pristine or slightly polluted. Finally, it is an area that hosts three different endangered marine mammals that require protection. However, all these different ecological information could not be spatially identified in order to be included in the sitting analysis and change the results of the offshore wind park sitting.

Finally, an assessment has been made regarding a positive impact that the park could have to fish population. More specifically, given the concerns about overfishing within the study area, the installation of an offshore wind park would possibly prohibit fishing, thus protecting fish and allowing their breeding. However, this is a quite unfounded assessment that requires further investigation in a social, economic and ecological level.



Map 10: Suitable area for the installation of an offshore wind park in Petalioi Gulf

6. OFFSHORE WIND PARK MICRO-SITTING IN PETALIOI GULF

After sitting the offshore wind park, based on the physical, spatial and environmental characteristics of Petalioi Gulf, the last step of this project is to make a preliminary assessment of the micro-sitting of the park, considering technical and economic aspects that affect it.

In this direction, the offshore wind park's layout should be firstly designed. In order to design a park's layout, according to the theory presented in Chapter 4, it is crucial to define the size of the wind turbines that will be used, the distance between them as well as the most suitable support structures. Based on the resulted layout, the economics of the park can also be assessed.

Such an assessment can contribute towards evaluating the technical and economic feasibility of the offshore wind park, revealing any technical difficulties or economic constraints and overall providing additional useful information towards the final decision making about offshore wind development in a region.

6.1 Wind Turbines and Distance

According to the theory presented in Chapter 4, the decision about the size of the wind turbines that can be used for an offshore wind park in Petalioi Gulf should be based on the wind and bathymetrical conditions of the this marine area, as well as the current technological status of offshore wind turbines.

Due to the fact that the wind potential of Petalioi Gulf is very good and the water depth is very high compared to the average water depth of European offshore wind energy projects, as indicated in the previous Chapters, the installation of support structures able to support larger wind turbines is favored. For that reason even the installation of wind turbines of 5 MW can be considered for an offshore wind park in Petalioi Gulf. This is also the size of wind turbines that were considered from both the governmental study and TERNA-Energy and thus the size that is also considered for the technical analysis of this project. Specifically, the installation of the Repower 5 MW offshore wind turbines with hub height of 100 m and a rotor diameter of 125 m is considered, which also coincides with the turbines proposed by the TERNA-Energy.

Although typically the distance between offshore wind turbines ranges from 6D to 10D, this can be decided according to the specific characteristics of each offshore wind energy project. For this purpose, the wind direction plays a crucial role in deciding the distance between the turbines. Based on the theory presented in Chapter 4, a larger distance should be applied between the turbines located horizontally to the most predominant wind direction with the ultimate purpose to reduce their high wake effects and a smaller distance to the ones located vertically to the most predominant wind direction.

As a result, and given the fact that the target here is not to find the most optimum distance between the turbines but a reasonable one in order for the analysis to proceed, a distance of 10D is considered for the wind turbines that are located horizontally to the most predominant wind direction and 7D for the rest of the turbines. Thus, since the most predominant wind direction is from north, the turbines located north to south are separated by a distance of 10D and the ones located east west are separated by 7D.

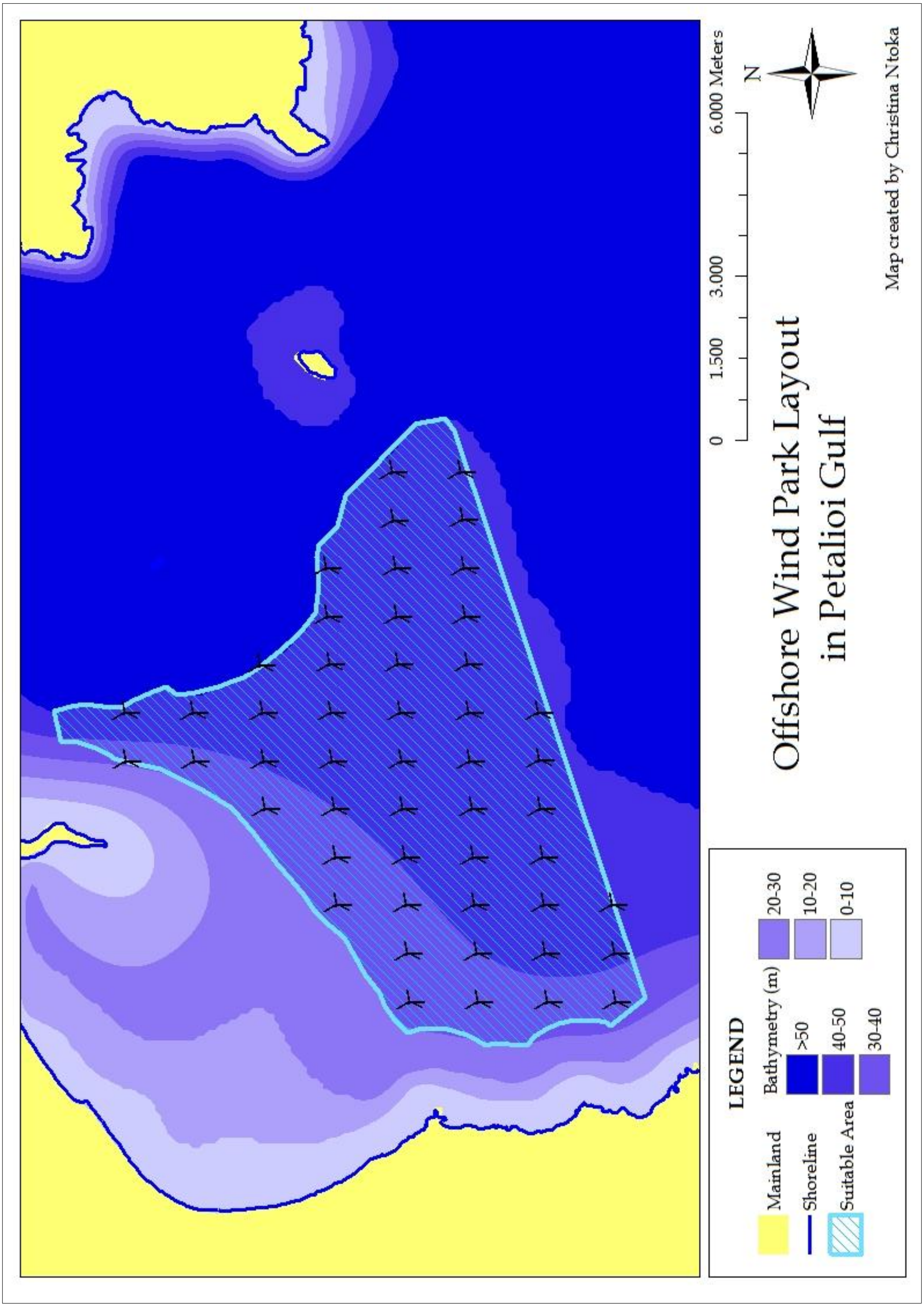
Map 11 shows the layout of the wind park that could be installed within the most suitable area of Petalioi Gulf, considering the use of Repower 5 MW wind turbines and turbine spacing of 10D X 7D. Based on these considerations, a wind park of 50 wind turbines, thus with a capacity of 250 MW, can be located in Petalioi Gulf.

6.2 Support Structures

Regarding the support structures that need to be used to support the offshore wind turbines, since they will located in water depth from 30 to 50 m, three types of support structures are the most appropriate; the gravity-based in depths up to 40 m, tripods in depths from 20 to 50 m and jackets in depths of 30 m and more.

Based on the investigation of the previous chapter, Petalioi Gulf might be a marine environment with high ecological importance, which hosts a great variety of benthic fauna and flora. For this reason, the installation of gravity-based support structures is immediately excluded since they cover a large part of the marine bottom, destroying the phytobenthic and zoobenthic habitats.

Then, the choice between using tripod or jacket support structures is mainly based on the recommendation from the manufacturer of the wind turbines used for this project, the REpower. Repower suggests the use of jacket structures as the most suitable for the support of 5MW offshore wind turbines, due to the experience that the manufacturer has gained by using this type of structure for this wind turbine (Seidel 2007). The main reason is that jackets are appropriate to support heavy wind turbines, such as the 5 MW turbines, but they are relatively lighter structures than tripods. Furthermore, based on the literature investigated in Chapter 4, jackets cause lower noise level than tripods during the construction phase, and since Petalioi Gulf might host three endangered species of marine mammals it is preferable to use the support structures that will have the lowest noise impact to them. Finally, although jackets can be easily affected by extreme wave conditions, this is not an issue of concern for Petalioi Gulf, since there no extreme wave conditions evidenced (Athanasopoulos 2013).



Map 11: Offshore wind park layout in Petalioi Gulf

Having defined the physical and technical characteristics of the proposed offshore wind park in Petalioi Gulf, as well as the water depth in which it can be installed and the maximum distance to shore, it is quite interesting to compare these characteristics with other European projects. So, Table 11 shows the physical and technical characteristics of five European offshore wind parks that have been installed since 2010 and the characteristics of the offshore wind park in Petalioi Gulf.

Table 11: Comparing the offshore wind park in Petalioi Gulf with other European projects

	BARD Offshore I	Thanet	Gunfleet Sands	Belwind	Apha Ventus	**Petalioi Gulf**
Country	DE	UK	UK	BE	DE	**GR**
Capacity (MW)	400	300	172	160	60	**250**
Turbine Size (MW)	5	3	3.6	3	5	**5**
Foundation	Tripile	Monopile	Monopile	Monopile	Tripod, Jacket	**Jacket**
Water Depth (m)	39 - 41	20 – 25	2 -15	15 – 37	28 – 30	**30 -50**
Distance to shore (km)	101	11	7	46	56	**13**
Year of completion	2012	2010	2010	2010	2010	**-**

Source: (Verum, et al. 2011)

As seen, the park of Petalioi is located at the highest water depth and comparatively very close to shore, which implies high investment costs and most probably high visual impact and low social acceptance. Moreover, as with the BARD Offshore I and the Apha Ventus, the high depth in which they are installed favors the use of larger turbines which will eventually have higher electricity output. However, the analysis that follows aims at investigating any technical or economic constraints that might be associated with the installation of an offshore wind park in Petalioi Gulf.

6.3 Energy Production

The different choices made for the wind turbines' size, their arrangement and their support structures affect the final energy production of the offshore wind park, which is estimated in this section.

As mentioned in the Methodology, WindPRO 2.9 is chosen as the software to be used in order to facilitate the energy calculations. Specifically, the so-called "PARK Module" is used, a module that allows the setting of the required parameters in order to estimate a wind park's annual energy production.

The first parameter that is set refers to the Wake Decay Constant (WDC) based on the terrain type of a wind park, a parameter that affects the wake loss calculation. "*The WDC gives the rate of expansion of the wake,* explained in Chapter 4*, and at the same time the rate at which the wind speed deficit recovers"* (Sørensen, Thøgersen and Nielsen 2008). Since the wind park of Petalioi Gulf is located offshore, the WDC is low because offshore and water areas experience low turbulence, thus higher wakes and lower energy production. The software's default WDC for offshore wind parks is set to be 0.040.

Then, some of the project's features are set, including the type and size of wind turbines, and their hub height. Very important is also to set the wind data that will be used for the energy calculations. The data used are the Meso scale data, modeled by EMD and ConWx, as described in the previous Chapter, and include wind data from 1997 to 2012 for a height of 100 m. Finally, climate data are also set from the climate database of WindPRO. For the offshore wind park in Petalioi Gulf, the climate data of a climate station in Athens (Hellinikon) are used, which although is a station 43 km away from our study area, is an area with low elevation and can simulate the climatic conditions of a marine environment.

Having set all the necessary parameters, the gross annual energy production is calculated, as well as the annual energy production after the losses caused by the wake effect. The results are shown in Table X. As it can be seen, with the park layout chosen to be implemented, a park efficiency of about 92% is achieved, which means that there are 8% losses from the wake effect, which is a very normal and acceptable percentage for an offshore wind park.

Table 12: Energy calculation for the offshore wind park in Petalioi Gulf

Total Rated Power of the Park (MW)	250
Gross Annual Energy Production (GWh/y)	858.9
Annual Energy Production (with wake losses) (GWh/y)	787.5
Park efficiency (%)	91.7
Mean WTG result (GWh/y)	15.7
Mean wind speed at 100 hub height (m/s)	7.8

However, besides the losses from the wake effect, it is also useful to account for losses that might occur due to the grid malfunction, electrical substations malfunction, grid unavailability, wind turbine's malfunction and/or unavailability etc. So, in order for all this losses to be taken into account for the final energy production, a default of 10% losses is applied which decreases the annual energy production to 708.8 GWh.

6.4 Economics

After investigating some of the technical aspects of the proposed offshore wind park, resulting to the calculation of an annual energy production, the last step is to assess the economic feasibility of the park. The results of the economic analysis can contribute towards the final decision making about the micro-sitting of an offshore wind park in Petalioi Gulf.

Table 13 shows the specific installated capacity costs relating to the installation and operation of the offshore wind prak in Petalioi Gulf. The wind turbine cost and the electric infrastructure cost is assumed based on the the costs given in Table 8 of Chapter 3. Specifically, due to the fact that large wind turbines are used, which are most probably more expensive than the ones that are mainly used today, the highest estimation cost is chosen to be used for the economic calculations, which is that of the accounting firm Ernst & Young. In contrast, due to the fact that the offshore wind park in Petalioi Gulf is located very close to shore compared to other European projects, but it is still a very large project with large electricity production, the average of the estimated electric infrastructure costs of EWEA and Ernst & Young is chosen to be used for the economic calculations, see Table 13.

Although the wind turbine and electric infrastructure cost is based on assumption, the costs for the support structures, the installation, the operation and maintenance are calculated with the use of the expressions (1), (2), (3) respectively, presented in Chapter 3, and considering the average water depth of the park (40 m) and its average distance to shore and a major supply harbor (7 km).

Table 13: Installed capacity costs

Wind Turbines (million €/ MW)	1.7
Support Structures (thousand €/ MW)	853
Electric Infrastrucrures (thousand €/ MW)	522
Installation (thousand €/ MW)	5
Operation and Maintenance (€/ MWh)	19

Comparing the calculated support structure, installation, operation and maintenance cost presented in the above table with the estimations of Tables 8 and 9, presented in Chapter 3, it seems that they are pretty accurate. Specifically, the calculated support structure cost is higher than the estimated cost and the real cost of the Rødsand II wind park, since the use of larger wind turbines and in deeper water than the average offshore wind parks in Europe, requires heavier and more technologically-advanced foundations, thus more expensive.

The installation cost, which is included in the "Other" category of Table 8, is also logical to be relatively lower since the installation takes place very close to a major supply harbor, thus decreasing the transport cost.

Finally, the operation and maintenance cost is almost half of the estimated costs presented in Table 9, mainly due to the short distance of the park to the shore, which again decreases the transport cost. Also, as also mentioned above, the mild wave conditions of Petalioi Gulf do not contribute towards the turbines' deterioration and as a result the operation and maintenance cost remains low.

Based on the above mentioned costs, the total investment cost, which consists of the wind turbine, the support structure, the electric infrastructure and the installation cost, is calculated to be about 3.1 million €/ MW, hence a total of about 776 million € for the offshore wind park. Among the negative cash flows is also the operation and maintenance cost which is calculated to be about 16 million € per year, based on the gross annual energy production of the park.

However, besides the negative cash flows accompanying the installation, operation and maintenance of the offshore wind park in Petalioi Gulf, there is also an annual income since the produced electricity will be purchased by the national electricity company. The feed-in-tariff, hence the price in which the produced electricity from an offshore wind park will be sold, is set to be 99.45 € / MWh for 20 years. As a result, the annual income is calculated to be about 78 million € per year, based on the final annual energy production of the park after the array losses and an extra 10% potential losses from the electricity grid. Table 14 summarizes the negative and positive cash flows of the offshore wind park in Petalioi Gulf.

Table 14: Cash flows of the offshore wind park in Petalioi Gulf

Total Investment Cost (million €)	776
Operation and Maintenance Cost (million €/year)	16
Revenues (million €/ year)	78

Knowing both the negative and positive cash flows relating to the offshore wind park in Petalioi Gulf it is useful to calculate the net present value of the whole investment in order to take into consideration the time value of money and assess the long-term feasibility of the investment. Figure 14 shows the relation between the net present value and the different discount rates.

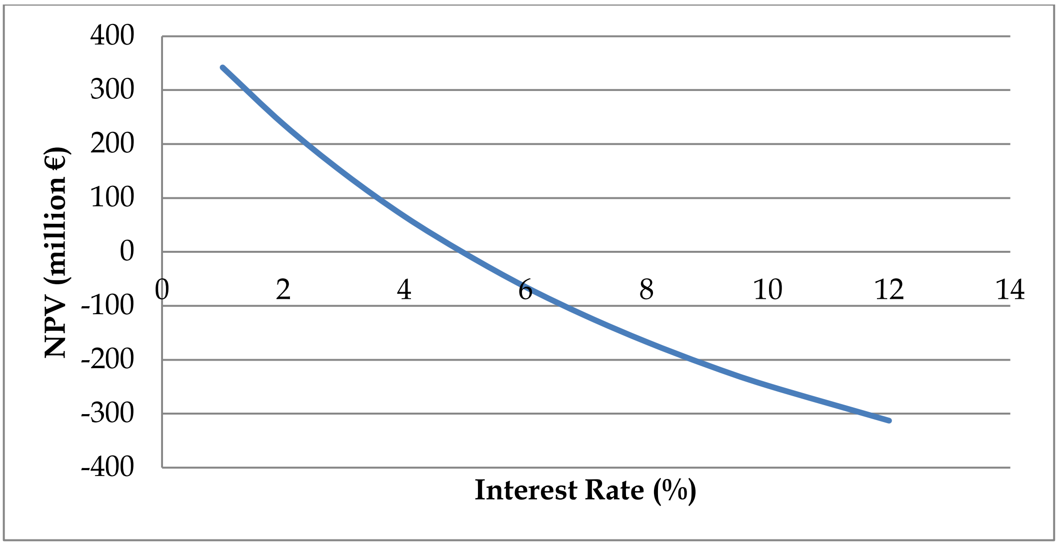


Figure 14: Net Present Value of the offshore wind park in Petalioi Gulf

As seen, in order for the installation of an offshore wind park to be feasible, a discount rate lower than 5% should be considered, which might be a rather low interest rate to be used for Greece, given the current economic situation. As a result, it seems that the studied micro-sitting of the offshore wind park in Petalioi Gulf might not be a feasible option, but it is also not the final one.

Although based on the investment, operation and maintenance cost and the annual revenues, resulted from this micro-sitting option,the investment seems to be non-economically feasible, but this is not a complete cost and benefit analysis to be used for the final decision making, since there are not any external costs and benefits included into the calculations.

The external benefits of an offshore wind park, as with onshore parks, can relate to the avoided CO_2 emissions that a wind park has, compared to non-renewable energy sources. This can also translate to monetary values in many different ways. For instance, the external benefits could be calculated in the form of health impovements. Specifically, the fact that the avoided emissions will eventually lead to a better air quality, might mean that people who suffered from breathing problems might get better and avoid the costs related to their disease. In this case, the costs saved by those people could function as an external monetary benefit to be added into the calculations for the offshore wind park's economic feasibility. Another example of external monetary benefits could be in the form of avoided fines, possibly implied by the European Union to energy producers with high output of CO_2 emissions.

However, in addition to the external benefits that may impove the project's economic feasibility, there are also external costs assocciated with offshore wind pak. For instance, the installation and opertion of an offshore wind park may cause ecological damage to the marine environment, destroy the benthos and as a result reduce the fish species imposing economic damage to fishermen. Furthermore, the visual impact of an offshore wind park can make the area an unattractive place for tourists, imposing economic damage to touristic services or an unattractive place for permanent residency, imposing economic damage to a range of services in the area. In all the cases there are external costs created upon society caused by the offshore wind park, costs that the owner of the park should account and compensate for.

So, the economic analysis conducted in this report cannot be considered as complete, leading to the final decision making. Future studies should be conducted in order to assess all the external benefits and costs related to an offshore wind park in Petalioi Gulf, in order to be incorporated in the calculations and lead to a more accurate result.

Then, in addition to the fact that no external benefits and costs are included in the economic calculation in order to lead to a more accurate result, there is also another reason that the economic result should not be considered as the final. Since optimization was beyond the scope of this project and it was thus not accounted for, it should be performed in a future study before the final decion making about the park's economic feasibility. More specifically, a sensitivity technical and economic analysis should be conducted in order to be investigated how technical changes will affect the park's economic feasibility. Towards this direction, the use of smaller wind turbines should be considered, as well as different scenarios for the turbines' layout and the park's electric network layout. In this way, there might be found a technical solution that makes an offshore wind park in Petalioi Gulf economic feasible.

7. CONCLUSION

At the beginning of this project the ultimate target was to investigate the status of offshore wind energy development in Greece along with the national efforts towards this development. Based on the investigation, it was found that the national efforts towards offshore wind development are only limited to a sitting study indicating the most suitable locations for the installation of offshore wind parks.

This governmental study was however conducted within a very short time and the accuracy of its results has been questioned. Specifically, (Chaviaropoulos, 2011), expressed concerns about the sitting analysis that took place, claiming that a lot of the locations found as suitable for the installation of an offshore wind park, might eventually be prohibited mainly due to conflicted marine uses. He also claimed that eventually the proposed capacity of offshore wind parks will get smaller after a more detail analysis.

As a result it seemed that there might actually be factors that have not been accounted for, or they might have not been correctly assessed, when deciding about the offshore wind park's sitting and micro-sitting in Greece. So, after selecting Petalioi Gulf, one of the areas that the governmental study indicated as the most suitable for an offshore wind park installation, to be investigated, the main research question was formed as ***"How different factors affect the sitting and micro-sitting of an offshore wind park in Petalioi Gulf, Greece?"***

The methodology chosen to be used in order to address the research question is based on the technology theory described by Mueller, Remmen and Christensen, 1984 *in* (Lund 2009). Based on that theory, technology is a combination of four components: knowledge, technique, organization and product, meaning that if any of the above components change it will eventually affect the others.

So, considering as the product of offshore wind energy technology the installation of an offshore wind park, this project aimed at investigating how its implementation can be affected by changes in knowledge and technique. This methodology proved to be very useful since it guided the project towards the correct direction in order for the main research question to be addressed.

7.1 How different factors affect the sitting of an offshore wind park in Petalioi Gulf?

The knowledge, the first component that needed to be investigated, refers to the main factors which are necessary to be known when investigating the prospect of offshore wind park sitting in a specific region. According to the literature, these factors found to be physical, spatial and environmental, which after being theoretically examined, they have also been discussed according to the specific characteristics of Petalioi Gulf in order to be investigated how they can affect an offshore wind park's sitting in this region.

Physical Factors

For the physical characteristics of the study area, the wind speed and the bathymetry were examined. The mean wind speed at a height of 100 m above sea was found to be 8.2 m/ s based on statistics of 2012, which is a mean wind speed amongst the highest in Europe after the North Sea and thus pretty favorable for the installation of an offshore wind park.

Examining the water depth of the study area, it was observed that it increases sharply, limiting the areas with shallow water, because they are very close to the shoreline and the installation of an offshore wind park could conflict with many land and offshore uses. This means that considering the installation of an offshore wind park in deeper water was inevitable. Thus, although the average water depth where European offshore wind parks are installed is 22 m at a distance of 29 km from shore, this cannot be the case for Petalioi Gulf because such a depth is found at a maxim of 4.5 km from shore and still very close to potential conflicted onshore and marine uses. As a result, the installation of an offshore wind park was considered in water depths up to 50 m, which is associated with some advantageous and disadvantageous technical and economic issues described below.

Spatial Factors

The spatial factors examined refer to the site obstructions that restrict the available area for an offshore wind park installation. These found to be wrecks, lighthouses, submarine cables and shipping lines. Only the submarine cables and the shipping lines intervene and decrease the available area for the installation of an offshore wind park but both are marine uses that typically take precedence over an offshore wind park development. The wrecks are located in depth higher than 50 m and thus within an already restricted area for the installation of an offshore wind park. The lighthouses are also located at water depth higher than 50 m or very close to shore and within a distance of 1.5 km from it, a zone which is also restricted by the spatial criterion applied to the shoreline.

Environmental Factors

The National Park of Schinias, located in the Northwest part of Petalioi Gulf is the first environmental characteristic noticeable within the study area. The park is of great environmental importance having a strong ecological, aesthetic and recreational value. It is an area with sandy beaches which attracts thousands of tourists every year as the waters are suitable for swimming and water sports. The same applies for the coastline of the whole study area, because based on national studies the waters are of excellent quality and thus of high touristic importance.

Besides of investigating the coastal characteristics of the study area, the marine area of Petalioi Gulf has also been examined. Initially, the phytobenthic and zoobenthic conditions were examined with the use of some indices. Specifically, the phytobenthic conditions were examined through the existence of Posidonia oceanica, a sea weed which serves as an index for the ecological status of a marine environment. In other words, its existence in a marine environment is associated with high ecological importance since it only grows in pristine environments. Based on national studies, Posidonia exists in the wider area of Petalioi Gulf and within 20 km from shore, however is not spatially defined in order to be included in the spatial analysis.

Then, the zoobenthic conditions were assessed with the use of three indices, the Shannon-Wiener Diversity (H'), the Species Richness (S) and the BENTIX. Based on these, the area was categorized as having good to high ecological quality, meaning it is a slightly polluted area or a pristine environment. However, the samples used were collected in 2006 and may differentiate from the current situation. Thus, since the ecological status of Petalioi Gulf is ambiguous, based on phytobenthic and zoobenthic indices and characterized as either a pristine environment or a slightly polluted one, a more detail and up-to-date analysis is required before any human intervention to the Gulf.

Regarding the park's impact on fish habitats it is not clear if it will be negative or positive. On the one hand, fish can be negatively affected by high noise levels and magnetic fields. On the other hand, the installation of an offshore wind park can contribute towards prohibiting fishing, when overfishing is a problem of serious concern for Petalioi Gulf, and contribute positively towards fish diversity and protection.

Then, three endangered species of marine mammals occur in Petalioi Gulf but a more careful examination of their specific location need to be conducted in order for the installation of an offshore wind park to be restricted within these habitats.

Finally, according to national studies, Petalioi Gulf is not among the marine areas that host the two priority avian endemic species of Greece. So, it is assumed that the installation of an offshore wind park will not interfere with the avian population.

In conclusion, given the status of the environmental studies of Petalioi Gulf, it is not possible to conclude whether an offshore wind park should be restricted by an environmental perspective. Although there are evidences that it might be of high ecological importance, the data revealing this are old and the situation might have changed. Either way, nature conservation and offshore wind development can possible co-exist under certain conditions that need to be defined when up-to-date studies are conducted, revealing the exact environmental characteristics of Petalioi Gulf. Besides the environmental conditions that may restrict the sitting of an offshore wind park in Petalioi Gulf, the physical characteristics of the region seem favorable for an offshore wind park sitting. Moreover, the spatial characteristics are also favorable if accounted for as indicated in the analysis.

The use of GIS for the analysis of all the above characteristics proved to be very effective, since all the data were collected in a single database, processed with two main spatial tools (buffering and overlaying) and displayed in order for the final most suitable location for an offshore wind park installation to be indicated. Thus, an area of about 55 km^2, located in water depths from 30 to 50 m and at a minimum distance of 1.5 km and a maximum of 13 km from shoreline was identified.

7.2 How different factors affect the micro-sitting of an offshore wind park in Petalioi Gulf?

The technique, the second component that needed to be investigated, refers to the technical factors which are necessary to be known when investigating an offshore wind park's micro-sitting in a specific region. According to the literature, among the technical issues that need to be investigated for a micro-sitting study are the wind turbines' size, their support structure and the wind park's layout.

The park's move to higher depth than the average depth where the European offshore wind parks are located, is accompanied by both positive and negative techno-economic aspects. Specifically, the good wind potential and the high water depth allow the utilization of larger wind turbines resulting to higher energy output. Thus, the use of 5 MW wind turbines were considered, when the average capacity of the offshore wind turbines used in European projects is 4 MW.

Specifically, the use of 50 wind turbines with rated capacity of 5 MW was considered for an offshore wind park in Petalioi Gulf, proposing an installed capacity of 250 MW. The spacing between the turbines was not investigated to be the most optimum one, but with the main target to reduce wake losses, a distance of 10 D was considered for the wind turbines that are located north to south, because north wind is the most predominant and 7D for the wind turbines that are located east to west. With this park layout an efficiency of almost 92% is achieved, which is very reasonable and in accordance with the efficiency of installed European offshore wind parks.

Then, considering the benthic importance of Petalioi's Gulf, the support structures that were considered to be installed are the Jackets. Besides the benthic constraints, although these support structures are quite expensive, they are less noisy during the construction phase, and since Petalioi Gulf might host three endangered species of marine mammals it is preferable to use the support structures that will have the lowest noise impact to them.

The specific choices made about the wind turbines' size, their arrangement and their support structures affect the final energy production of the offshore wind park, which was calculated with the use of WindPRO. The use of WindPRO software proved to be very helpful and effective, mainly due to the two of its advantages: the provision of online data, which were crucial for the accurate estimations and which would not be otherwise available and its default parameters that facilitate the calculation procedure for an inexperienced user of the software.

So, with the use of WindPRO, the final annual energy production was estimated to be 708.8 GWh. This production is more than a third of what the government had planned the electricity production to be until 2020, in order to contribute towards the binding "20-20-20" target and the interim target of the share of renewable energy to the electricity sector by 2020, which was 1763 GWh cumulatively.

However, based on the examined micro-sitting and the annual energy production, such an investment would not be economic feasible when considering a discount rate higher than 5%, which is very likely for Greece given the current economic situation. Towards this direction, two suggestions for future work were made; a detail analysis of the external costs and benefits that will eventually change the economic result and/or multiple scenario development considering the use of smaller wind turbines, different turbine's layout and different electric network layout.

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