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Offshore Wind Farm in Southeast Aegean Sea

GEORGIOS N. DELAGRAMMATIKAS

REGISTRATION NUMBER: MEN19014

SUPERVISOR PROFESSOR: Dr. SPYRIDON ROUKANAS

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Acknowledgement

The development of this thesis marked the completion of my postgraduate studies, especially important for me. On this occasion, therefore, I would like to thank wholeheartedly my family, who have supported me in every way throughout my life and have done the same during my master degree studies. Also, I would like to thank my girlfriend for her support, understanding, help and encouragement.

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Abstract

In this thesis, the author deals with his exclusively own creation, in realistic terms, of an offshore wind farm between the Greek islands of Karpathos and Kassos, in the Dodecanese complex.

The objective of this thesis is twofold and for that two phases are developed. Specifically, the first goal (first phase, January 2023 – December 2027) is to be presented a plan, via the construction of an offshore wind park, in order for the energy needs of two islands to be covered at an extremely high rate. At present (January of 2021), these two islands, Karpathos and Kassos, are not interconnected with the mainland system and at the same time the one of them (Kassos) is energy dependent by the other (Karpathos). The second target (second phase, January 2028 – December 2052), after the anticipated interconnection (by 2027) of Karpathos and Kassos islands with the mainland system and therefore with the Hellenic Electricity Transmission System, is the contribution of an offshore wind farm in the national energy mix and the author assesses its operation mainly from this perspective. The transition from the first to the second phase has also been provided. In any case, both the islands have been selected to participate in the project. However, some differences regarding parameters of the project are observed between the two phases.

In Greece, until the time of the delivery of this thesis (January of 2021), no offshore wind farm had been installed. The characteristics of some areas of the country are considered to be favorable for the construction of such a wind park and for that reason this technology can possibly be developed, gradually, in Greece as well.

In the study of this thesis, the author, after the introductory chapter, records and clarifies, among others, the terms and the conditions for the possible existence of an offshore wind farm in Greece, refers to the technical components of such a project, presents the offshore wind park, which he designed, as well as the point where he selected for its installation, analyzes financial data adapted to the specific offshore wind farm and he is mentioned, also, to the way of the funding for the project. In

addition, the energy storage (batteries), is combined, in both phases, with the operation of this offshore wind farm, the benefits that Karpathos and Kassos could have in total are analyzed and different forms of impact of such a project are studied.

At the end, the conclusions are presented, as well as suggestions on further research.

Abbreviations - Keywords

** In the list below, only the abbreviations that are mentioned more than once in this thesis have been registered.*

OWF: Offshore Wind Farm / OWP: Offshore Wind Park

OWT: Offshore Wind Turbine

RES: Renewable Energy Sources

IRENA: International Renewable Energy Agency

GWEC: Global Wind Energy Council

RAE: Regulatory Authority for Energy

IPTO: Independent Power Transmission Operator

TSO: Transmission System Operator

HETS: Hellenic Electricity Transmission System

HWEA: Hellenic Wind Energy Association

EU: European Union

ETS: Emissions Trading Scheme

EIB: European Investment Bank

PPC: Public Power Corporation

kW: kilowatt

MW: Megawatt

GW: Gigawatt

kWh: kilowatt-hour

MWh: Megawatt-hour

m/s: meters per second

km: kilometer

Energy; Offshore wind farm; Greece; Karpathos; Kassos

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1. Introduction

1.1 The transition to «cleaner» energy paths, the strategies, the targets and the benefits, regarding RES

The transition to a «cleaner» society constitutes an urgent challenge, in order to be limited further negative environmental implications. Renewable Energy Sources (RES) play a vital role regarding the attempt in the way of the accomplishment of energy targets for the climate protection. Therefore, the contribution of RES in the plan of the transition is crucial and its importance is indissoluble connected with the relevant objectives.

RES could have a significant portion in the creation of a more competitive, secure and sustainable energy system (Council of European Energy Regulators, 2016). Furthermore, renewable technologies could mitigate greenhouse gas emissions, which are emitted from fossil fuels and thus reduce global warming, with the support of traditional energy sources and in combination with them. RES, which include biomass, hydropower, geothermal, solar, wind, marine energies (i.e. tidal and wave energy) (Lei et al., 2019), are not only clean and alternative, non-conventional, sources of energy, but also abundant - inexhaustible (Kaushik et al., 2011).

Climate change is one of the fundamental concerns of the current century. For that reason, there are climate strategies (short term or long term) for the achievement of the transition towards a low-carbon global economy through cutting emissions. For instance, in the 2020 energy package of the European Union (EU) have been set as goals the derivation of 20% of EU energy from renewables, as well as the 20% cut in greenhouse gas emissions in comparison with 1990 levels (European Commission, n.d., a). In the 2030 climate and energy framework of the EU these percentages are modified to 32% for renewable energy and to 40% in greenhouse gas emissions in comparison with 1990 levels (European Commission, n.d., b). It is noteworthy the fact that the above targets differ from country to country and they not reflect invariable starting points. Moreover, EU member countries should map out, also, their own national targets on the basis of the climate protection. On the other hand, the long term strategy of 2050 poses as target an economy with net-zero greenhouse gas emissions and a climate-neutral society (European Commission, n.d., c).

At the same time, there is an agreement about the climate change, so called Paris Agreement. This particular agreement «sets out a global framework to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C. It also aims to strengthen countries' ability to deal with the impacts of climate change and support them in their efforts», is underlined in the webpage of the European Union (European Commission, n.d., h). The Paris Agreement is a benchmark for the history, because it is the first universal agreement for the climate change and it is signed (2015) by 190 parties. It is not only environmentally beneficial to be kept the global temperature rise below 2 degrees Celsius, but also economically and socially favorable, as a report of International Renewable Energy Agency (IRENA) remarks (2018).

Among the strategies of the European Union, there is also one more. Specifically, via the European Green Deal, the European Union tries to overcome the environmental challenges, by investing in friendly technologies, by decarbonizing the energy sector (European Commission, n.d., d) and by performing other significant actions. Moreover, Kyoto Protocol, which was adopted in 1997 and has been signed by 192 parties, is included in the global actions of reducing greenhouse emissions via appropriate measures and policies (United Nations Climate Change, n.d.).

All the above targets could not be succeeded, without the implementation of the RES. Besides, nowadays, governments and citizens link the process of combating of the climate change with RES, which not only minimize the pollution, but also provide a higher level of energy security, as it was already mentioned above, via their increasing presence in the energy mix.

Indicative for the importance of RES is the fact that IRENA stated that «renewable energy should account for two-thirds of the total energy supply in the world by 2050» (Gao et al., 2019). The widespread focus on renewables and the growing attention on them, during last years, could not leave unaffected governments of Greece, which promote the exploitation of RES. Specifically, in Greece, RES should have substituted completely, in collaboration with other forms of energy, according to the commitments of the Greek side (Zachariadis, 2019), the electric generation from lignite by 2028. Besides, it is cheaper to build wind or solar infrastructure than to operate existing lignite assets (BloombergNEF, 2020). In general, the penetration of RES is encouraged by many States, through various regulatory measures, incentives, and subsidies (Lei et al., 2019), since the decarbonization and not only is «at the core of the transition to a sustainable energy future» (International Renewable Energy Agency (IRENA), 2018, p.10).

One more benefit from the use of RES is that they could create 11 million additional jobs by 2050 (in the offshore wind industry is calculated that 74 occupations could participate in a project (Hensley and Wanner, 2020), in the sector of energy, according to IRENA. This is adding to the reasons for which RES and energy efficiency are the main pillars for energy transition from fossil fuels. In addition, offshore wind accounted for 210.000 jobs in Europe, in 2018 and in other words it accounted for 51% of the total employment in the wind energy field. Most of these jobs were in manufacturing (60%) (Wilson, 2020).

Moreover, concerning the renewable energy forecasting –RES present fluctuations in energy generation that they are difficult to be predicted-, which is fundamental for the planning, management and operation of the energy system, a number of different approaches have been performed in the literature. Nevertheless, the accuracy in the prediction, even for the next few minutes or days, is a very difficult task for experts, due to the chaotic energy data (Lei et al., 2019).

In any case, the global energy demand is rising, due to economic and population growth. This fact leads to a result, among others: The world needs new reserves and RES provide an endless wealth.

1.2 A brief history for wind energy and noticeable facts

Since thousands of years, people have been using wind energy. There are historic elements, which evince the use of wind energy even at 5,000 BC, when, for example, people were using wind energy to propel boats. Wind energy was used, also, in places around the world in order to be pumped water, while windmills, at their first form of course, were used for food production. Later, these structures and ideas were developed, with the aid of technology, mainly from European and American colonists and immigrants. One of the results was the generation of electricity from wind turbines, in the context of developing alternative sources of energy (Energy Information Administration (EIA), 2020). Actually, in Scotland, was installed, in 1887, the first known wind turbine, which was producing electricity for a cottage (Shahan, 2014).

It is noteworthy, also, the fact that the earliest windmills had vertical-axis. Indeed, the first historic documents about horizontal-axis windmills are detected around 1,000 AD in Persia, Tibet and China (Sahin, 2004). Consequently, it becomes perceivable that there are two types of wind turbines: the horizontal-axis wind turbines (HAWTs) and the vertical-axis wind turbines (VAWTs), but the first is the most common type.

In 1980, the world's first wind farm was installed on Crotched Mountain (New Hampshire, USA) and it was including 20 turbines at 30 kilowatts (kW) each, with a total generating capacity of 600 kW. The first European wind farm, with 5 turbines of 20 kW each, was placed, in 1982, in the Greek island of Kythnos (windeurope.org, 2020a).

However, the first OWF was posed in function 11 years after (1991) the first wind farm in the USA (on Crotched Mountain – New Hampshire) and specifically 2.5 km off the Danish coast, opposite of the town of Vindeby (Denmark). It had 11 turbines (450 kW each) and a total capacity of 4.95 MW. The Vindeby OWF (Figure 1) was dismantled, in 2017. During its lifetime, it produced 243GWh of power, in other words «what seven of the largest offshore wind turbines today can produce in a single year» (offshorewind.biz, 2017). Although the fact that Vindeby OWF seemed like a miniature in front of the today' s giant projects, it offered a vast experience in the offshore wind industry. Besides, it signalized the birth of this industry.

Figure 1: The Vindeby offshore wind farm, the first in the world (1991)

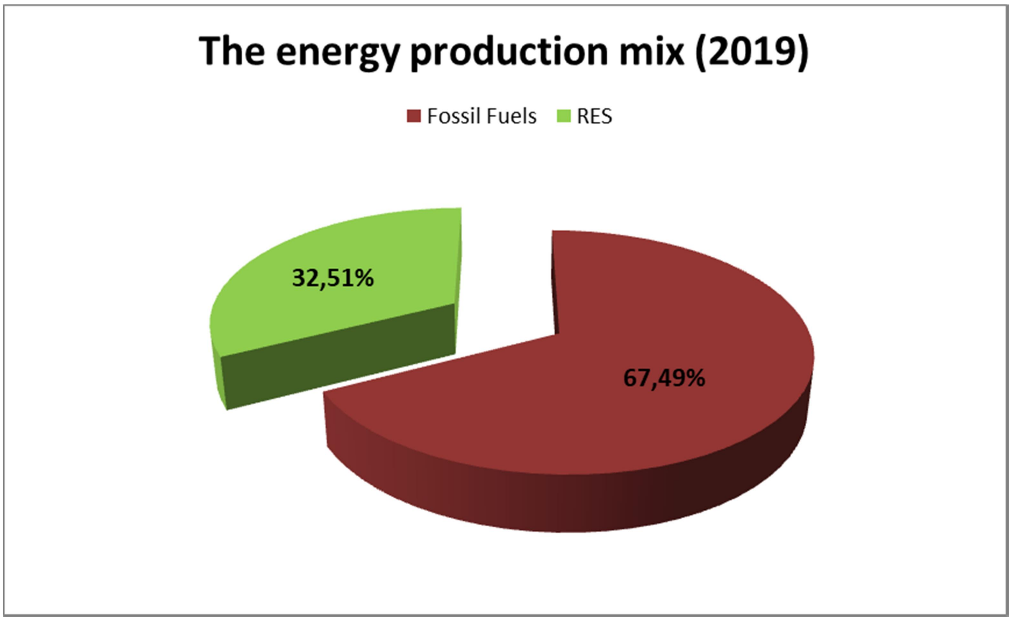
Source: WindEurope, n.d.

Another noticeable fact was the foundation of the European Wind Energy Association, in September of 1982, in Stockholm (Sweden). Currently, the WindEurope (i.e. formerly the European Wind Energy Association) has its base in Brussels (Belgium) and it promotes the use of wind power in Europe.

1.3 The energy mix and the energy targets of Greece

The energy production mix in Greece, in 2019, was shaped at 32.51% from the RES and at 67.49% from the fossil fuels (Graph 1). Furthermore, the residual energy mix, in 2019, was 22.93% for the category of the RES, 71.23% for the category of the fossil fuels and 5.84% for the category of the nuclear power (Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP), n.d.).

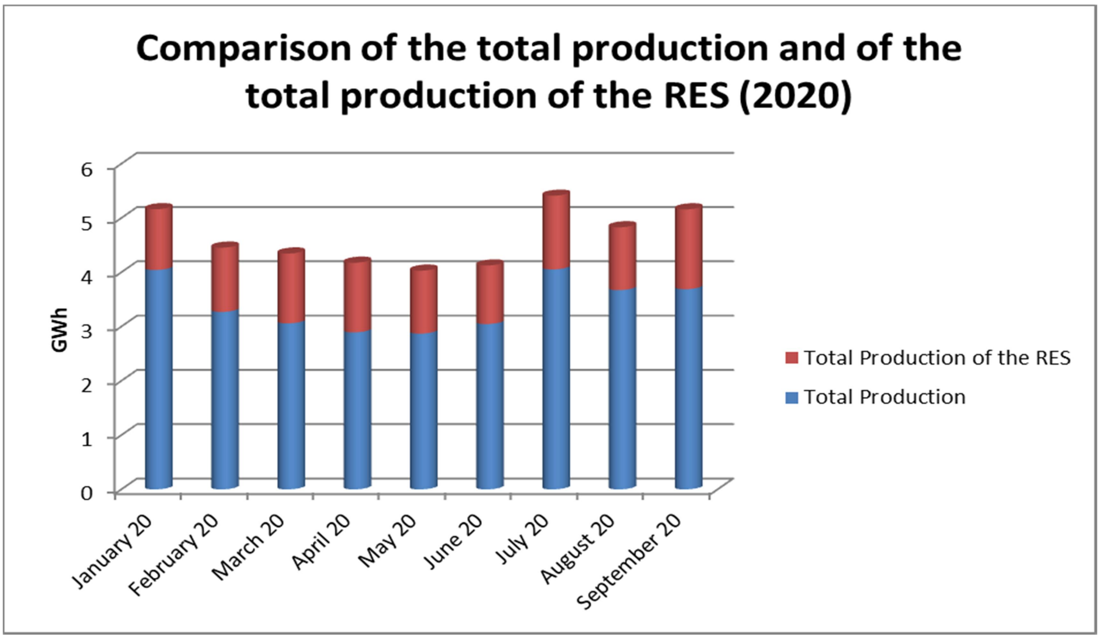
Graph 1: The energy production mix of Greece, in 2019



Source: Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP), 2020, p.8 / Edited by the author

The total production of energy from January to September of 2020, in Greece, was ranged from 2,870 to 4,053 GWh and the total production from the RES, during the same period, was fluctuated from 1,079 to 1,470 GWh (Graph 2) (Independent Power Transmission Operator (IPTO), 2020a).

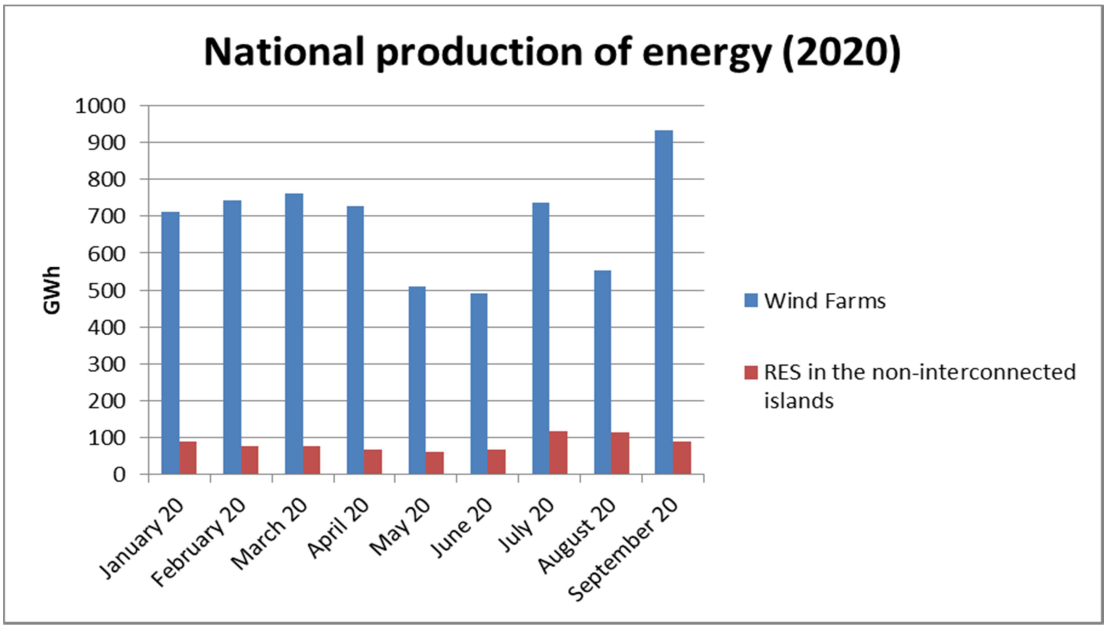
Graph 2: Comparison of the total production and of the total production of the RES in Greece, in 2020



Source: Independent Power Transmission Operator (IPTO), 2020, p.12 / Edited by the author

Graph 3 below represents the Greek production of energy from wind farms, from January to September of 2020 and the national production of energy from the RES in the non-interconnected islands (Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP), 2020b).

Graph 3: The production of energy in Greece, in 2020

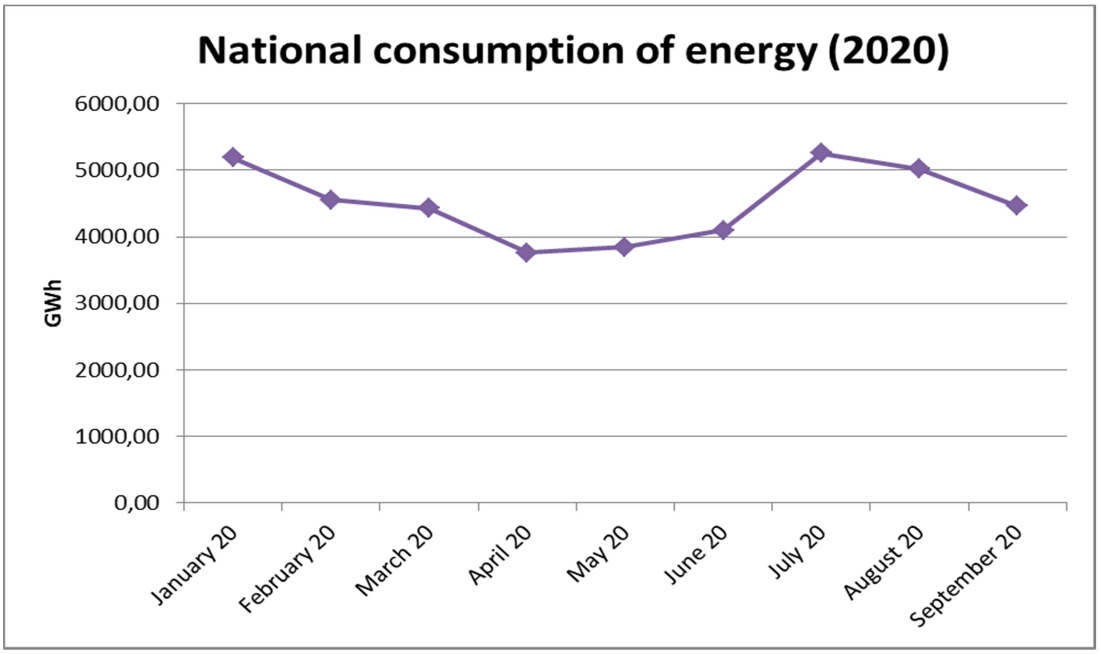


Source: Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP), 2020, p.9 / Edited by the author

In 2020, 200 new wind turbines of total capacity 517.5 MW were connected to the Greek network. This fact led to an increase of 14.4% in comparison with the year 2019. In total, the capacity of the wind farms, which were in commercial or test operation, in Greece, in 2020, were 4,113.5 MW. It is noticeable, also that in 2000 there were wind farms of total capacity 237 MW only (Hellenic Wind Energy Association (HWEA), 2021b, p.1). At the end of 2020, Central Greece was at the top of installed MW regarding the wind farms and specifically it had 1,678 MW (41%), followed by Peloponnese with 619 MW (15%) and Eastern Macedonia - Thrace with 485 MW (12%) (Hellenic Wind Energy Association (HWEA), 2021c).

Graph 4 below depicts the Greek consumption of energy from January to September of 2020. In this nine month period, it is observed that the national consumption ranged from 3,762.9 (April) to 5,251.7 (July) (DAPEEP, 2020b).

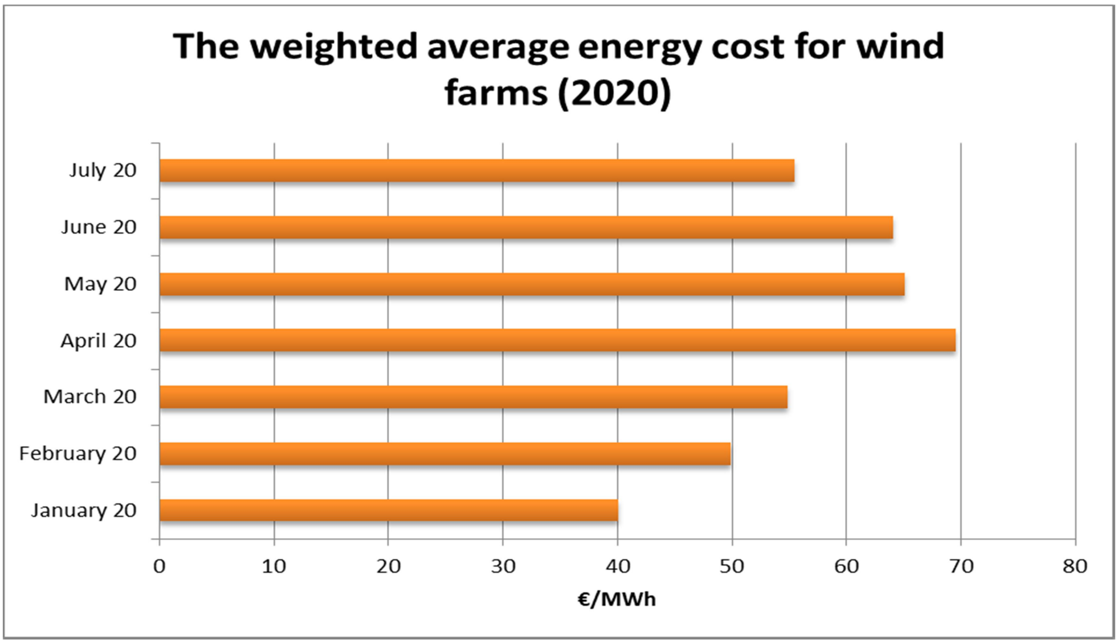
Graph 4: The consumption of energy in Greece, in 2020



Source: Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP), 2020, p.16 / Edited by the author

Also, the weighted average energy cost for wind farms, in Greece, for the period January – July of 2020, was fluctuated from 40.09 to 69.56 €/MWh (Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP), 2020a), as the diagram (Graph 5) below illustrates.

Graph 5: The weighted average energy cost for wind farms in Greece, in 2020



Source: Renewable Energy Sources Operator & Guarantees of Origin (DAPEEP), 2020, p.19 / Edited by the author

Regarding the energy targets of the country, the objective for the share of the participation of the RES in the gross final energy consumption for the year 2019 was 16% (in 2019, Greece succeeded the percentage of 19.6% (European Commission, n.d., e), the same target for the year 2020 was 18%, for the year 2030 is 35% (Hellenic Republic, 2014) and for the year 2050 is approximately 67% (Hellenic Ministry of the Environment and Energy, 2019b). Furthermore, the forecast for the installed power of OWFs, in Greece, for the year 2030, is 0.3% GW and for the year 2050 is 0.4 GW (Hellenic Ministry of the Environment and Energy, 2019b).

Greece can become one of the leaders of the energy transition in Europe by 2030, according to a study of BloombergNEF (BNEF) (2020). Actually, a total of 27 billion Euros is needed to be invested in new electricity generating capacity in Greece by 2050, is highlighted in the same study. Also, approximately 11.5 billion Euros is expected to be invested by 2030 in new renewable generating capacity, more than double from the 5.3 billion Euros invested in green energy in the country into the period 2009-2019.

1.4 Terms of «wind energy» and «offshore wind farm»

Although the fact that the today's wind turbines are much more complicated regarding their mechanisms in comparison with older machines, the principles of their function are the same.

«Wind energy (or wind power) refers to the process of creating electricity using the wind or air flows that occur naturally in the earth's atmosphere. Modern wind turbines are used to capture kinetic energy from the wind and generate electricity», is marked by American Wind Energy Association (AWEA) (n.d.), as a term of wind energy. So, wind turbines convert the kinetic energy into mechanical power and a generator can convert mechanical power into electricity (Sahin, 2004).

The wind farm or wind park contains a number of wind turbines, which are established in the same location and produce electricity. Wind farms could be either onshore or offshore. OWFs are collections of wind turbines located in water. Wind farms differ, also, in size, since some of them include small number of wind turbines, while others have encompassed several hundreds of wind turbines.

Figure 2: An offshore wind farm

Source: Basova, M., n.d.

1.5 Offshore wind farms around the world and the locations where there are the most and the biggest of them – Reference to the biggest offshore wind turbines

Installations of OWTs have taken place in 18 markets across the world. Twelve (12) of those are in Europe (Hellenic Wind Energy Association (HWEA), 2021a). These markets are: UK (leader), Germany, China, Denmark, Belgium, the Netherlands, Sweden, Vietnam, Finland, Japan, South Korea, the USA, Ireland, Taiwan, Spain, Portugal, Norway, France.

The world's largest OWF is going to start producing energy for use during the first months of 2021. The project is named «Hornsea One» and it is located 120 km off England's Yorkshire coast, in the Humber region. The wind farm is composed of 174 wind turbines (190 meters height each) and the area, which is covered, is bigger than Malta or the Maldives. Also, it has 1.2 GW of capacity and for that reason it is the first with more than 1 GW of capacity. Moreover, it could power approximately one million UK homes and it is expected to create 2,300 jobs. Just a single rotation of one and only of the turbines has the possibility to supply energy to an average home for an entire day (Ørsted, n.d.; power-technology.com, n.d.; Ziady, 2019).

At the same time, under construction is the «Dogger Bank wind farm», a cluster of wind farms, which is located off the east coast of Yorkshire, in the North Sea, in England. It is expected to offer, as a total of four OWFs, a capacity of 4.8 GW (1.2 GW each OWF). The completion of the ambitious project, which will generate renewable energy for over 4.5 million homes each year, has been scheduled between 2023 and 2025.

Nevertheless, the biggest and most powerful OWT in the world, in –almost- commercial function and as a unit, is the «Haliade-X», located in Maasvlakte, in the Port of Rotterdam. It is a wind turbine with capacity of 12 MW, 260 meters height (Eiffel Tower has 324 meters height), 220-meter rotor, a 107-meter blade, and digital capabilities. «The Haliade-X can capture more Annual Energy Production (AEP) than any other OWT even at low wind conditions», underlines the General Electric Company, which is the manufacturer of this project and also points out that the

«Haliade-X» could provide «enough clean energy to power 16,000 European households and save up to 42,000 metric tons of CO_2, which is the equivalent of the emissions generated by 9,000 vehicles in one year» (General Electric, n.d.). The wind turbine is at the moment (January of 2021) at the testing phase and its normal function was planned to begin during the second half of 2021 (Skopljak, 2019).

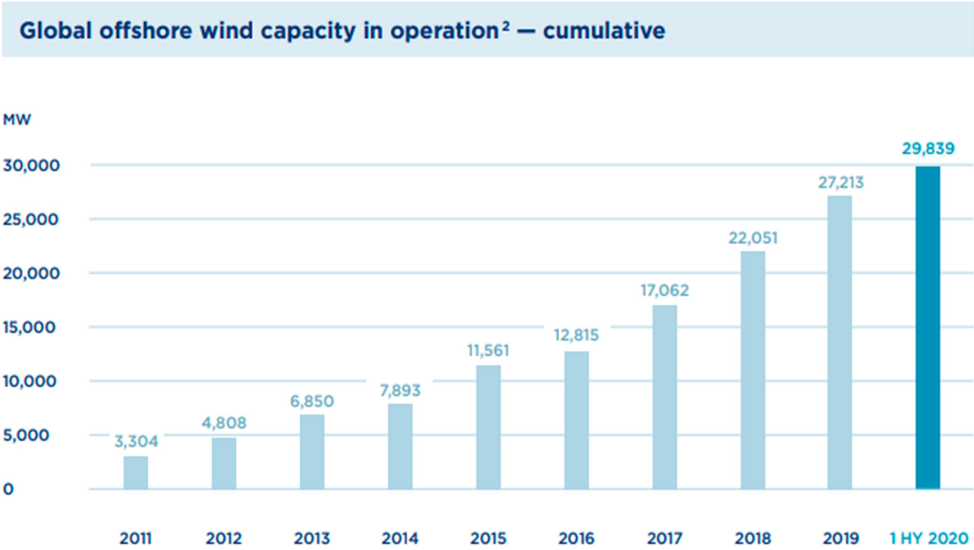
Nevertheless, 190 «Haliade-X» 13 MW wind turbines (220-meter rotor, 107-meter blade), an improved version of «Haliade-X» 12 MW model, will be put to the «Dogger Bank offshore wind farm» A and B. The turbine installations are expected to begin in 2023 (Buljan, 2020a).

At the same time, Siemens Gamesa released in May 2020 its SG 14-222 DD model (OWT), which can reach 15 MW, but it will be commercially available from 2024.

1.6 Forecasts about the wind energy and the offshore wind industry

The global expansion of the offshore wind industry is continued. According to the elements of the Global Offshore Wind Report, in the first half of 2020 there were in operation nearly 30 GW of offshore wind capacity around the world (Figure 3) (Backwell, et al., 2020). At the same time (2020), there were more than 8 GW of offshore wind capacity, under construction, globally (Backwell, et al., 2020).

Figure 3: Global offshore wind capacity in operation

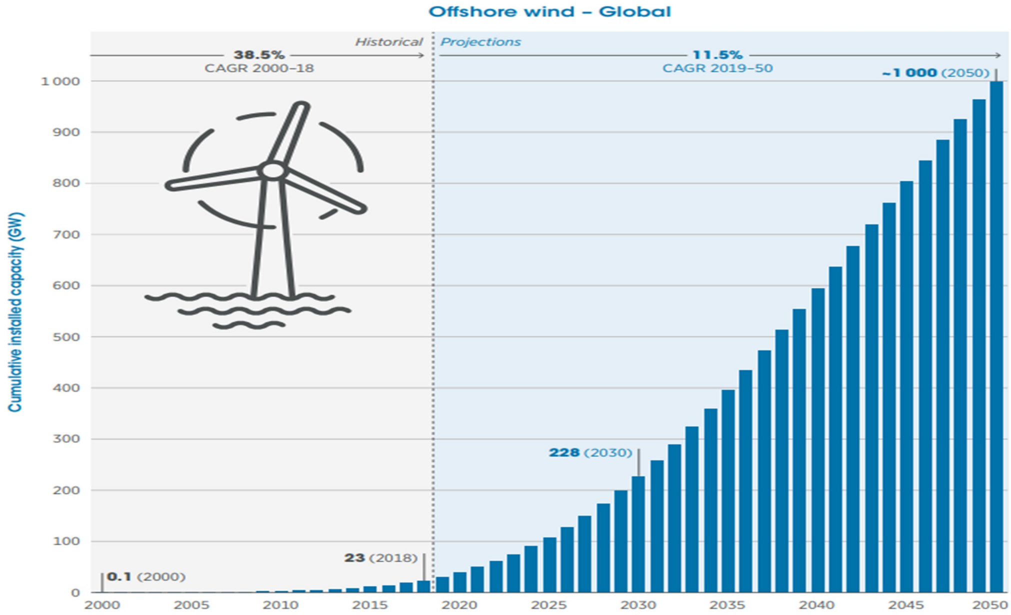


Source: World Forum Offshore Wind (WFO), 2020, p.4

Furthermore, Organization of the Petroleum Exporting Countries (OPEC), underlines (2020) that between 2019 and 2045, renewables -including wind energy- will thrive by 6.6% on average, in other words faster than any other source of energy.

In the offshore wind outlook to 2050, IRENA (2018) underlines that the offshore industry is predicted to grow significantly during the next three decades and the offshore wind capacity is expected to reach approximately the 228 GW in 2030 and the 1 TW in 2050, globally (Figure 4).

Figure 4: Cumulative capacity of the offshore wind

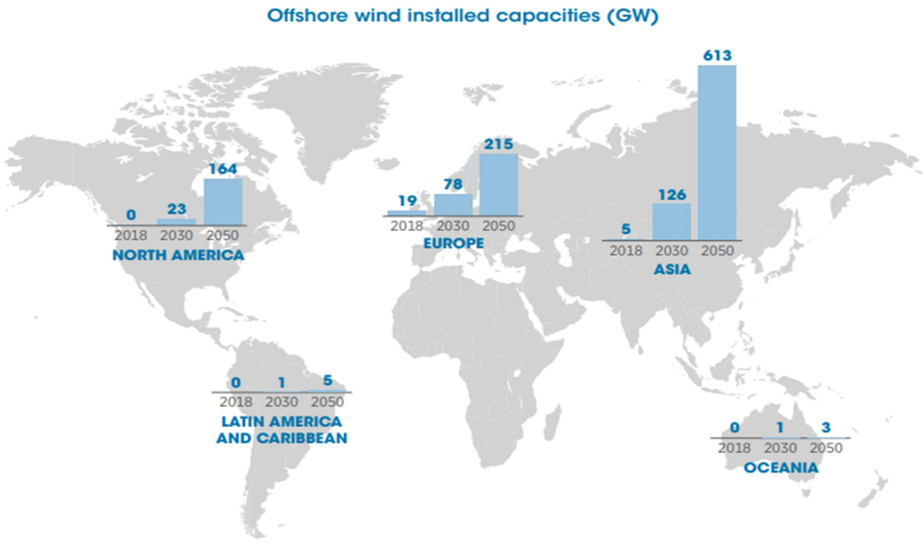


Source: International Renewable Energy Agency (IRENA), 2019, p.43

Although the fact that Europe dominates (in terms of technologies and manufacturing), at the moment (January of 2021), in the offshore wind market (in 2019, the 75% of the total global offshore wind installation was situated in Europe (Backwell, et al., 2020) and 2027 is expected that it will be the first year, in which, in Europe, the offshore wind will exceed in MW the onshore wind (Arapogianni, et al., 2011), Asia is foreseen to gain a significant lead in 2030 and expand it by 2050, as the picture below (Figure 5) indicates. China, which was the world's no. 3 power (Lim, 2020), after the UK and Germany, in the offshore wind market at the end of 2019, is expected to be the ruler in the offshore wind industry just from 2030. Powerful rise is predicted also to take place in the North America, as well as in India.

Nevertheless, the best year in history for the global offshore wind market was 2019, with 6.1 GW new offshore wind installations added, almost twice the 3.4 GW of 2015 (Backwell, et al., 2020).

Figure 5: The offshore wind capacity around the world



Source: International Renewable Energy Agency (IRENA), 2019

However, in the global energy mix there have been meteoric changes during the past two decades and especially during the last decade. Due to these rapid changes, projections of the future global energy mix are inclined to become less long term (Ting and Vasel-Be-Hagh, 2020) or at least to be reviewed.

1.7 Comparison between offshore and onshore wind farms

Offshore and onshore wind farms have not only commons -their nature and objectives are similar-, but also differences, since the circumstances in sea and in shore respectively, vary.

First of all, OWTs have differences in foundation procedures in comparison with onshore wind turbines (Apostolou and Kaldellis, 2017). At the same time, the majority of the offshore projects demonstrate higher energy performance and higher capacity factors than the onshore wind parks, due to the better wind conditions in sea (Apostolou and Kaldellis, 2017) and also due to the absence of possible physical obstacles, like mountains, hills etc. One of the key differences between offshore and onshore wind power generation is the consistency. OWFs generate electricity at a steadier rate. Moreover, OWPs could be placed to a greater extent, into the sea, in relation to onshore wind parks. Besides, difficulties related to available space, such as land acquisitions, may arise complications regarding a possible installation of an onshore wind farm. Furthermore, OWFs have, in general terms, lower risk of social opposition (Enevoldsen and Valentine, 2016), but this conclusion is stemmed, mainly, from projects, which are not near to coastlines (visual impact).

Also, the high costs for the installation, operation and maintenance of OWFs constitute the main drawbacks for such a project. The construction of an OWP is more expensive than this of an onshore, due to larger wind turbines, larger foundation structures, submarine cables and special vessels (Enevoldsen and Valentine, 2016). Consequently, offshore wind projects are, usually, larger than the onshore, in order to be offset higher investment costs.

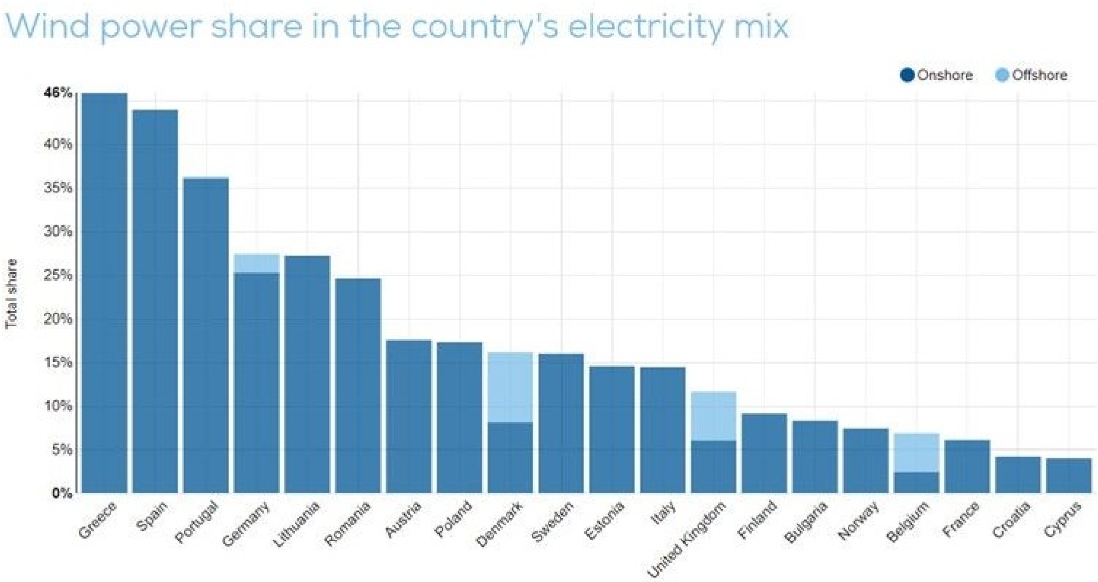
In conclusion, onshore wind farms are, at the moment (January of 2021), the most prominent type of wind parks. Nevertheless, OWFs are attracting more and more interest. This particular technology is not as developed as that of onshore wind, but it is growing rapidly and when it becomes even more mature and costs competitive, OWFs could be very appealing. However, many variables will define even then the selection between offshore and onshore. So, the case by case examination is the safer way of observation.

2. The offshore wind in Greece

2.1 The possibility of the installation of an offshore wind farm in Greece

Greece does not have, currently (January of 2021), even one installed OWP, although the fact that the wind potential of the country is high, especially in the Aegean Sea. Actually, Greece presents some days the highest wind share into the electricity mix among European countries. One of these days was the 29th of December 2020, when the wind power had a participation of 45.9% to the energy mix of Greece (Figure 6), according to WindEurope.

Figure 6: The wind power share in the country's electricity mix



Source: WindEurope, 2020

Indeed, the ex-Minister of Environment and Energy of Greece, Giannis Maniatis, claim in the context of a study of him that in the Aegean Sea there is wind potential of 7-10 GW (Maniatis, 2020). However, according to estimations of European Wind

Energy Association (EWEA), Greece will have, in 2030, at a high scenario, 500 MW installed capacity of offshore wind (Corbetta, et al., 2015).

It is noteworthy, also, the fact that the objectives of Greece regarding the green energy cannot be satisfied without the aid of OWFs. For that reason, the Ministry of the Environment and Energy had announced (April 2019) the procedure of the first pilot competition (Liaggou, 2019), during the second semester of 2020, for the installation of an OWF. Nevertheless, this particular competition is possible to be accomplished during the year 2021, as long as there will be a relevant ministerial decision, according to the information that was provided by the current (January of 2021) President of Regulatory Authority for Energy (RAE), Mr. Athanasios Dagoumas, to the author, via an interview (16/09/20). Mr. Dagoumas also said, in the context of the same communication, that there is a perspective, in general, for the construction of an OWF, in Greece. Indeed, during the first semester of 2022, it is expected that the first –not pilot- competition for OWFs in Greece will be conducted.

In 2010, the Ministry of the Environment and Energy of Greece assigned the selection of marine areas across the country, appropriate for the installation of OWFs with a horizon to 2017. The selection criteria set were:

• Exclusion of areas where the development of OWFs is incompatible with other uses, within a zone of six (6) nautical miles.

• Exclusion of areas with depths greater than 50 m.

• Avoidance of places with significant effects on the environment.

• Minimization of visual disturbance.

Also, areas, which are bounded by the Greek armed forces, were excluded.

Twelve areas (Figure 7) were finally chosen and these are located in Saint Efstratios, Alexandroupoli, Karpathos, Othonoi, Thassos, Kymi, Lemnos (north and south), Lefkada, Petalious, Samothrace and Fanari, with a total capacity of 1.2 GW. However, spots for floating OWPs were not examined. Instead, only bottom fixed technology was assessed (HWEA, 2021a).

Figure 7: The twelve (12) selected zones, in Greece, appropriate for possible installations of offshore wind farms

Source: Wikipedia, 2020 / Edited by the author

However, since 2010 until now (January of 2021) the plans have been remained as archive, even though in a seminar during April 2019 between representatives of the Norwegian embassy in Greece and executives of the HWEA, had been underlined by the Norwegian ambassador, Jorn Gjelstad, that «the offshore wind farms not only could convert Greece in a leading energy factor, but also could revitalize significant sectors of the Greek economy». At the same time, the representative of the Norwegian company, Equinor, Arne Eik, highlighted that Greece has one of the best prospects in the whole Europe, regarding the offshore wind energy (economistas.gr, 2019).

In addition, it is noteworthy that there is a wind farm in Saint Georgios (Greece), in the complex of Saronic islands, which has offshore characteristics (for example, submarine cables), but it is an onshore wind park and it is connected with the mainland system (Figure 8).

Figure 8: The onshore wind farm, with offshore characteristics, in the island, Saint Georgios, in Greece

Source: Terna Energy, n.d.

2.2 Legislative framework in Greece

With the law 3468/2006 (Hellenic Republic 3468/2006), Greece permitted for the first time the installation of OWFs. Chapter C, article 7 of this particular law provides the opportunity of installation and operation of stations of production of electricity by RES, as well as of each relevant project, into the sea, since the right of use has been granted.

Two years later (December of 2008) with the article 5 of the joint ministerial decision (n. 49828) for the approval of the «Special spatial planning framework for renewable energy sources» (Hellenic Republic 49828/2008), the national area was divided into categories, including that of the offshore marine area. In the article 10 (paragraph A.1.) of this particular decision were mentioned «the special criteria for the location of wind farms in the sea area and the uninhabited islets», in which was underlined also that «the positioning of wind farms is allowed in all marine areas of the country, which meet wind exploitation conditions, provided that they are not part of special institutional regime of explicit prohibition of the installation or are not an exclusion zone (…)».

Further regulations, which will be analyzed below, were institutionalized with the enactment of the law 3851/2010. Moreover, there are references about the offshore wind and about the exploitation of marine potential, in general, also in the laws 4414/2016 and 4546/2018 respectively.

Between the laws 3468/2006 and 3851/2010 there are some differences. For example, in the article 6A of the law 3851/2010 (Hellenic Republic 3851/2010), which is mentioned exclusively to OWFs and specifically in the paragraph 4, is declared that for the installation of any OWF, a permission is published by the Minister of Environment and Energy by way of derogation from the licensing provisions of law 3468/2006. In the aftermath, as defined in paragraph 5 of the same article, an open public competition, with decision of the Minister of Environment and Energy, is conducted, before the construction of an OWF (Hellenic Republic 3851/2010).

Of course, the choice for the installation of an OWF should be harmonized with the «Special framework for spatial planning and sustainable development for renewable energy sources». In this (Article 10), 11 special criteria are defined for the spatial planning of OWFs (Hellenic Republic 49828/2008). In this framework, directions of spatial organization at national level are included, among others, for «areas that are of particular importance from a spatial, environmental, developmental or social point of view, such as in particular coastal, sea and island areas, mountainous and problematic areas» (Hellenic Republic, 2014).

The Ministry of the Environment and Energy of Greece published in November 2019 its national energy and climate plan, in which it marked that the aim is to operate, by 2030, in Greece, OWPs of total installed capacity 250 MW. Moreover, it underlined the importance of their possible, in future, contribution in the energy mix of the country. OWFs, according to the Hellenic Republic, are predicted to set a new, but necessary, challenge for the regulatory framework (Hellenic Ministry of the Environment and Energy, 2019a).

The Secretary General for Energy and Mineral Resources, in Greece, Alexandra Sdoukou, underlined (HWEA, 2020) during a webinar (07/10/20) with title «Necessary legislative adjustments to promote offshore wind energy in Greece» that the Greek State is working on a comprehensive policy on this issue. Also, she revealed the three pillars on which the methodology of the Greek experts should be based: a) the issues about the positioning of OWFs and about their permission are extremely important. In other words, the regulatory framework should be one of the priorities, b) the interconnection with the electricity system and the selection of the relevant model, c) the way of compensation of investors. At the same time, Mrs. Sdoukou mentioned that «Greece will have quite soon a robust legislative framework for offshore wind farms». It is noted also that the marine spatial planning shall be completed by 31 March 2021 at the latest, according to the law 4546/2018 (Article 5, par. 3), fact that could entail progress concerning the preparation for a possible installation of an OWF in Greece.

However, at the moment (January of 2021), there is not a defined timetable for OWPs regarding a potential implementation, although the fact that the desire for their development in Greece and finally for their contribution in the Greek energy mix is taken for granted, as it is mentioned in the national energy and climate plan of the Ministry of the Environment and Energy of Greece (2019a).

2.3 One appropriate model for Greece, for the design of OWFs

Three models, which are met in European countries, distinguish the design of an OWF and provide main principles for it. These models are the decentralized, the intermediate and the centralized model, while in all of them the support regime of the State to the producer is provided through competitive procedures.

According to a study developed by HWEA, in cooperation with the Norwegian Wind Energy Association (NORWEA) (2021a), was assessed that Greece should aim to a decentralized model, in order to design OWPs. In case of a decentralized model, which is used by the UK (the leader in OWFs around the world), according to the same study (HWEA, 2021a, p.15), «the State regulates the development of wind farms via offshore spatial plans and environmental law. The State chooses investors, who subsequently have the right of preference in the development of wind farms in broad marine areas, through a substantially competitive bidding process with criteria their economic and technical ability to implement the proposed projects (…). The final decision on project assignment is obtained based on the economy of kWh produced by the OWF, through competitions for contracts for difference. In the countries, which follow the decentralized development model of OWFs, the responsibility of their interconnection in both parts, offshore and land, belongs to private investors».

Some of the advantages of the decentralized model are that it not requires neither excessive investments by the State, nor excellent efficiency by the Public Administration. In addition, the potential investors are not exposed to great risks. Of course, Greece should improve points of this model.

At the same time, Greece should review and update elements of its legislation about OWFs and also it should encompass ingredients from the international experience. Moreover, some other actions are necessary for the development in this field, for example the creation of «blocks» for the installation of OWFs, as it happens for the hydrocarbons, an initial screening process in the marine spatial frameworks, regarding the environmental risks and the definition of the wind potential of the marine spatial frameworks.

On the other side, it should be mentioned that the Independent Power Transmission Operator (IPTO) supports the model of Germany, which is intermediate, but it has also characteristics of the centralized model. In this model, the Transmission System Operator (TSO) is responsible for the connections to the grid.

2.4 Attempts for the creation of an offshore wind farm in the area of Greece and the two production licenses from RAE

During last years, firms have examined the possibility of exploitation of wind potential in Greece, through the installation of an OWF.

One of the representatives of the Greek Regulatory Authority for Energy (RAE), Nikos Christantonis (Engineer of renewable energy systems), informed the author, via an interview (14, 19/10/20) that from 2001 until 19/10/20 a total of 40 applications had been submitted for production licenses from OWFs, with an overall capacity of 5.974,15 MW. Of these, 14 applications with a total capacity of 1,034 MW have been rejected/withdrawn and 24 applications with a total capacity of 4,225 MW are being evaluated by RAE. Also, two production licenses from OWFs with a total capacity of 714,15 MW have been granted already by RAE. These two areas are in Alexandroupoli (Figure 9) and in Lemnos (Figure 10).

Moreover, after the year 2010, a total of 6 applications were submitted for production licenses from OWFs with a total capacity of 1,957 MW and of these 1 application with a capacity of 306 MW has been withdrawn, while 5 applications with a total capacity of 1,651 MW are being evaluated by RAE (Table 1).

Table 1: The applications to RAE for offshore wind farms in Greece, into the period 2001-2020

APPLICATIONS TO RAE FOR OFFSHORE WIND FARMS IN GREECE (2001 - 2020)	
TOTAL APPLICATIONS 40	OVERALL CAPACITY (MW) 5.974,15
STATUS (TOTAL): REFUSAL / WITHDRAWAL 14	OVERALL CAPACITY (MW) 1.034,00
STATUS (TOTAL): UNDER EVALUATION 24	OVERALL CAPACITY (MW) 4.225,00
STATUS (TOTAL): PRODUCTION LICENSES 2	OVERALL CAPACITY (MW) 715,15
AFTER THE YEAR 2010 6	OVERALL CAPACITY (MW) 1.957,00
WITHDRAWAL AFTER THE YEAR 2010 1	OVERALL CAPACITY (MW) 306
UNDER EVALUATION AFTER THE YEAR 2010 5	OVERALL CAPACITY (MW) 1.651,00

Source: Christantonis, N. (interview), 2020 / Edited by the author

Figure 9: The area in Alexandroupoli, for which (i.e. with the green color) a production license from offshore wind farm has been granted by RAE

Source: Regulatory Authority for Energy (RAE), Geoinformation map, n.d., a

Figure 10: The area in Lemnos, for which (i.e. with the green color) a production license from offshore wind farm has been granted by RAE

Source: Regulatory Authority for Energy (RAE), Geoinformation map, n.d., b

For the project in Alexandroupoli, which includes 60 wind turbines of 3.6 MW (Siemens SWT/3.6 MW) each (216 MW in total), RAE licensed in 2012 the Greek firm, «Thrakiki Aioliki 1 A.E.», which belongs to the Copelouzos Group. The firm has received, also, license from IPTO and during the period of the writing of this thesis, it was drawing up the environmental impact study.

Concerning the project in Lemnos, the Greek company, «City Electric A.E.» (it is subsidiary of the company «RF Energy S.A.»), manifested, in previous years, its interest about the fulfillment of its plan regarding OWF in the area and was licensed by RAE. The project has designed to encompass 81 wind turbines of 6 MW (Repower 6 MW) each (486 MW in total). The interest of the company still exists, but in order to move on it needs a complete framework for OWFs. So, the Greek State should create a legislative framework and then the company will have the possibility to evaluate all the parameters to decide if it will be feasible for the project to be implemented.

Last but not least, it is noticeable the fact that Equinor, which is one of the most well-known corporations that operate also in the field of this particular technology, shared its proposal for the installation of an OWF in the area among the islands, Tinos, Syros, Mykonos. The Norwegian firm considers that Greece offers ideal conditions for such a development (amna.gr, 2019). Such an investment could power, according to the firm, 40,000 households. Of course, interest for installations of OWFs has been expressed also by other companies, Greek and foreign.

2.5 A Greek innovation for the collection of wind and environmental data

In 2017, «FloatMast» (floatmast.com, n.d.) offshore wind measurement platform was installed in the Aegean Sea (Figure 11), in Greece and specifically off the coast of the island of Makronissos, at a sea depth of 65 metres and at a distance of 250 metres from the shore (Durakovic, 2019).

It was the first Tension-leg platform (TLP) mast in the world and it would provide advanced wind and environmental data for prospective investors, who may interest for the installation of an OWF in Greece. It was developed by the Greek firm «ETME» and it was funded to a degree by the program Horizon 2020 of the EU, with 2 million Euros (European Commission, 2020a).

Figure 11: The «FloatMast» offshore wind measurement platform, in Greece

Source: FloatMast, 2017

A meteorological mast should be installed in the area of the interest for this thesis, in order to be examined accurately the necessary data, before the installation of the OWF between Karpathos and Kassos.

3. Technical issues about the offshore wind industry

3.1 Types of foundation and the two groups of wind turbines

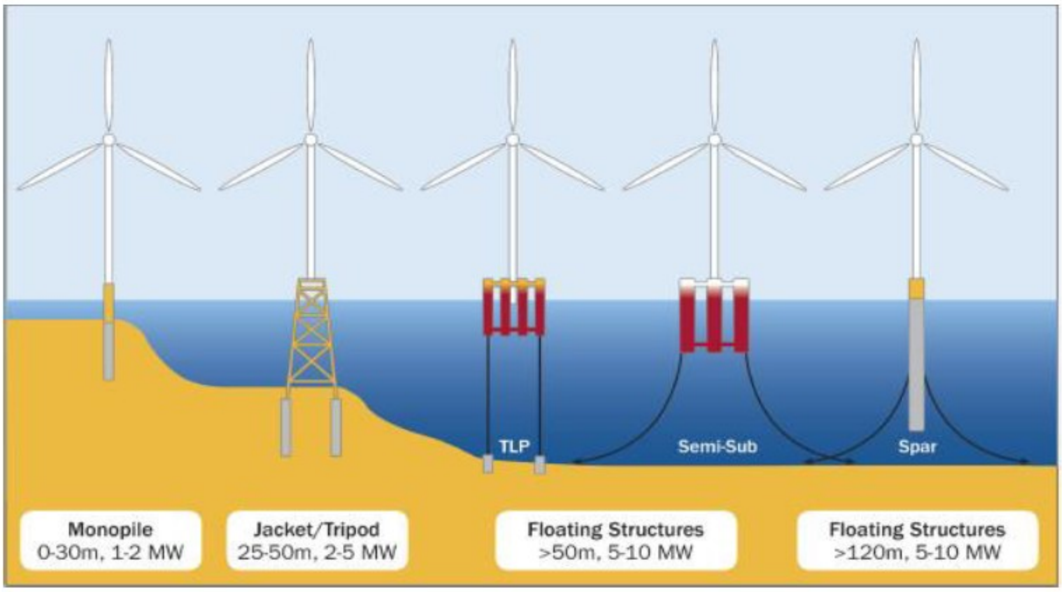
One point of difference between the offshore and onshore wind turbines is the way of foundation, because the OWTs should be resistant to wave loads and sea currents. The foundation of OWTs (Figure 12) is a sector that it is developing constantly, since the desire for installation of wind farms farther and farther away from the coast, creates the need of finding of new ways for the foundation of towers.

Monopiles, which are adopted, in the major part of the cases, as a technique, are the most common sort of foundation in shallow waters and they are characterized by their lower cost, their simplicity during the process of foundation and also by the quick installation procedures. This type of foundation has large diameter (approximately 4-6 meters), thick walled (approximately 5 cm) and steel tube (Soursou, 2017). A percentage of 40-50% of the pile is embedded into the seabed with the aid of a large floating hydraulic hammer, which rotates the steel tube into the seabed. The large diameter and the thick walled are used as a defensive tool to soil, water and in general to environmental conditions. Of course, before the foundation should be conducted inspection to the seabed, since if it has thin sandy material, there is jeopardy of collapse in the case of an earthquake. For that reason, also before the foundation, is necessary an analysis for the resistance of the seabed. Furthermore, in monopile structures is of paramount importance the insurance of the inflexibility, in other words of the stability of the tower.

Regarding the selection of the material of the construction, steel that it is used in oil and natural gas offshore platforms, has average life expectancy of 50 years, while the concrete, with appropriate maintenance, 100 years. The foundation constitutes, approximately, the 40% of the cost of the total construction, so the use of concrete could decrease the expenses and offer a better prospect for amortization, due to its longer lifecycle.

The other types of foundation are: Jacket/Tripod (they are proper for supporting relatively large OWTs installed in deep waters and their structure is weighed 600 tonnes, so they provide a stiff supporting design) and Floating Structures (in this category, which encompasses many challenges and high costs, are included the three main floating base types, which are stemmed from oil and gas offshore platforms: Tension-leg platform (TLP), Semisubmersible, Deepwater floating Spar).

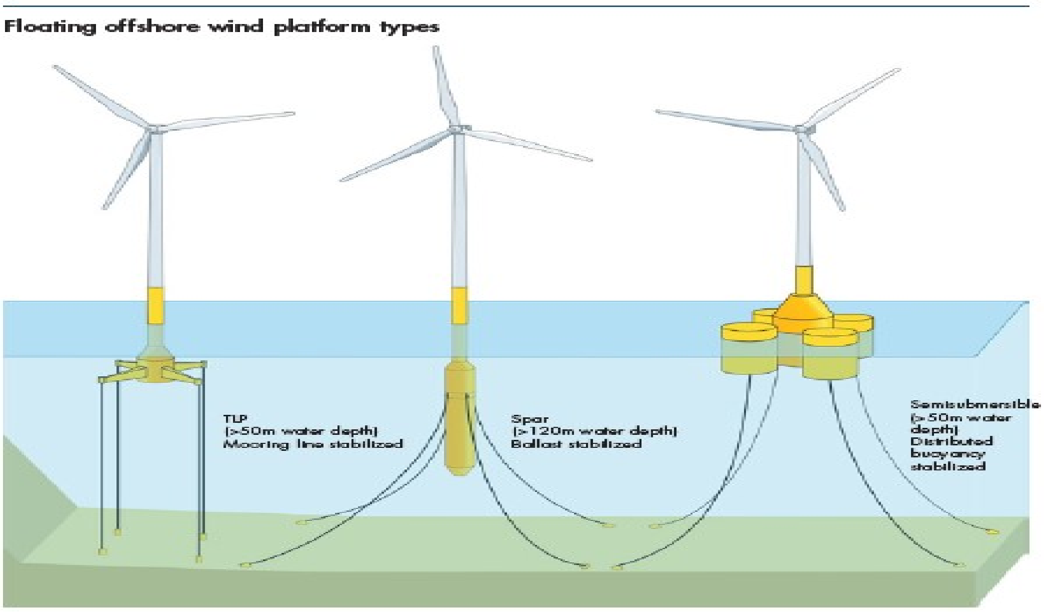
Figure 12: The types of foundation of offshore wind turbines



Source: Bailey, et al., 2014, p.9

Floating structures (Figure 13) for wind production could be proved a game changing technology, since they allow much extensive exploitation of wind resources. In addition, it is considered that this technology could minimize the criticism of habitants, because it is installed in deeper waters and even farther from the shore. The world's first commercial floating wind park (2017), in 220 meters water depth, was the «Hywind Scotland», with a total capacity of 30 MW (i.e. there are also other OWFs of similar total capacity, in Europe). Around 2024, a 200 MW floating wind farm in Canary Islands may become the largest floating wind project globally (Institute for Energy Economics and Financial Analysis (IEEFA), 2019). Floating wind, which is the future of the offshore wind, is beginning to expand in the EU and in Asia and is likely to boom from 2025, due to its full commercialization that it is expected to open new markets for the offshore wind (European Commission, 2020c).

Figure 13: Floating offshore wind turbines types



Source: Backwell, et al., 2020, p.85

Contemporary wind turbines are divided into two main groups: the horizontal-axis variety and the vertical-axis design. The most common type is the horizontal-axis wind turbines (they operate «upwind»), which consists of two or three blades and is more efficient compared with those of vertical-axis. On the other side, vertical-axis wind turbines are not manufactured for commercial purposes. Indeed, the only vertical-axis wind turbine, which has ever been constructed, is the Darrieus machine

(Figure 14). It took its name from the French engineer, Georges Jean Marie Darrieus, who fabricated it in 1931.

Figure 14: The so-called «Darrieus wind turbine»

Source: Sandia National Laboratories, 2012

3.2 Monopile vs Floating type in Greece and the reasons behind the selection of the author

It is noteworthy the fact that at least in Greece there are a few sites with distance of 42 km (see pages 58-59 of this thesis) from the coast and at the same time appropriate for the installation of an OWF. Besides, in Greece the Exclusive Economic Zone (EEZ) has not been defined for all the areas and in some of them the limit continues to be the 6 nautical miles (approximately 10 km), while, for example, England, which has developed big offshore wind projects in the North Sea, has rights, also, very far from its coasts, due to its EEZ (approximately 200 nautical miles - approximately 322 km).

According to predictions (Kielichowska, et al., 2020), the first OWF in Greece, if there will be one, will be floating and not with monopile foundation. The reason is that the Mediterranean region, including Greece, has deep waters even at a very short distance from the coast. This fact means that for example, even at a distance of 5 km from the shore, the water depth may be 150-300 meters and in general, in the major part of the cases, more than 30 meters, which is the limit for the monopile foundation. On the contrary, these water depths are not met in the North Sea, where the water depths are usually shallow. Actually, the «Dogger Bank offshore wind farm», in the North Sea, one of the biggest in the world, is installed at water depths 15-36 meters, approximately 130 km off the east coast of England and monopile foundation has been used.

Consequently, in Greece, in addition to the fact of deep waters and in order to be limited the visual impact (and the social reactions), in order to be increased the profit and the participation of the OWF in the energy mix (less visual impact, more wind turbines), as well as in order to harness more the wind potential, the choice of the installation of a floating OWP is substantiated by its supporters.

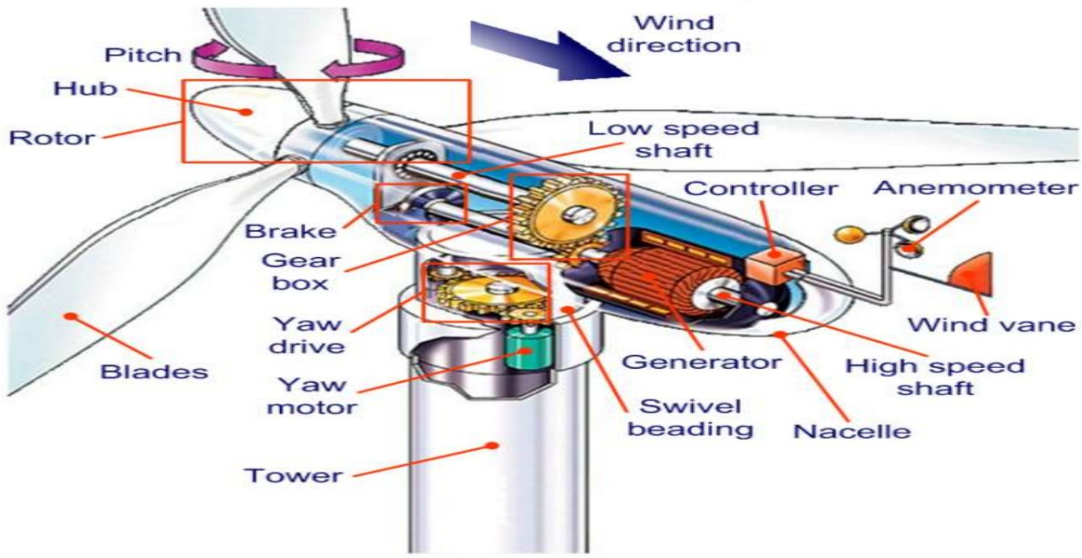
Nevertheless, the author selected, for the project analyzed in this thesis, monopile foundation, mainly because of the reasons mentioned in the page 40 (lower costs, common technique in shallow waters, simpler installation and mature technology). Also, he considers that due to the fact that Greece has not yet an OWF and in order to be obtained experience, a smaller OWF, with lower costs, simpler procedures and limited social reactions, like that described in this thesis (between Karpathos and Kassos), with the specific requirements of it (in each phase), may approach the interest more easily. Moreover, the author considers that such a park could create a basis for bigger projects, in the future, when the technology of offshore wind becomes familiar, in Greece. Besides, even an investment for a small-scale project, with similar with the study of this thesis characteristics, could be profitable and feasible, as it is proved by the economic analysis of the author (see the paragraph 4.8 of this thesis). At the same time this project could contribute, to a smaller degree, to the energy mix of the country.

Concerning the possible social reactions of a project at a very short distance to the shore, like that described in this thesis, a floating OWF in Greece, could also trigger reactions, due to possible visual impact, since a wind turbine, as it is cited below (see pages 58-59 of this thesis) could be visible even at a distance of approximately 40 km. Moreover, the two projects already licensed by RAE, in Alexandroupoli and in Lemnos, are designed at a distance of 10-15 km (at water depths 30-45 meters) from the shore, with bottom fixed technology, so the visual impact is also inevitable and social oppositions are possible to be provoked.

3.3 How a wind turbine works

The kinetic energy coming from the wind is converted to mechanical energy, with the rotation (using the aerodynamic force), due to the air, of the blades of the wind turbine. Then, a gearbox is activated and starts to give power to a generator in the nacelle. The electricity, which is produced, is sent, afterwards, to the transformer settled at the base of the wind turbine and it converts the electricity to higher voltage energy.

Figure 15: The main components of a wind turbine



Source: Kasba, S., 2014

3.4 Submarine and onshore cables

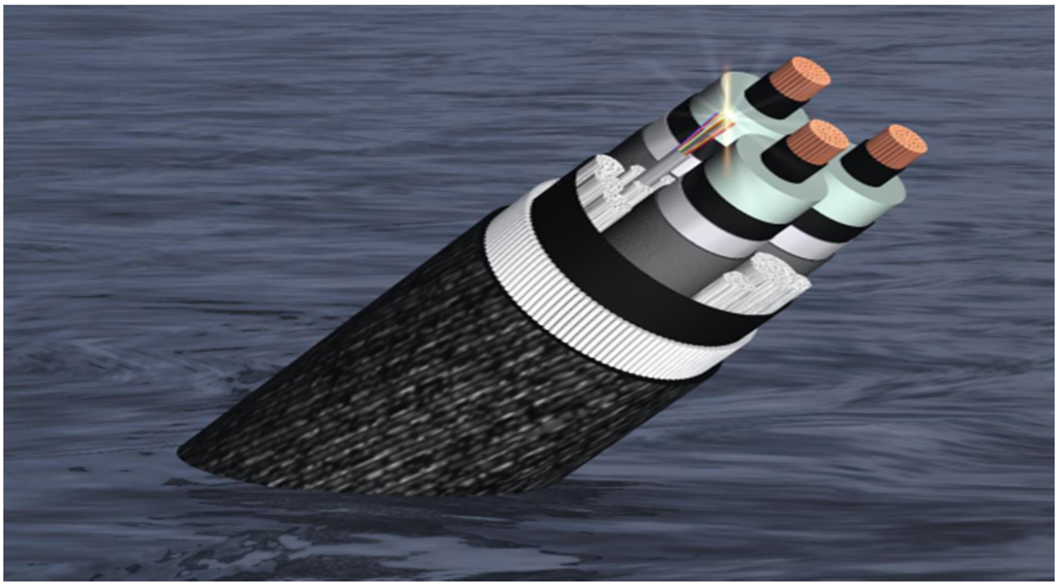
Submarine and onshore cables are necessary for the interconnection of the offshore structure with the onshore bases and they play a fundamental role in the installation of an OWF.

There are different types of submarine cables suitable for such an objective and at the same time there are, also, many firms globally that provide such services. These companies assume some relative activities, like: the design and manufacturing of the cables, the supply of all required accessories, the qualification testing of the system, the transportation and installation of the cables, the technical provision after the completion of the project etc.

Concerning the types of submarine cables, there are cables of medium (MV, by 33 or 66 kV), of high/extra high (HV/EHV, usually 150, 220, 275, 400 kV AC) or of High Voltage Direct Current (HVDC) up to 525 kV voltage capability. At the same time, there are two technologies of submarine cables, which can be used for the transportation of the electrical energy and consequently for the connection of an OWF: the alternating current (AC) and the direct current (DC). There is, also, one more category regarding the interconnection of the system, the High Voltage Direct Current (HVDC), which transports energy over huge distances, while the AC technology can serve distances in the range of 10 km from the shore and on the other side, the DC technology can serve distances, which exceed 80 km. Furthermore, an OWF could include numerous cable connections and it could be linked via different electrical combinations, like AC/DC or DC/AC (multilink connection). One factor that it should be taken into consideration is the possibility of losses of power during the transportation via cables. A potential solution for that is the increase of the voltage.

Submarine cables (Figure 16) should be protected by environmental conditions and they should be extremely reliable and have depth and water resistance, due to very low temperatures, in order for possible disruptions to not be created in the power supply system. Besides, sometimes the repair of damages is a difficult task, due to weather and sea situations. For that reason, submarines cables should have an insulation material called XLPE and a sheath material, which covers the cable, called PVC or PE. Moreover, the conductor of the submarine cable should be constructed by aluminium or copper.

Figure 16: A submarine cable, appropriate for the installation of an offshore wind farm



Source: renewableenergyfocus.com, 2009

All the submarine cables used in a project of OWF should follow international standards. In particular, they must satisfy the specifications of the International Electrotechnical Commission (IEC) and they must have a certification by the International Organization for Standardization (ISO).

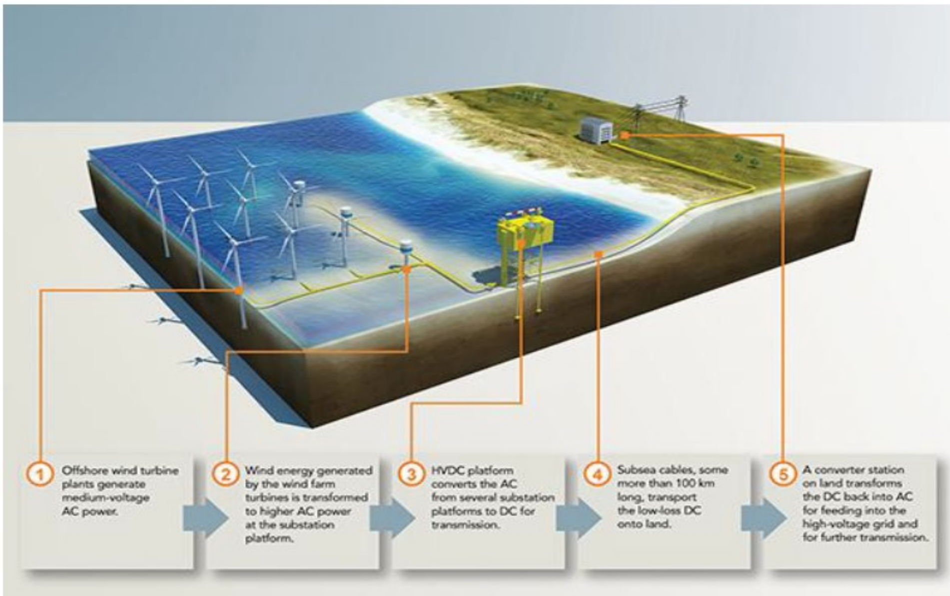
The principles to choose the appropriate submarine cables are: the cable route, the bathometry, the morphology of seabed (including the soil type), the power yield, the grid synchrony, the required time for the connection and of course the cost.

One of the basic differences of the submarine cables with the onshore cables is that the onshore cables have three monopolar cables and not a three-pole cable like the submarine cables. In addition, an armoring component consisting of steel wires is included to submarine cables to provide the necessary tensional stability and mechanical protection during transportation, installation and operation. On the other hand, there is not this need regarding the onshore cables, because they incur less mechanical attrition.

3.5 Offshore grid connection

First of all, every OWF has different natural and technical requirements and for that reason the proper solutions should be applied for each wind park, in order to be guaranteed its reliability and profitability (Siemens Energy, n.d.). It is significant, also, the fact that grid connections of OWFs differ in several characteristics from grid connections of onshore wind parks (European Association for Storage of Energy (EASE) - European Energy Research Alliance (EERA), 2013). Regarding the OWFs, the power is transmitted via submarine cables, which increase the cost and the obstacles and of course via onshore cables. Furthermore, the technological challenges are much more in comparison of one possible installation of onshore wind farm.

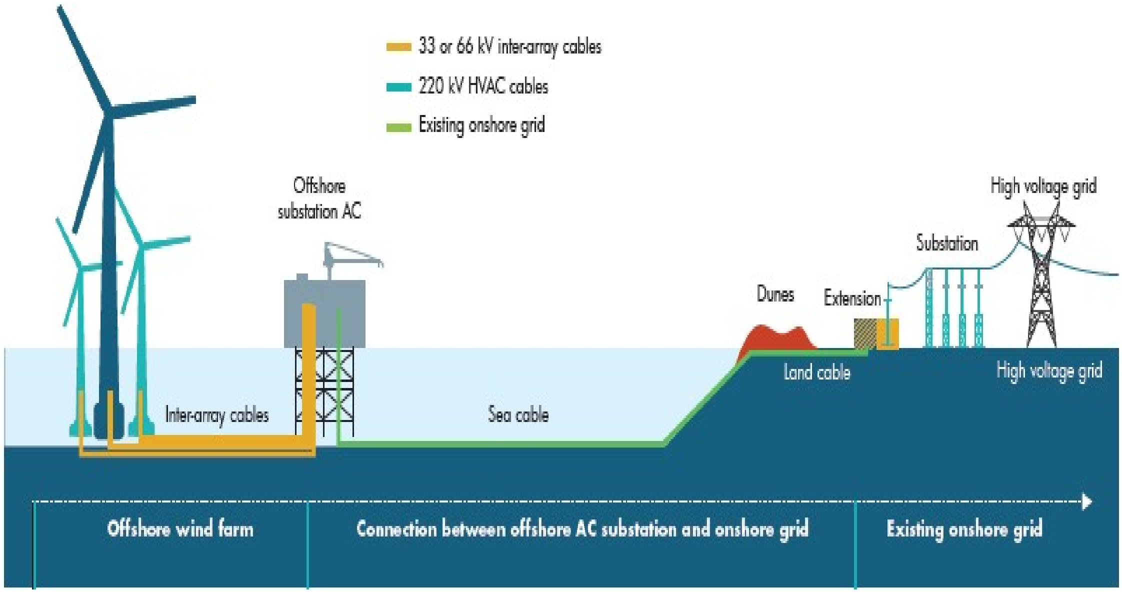
Figure 17: An offshore wind farm



Source: Soursou, P., 2017

Offshore wind grid connection is distinguished, usually, by two points (Backwell, et al., 2020): 1) OWTs are connected via cables to an offshore AC substation, and 2) then the AC offshore substation is connected via HVAC export cables with an onshore substation, from where electricity is transported to the local/mainland grid.

Figure 18: An offshore wind farm



Source: Backwell, et al., 2020, p.42

The basic target concerning an offshore substation is to be achieved the raise of the voltage produced by wind turbines (Rampion Offshore Wind, n.d.), in order to be limited potential losses.

The substations (offshore and onshore) are, in general, the «heart» of wind farms. For that reason, they are necessary also for the operation of an OWP (Soursou, 2017). Nevertheless, in some cases there is not an offshore substation, but only an onshore, fact that depends on the distance to shore and on the produced power.

The offshore substation, which seems to structures used in the oil and gas industry, is a steel building and is installed approximately 40m above the sea level. It consists of two parts, the upper part and the lower part. The upper part includes grid transformers, switchgear and auxiliary power supply for lights, safety systems and data, as well as a control system and an emergency diesel generator (Nordsee One GmbH, n.d.). Also, there is a basis for a helicopter on the substation (drones and robots can be used for the repair and in general for the control and maintenance of wind turbines, as well as of offshore substations (Hellenic Ministry of the Environment and Energy, 2019a) and of course workers can be transported with helicopters for the maintenance, also, of wind turbines). The lower part is established into the subsea.

Figure 19: An offshore wind farm

Source: transformers-magazine.com, 2020

An interesting element is that the connection into an OWF could have different shapes, except of the individual connection. There are: the wind farm hubs (joint connection of various wind parks in close proximity to each other), the tee-in connections (the connection of a wind farm or a wind farm hub to a pre-existing or planned transmission line between countries) and the hub-to-hub connection (the interconnection of several wind farm hubs, creating transmission corridors between various countries) (De Decker and Kreutzkamp, 2011).

4. The presentation of the plan of the author for the installation of an offshore wind farm in the southeast Aegean Sea

4.1 The selection of the point

One of the 12 zones, which had been selected (see pages 29-30 of this thesis) for the installation of an OWF in Greece, belongs to marine areas of Karpathos and Kassos islands (Figure 20), which are in the southeast part of Greece and specifically in the Dodecanese complex. A company, named as «Minoika Thalassia Aiolika Parka A.E.», had been made an undivided application for 6 points, in total, of Karpathos and Kassos. Of these points (i.e. they are visible in the picture below with yellow context, into the sea), 4 are in Kassos (north) and 2 in Karpathos (southwest). The total capacity was designed to be of 350 MW. The application for Karpathos and Kassos islands is under evaluation from RAE.

Figure 20: The areas, in Kassos and Karpathos, for which had been made an application for the installation -of one of these points- of an offshore wind farm

Source: Regulatory Authority for Energy (RAE), Geoinformation map, n.d., c

However, the author of this thesis selected to put the OWF not in all the proposed areas (i.e. the potential investor, most probably, will be obliged to limit the initially wider selected area to a more specific polygon), but in a spot in the southwest angle of Karpathos (Figure 21), which was also fallen under the assessment of the Ministry of the Environment and Energy of Greece. The choice of the author will be analyzed below.

Figure 21: The spot of the installation of an offshore wind farm, for the purposes of this thesis, was selected by the author in the southwest angle of Karpathos

Source: Regulatory Authority for Energy (RAE), Geoinformation map, n.d., d

The selection of the 12 zones -including the areas around Kassos and Karpathos islands- appropriate for the installation of an OWF, in Greece, is a result of a detailed study from experts, with the use of a series of criteria (see page 29 of this thesis). Some of them led to the exclusion of potential points and on the contrary, the same sequence of prerequisites led to the choice of some other marine spaces.

In this thesis, the author was based on the criteria that they were posed by experts and that they compose, finally, their choices, in order to present one of the best points in Greece for the fulfillment of such a project.

It is remarkable the evident that in one of the studies regarding OWFs in Greece (Karanikolas and Vagiona, 2012), Karpathos is indicated as one of the three (Anafi, Karpathos, Amorgos) top choices for an OWF siting.

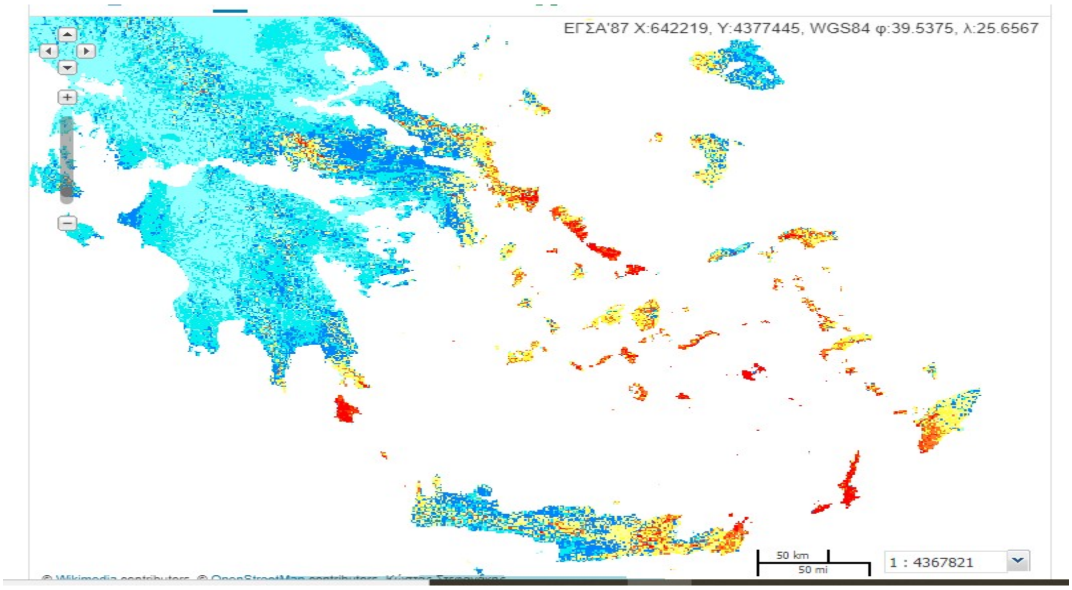
4.2 The assessment of the criteria for the selection of the area

4.2.1 Wind potential

First of all, the wind potential (Figure 22) of the area examined is extremely powerful. According to an analysis (Avgoustoglou, et al., 2017), which took into account wind data from 1995 to 2009, characteristics at Kassos are ideal for the development of an OWF (the mean annual wind speed of the island was measured at 8.03 m/s). However, according to the transition energy plan of the island of Kassos (Municipality of the Heroic Island of Kassos, 2020), the mean annual wind speed (i.e. the period of the calculations does not refer to the relative analysis) has been calculated at 11.61 m/s. This value has been occurred by the measurement data of the measurement mast (i.e. it was installed around 2011 by the firm, «Energy Electromechanical Works S.A. - ENET S.A.»), which has 20 meters height, in Saint Mamas (Kassos), a location, in which are presented one of the most powerful wind speeds in Greece.

Also, in the context of the first analysis, was observed that in the Karpathian Sea there was the highest average value during summer, with around 9 m/s. During winter the maximum value was 8 m/s over the north Aegean Sea, during autumn the highest value was 7.35 m/s over the central Aegean Sea and during spring was 7.03 m/s over the east Aegean Sea. Moreover, according to the same study, the largest value of the year, in Greece, was observed during July over the Karpathian Sea, where wind speed of 9.80 m/s was recorded, while the second largest value was 9 m/s, during August, in the same area. Finally, regarding the wind speed, the area of the interest for this thesis is not only favorable (i.e. the wind speed is up to the limit of 6 m/s, under which areas are excluded from the further study of a potential installation of an OWF in Greece), but also ideal.

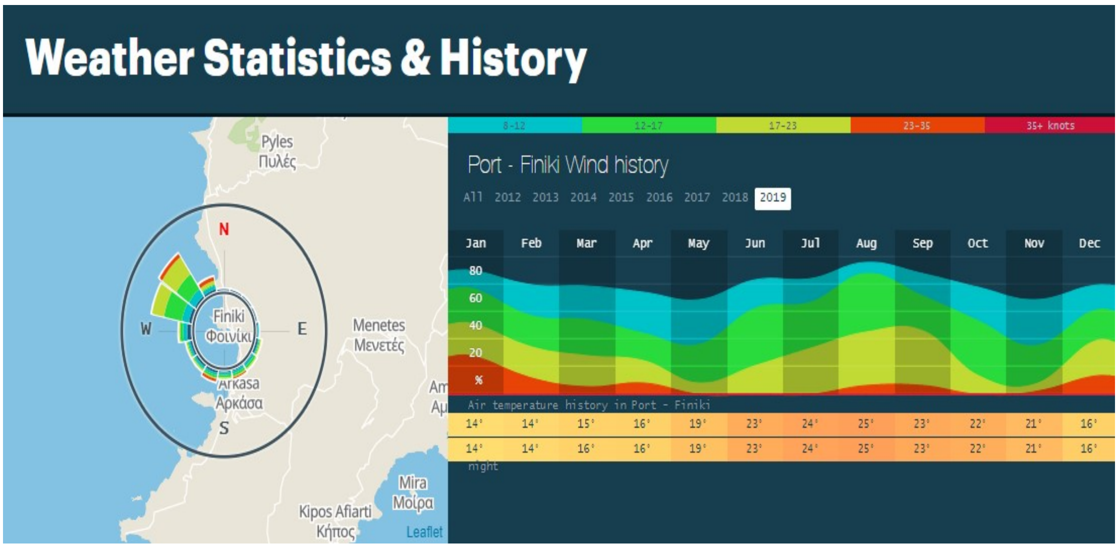
Figure 22: Map of the wind potential of Greece



Source: Regulatory Authority for Energy (RAE), Geoinformation map, n.d., e

As someone can observe from the following picture (Figure 23), the most frequent, in 2019, direction of the wind, around the area examined for this thesis, is the southeast.

Figure 23: The direction of the wind, in 2019, around the area examined (Karpathos)

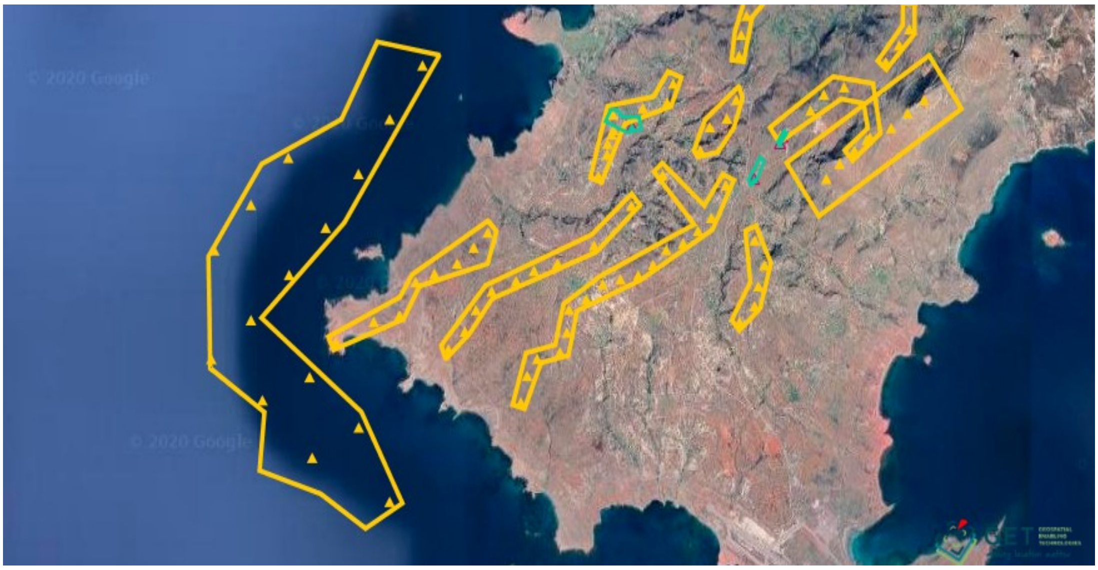


Source: windy.app, 2019

4.2.2 Water depth

The water depth of the southern selected –at an initial stage- by the Ministry zone (Figure 24), in the wider part of Karpathos, is fluctuated between 10 and 50 meters.

Figure 24: The area selected, at a first stage, by the Ministry, in Karpathos, for the installation of an offshore wind farm

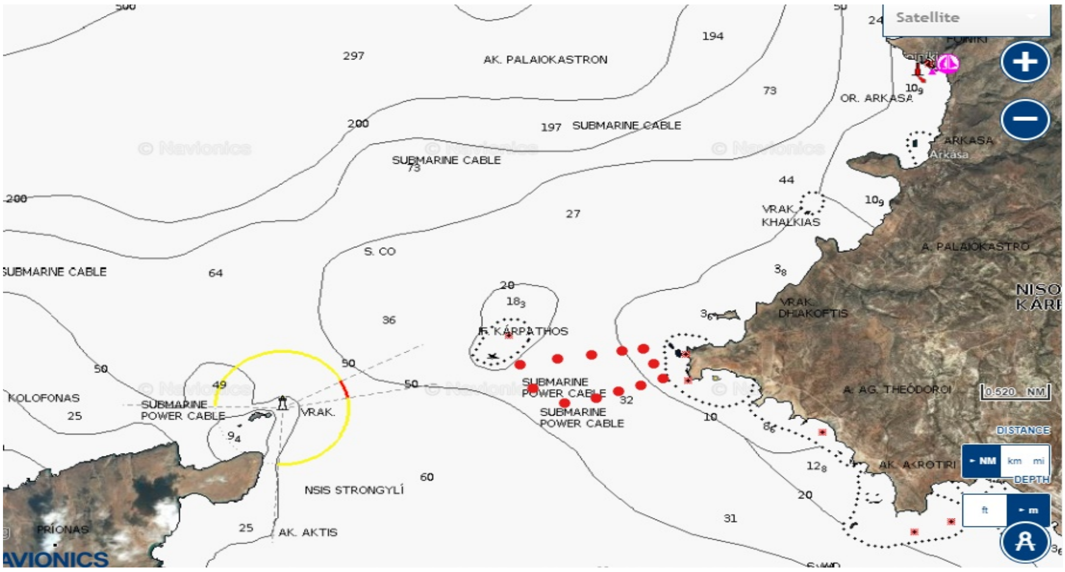


Source: Regulatory Authority for Energy (RAE), Geoinformation map, n.d., f

Specifically, the water depth is 10-32 meters in the south part of the selected area, 20-50 in the central part and 27-44 in the north part of it. In 2010, the Ministry of the Environment and Energy of Greece excluded from the possibility of installation of an OWF, areas with water depth greater than 50 meters (see page 29 of this thesis). At the same time, it should be underlined the fact that the monopile type of foundation for OWTs cannot be installed in water depths greater than 30 meters.

Examining the data mentioned above and evaluating, also, other factors, which will be analyzed below, was decided by the author that the most suitable spot for the installation of an OWF, for this thesis, is in a place into the selected by the Ministry area, in the southwest angle of Karpathos and specifically in a location, where the water depth is mainly 32 meters (the average water depth in Europe, regarding the installations of OWFs, until the end of 2019, was 33 meters (Brindley, et al., 2020b) and in some points 10 meters. This spot is opposite of the Saints Thedoroi area. The exact place of the planning, for this thesis, OWF is marked by red dots (Figure 25).

Figure 25: The area selected, by the author, with red dots, between Karpathos and Kassos islands



Source: sailingheaven.com, n.d. / Edited by the author

4.2.3 Visual impact assessment

An OWF may be visible even at a distance of 42 km in daytime and 39 km in nighttime (i.e. mainly due to the red lights of wind turbines), while it may be clearly visible at distances of up to 16 km (Figure 26). However, the major part of studies concerning the visibility was conducted some years ago, when the wind turbines had smaller size and for that reason the results are not representative to an absolute degree, since they are not fully adapted at today's data (Cothren, et al., 2013).

Consequently, the matter of the visibility may be more composite, because the current (2021) size of the wind turbines is greater, so they could be visible even at a distance farther than 42 (daytime) or 39 (nighttime) km.

Figure 26: What a wind turbine looks like depending on the distance difference

Source: Kanellas, P., 2016, p.16

The evaluation of the visual impact should be one of the first steps during the discussion for the installation of an OWF and usually causes conflicts. An OWF could be visible in different ways, which means from different angles and different distances, so the aesthetic factor is subjective, due to the different observation points. Maybe a series of surveys on local population, via photomontages for simulation and 3D depiction also for the virtual illustration of the project, are useful tools to be collected opinions from local people and to be estimated the degree of their acceptance (Claramunt, et al., 2017).

In the selected spot, for this thesis, the existence of the visual impact, due to a potential installation of an OWF in water depths of approximately 10-32 meters, is inevitable. In this thesis, the author made a tremendous effort to limit at the lowest level the visual impact and he demonstrated fully respect to the local people, who wouldn't like to have visual disturbance, but this is impossible.

Nevertheless, there is a point, in the context of the selected area, where the author chose, for the needs of this thesis, to design the OWF and this place is in the southwest angle of Karpathos (Figure 25). Opposite of this place there is the beach of Saints Theodoroi, but due to the fact that the author «hided» the OWP back from the hill, which is on the right side of the beach, the OWF is not visible from the beach. However, the OWF is visible from the hill, where there is a tavern with view on it, if hypothetically the OWF would be in the point described. Furthermore, the OWF is impossible to not be visible from the beach Araki, which is on the right side of the bay, as well as from the Araki resort (Figure 27).

Figure 27: On the left side of the picture, behind the hill, the offshore wind farm for the purposes of this thesis was installed

Source: Google Maps, n.d.

If the OWF was put higher -from this point- in the map, this would entail a serious risk, since it would be at a short distance from the very commercial locations of Karpathos, Finiki and Arcesine and then the effect would be much greater.

So, the author tried to minimize the visual impact put it in the less touristy, in comparison with Finiki and Arcesine, zone of Saints Theodoroi. However, in any case, the visual annoyance remains, as it is highlighted above.

4.2.4 Environmental protection and «Natura 2000»

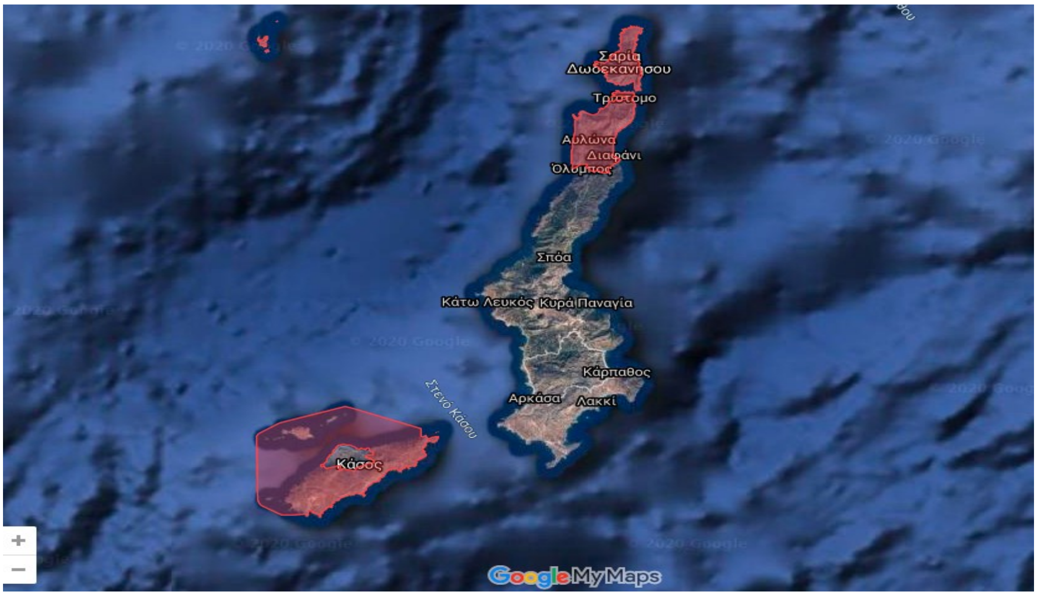
The environmental protection constitutes one of the main concerns into the process of the assessment of the criteria for the installation of an OWF. The development of the human kind should be harmonized with the nature, in order for it not to be harmed. Human kind should also be respectful to nature and try to minimize the negative impact coming from its activities.

Concerning the places called as «Natura 2000», the aim is to be protected, because there selected species of flora and fauna are observed, as well as types and bird species of importance inhabit. All these are threatened with extinction, are vulnerable, rare or locally prevalent. Moreover, these areas may belong to one or more from the nine biogeographical regions of Europe. Furthermore, «natural refuges, national parks and other national and regional protected areas are defined solely on the basis of national or regional legislation, which often vary from country to country. They do not have the same status as ''Natura 2000'' areas, but may be classified as such» (European Commission, n.d., e).

The Figure 28 depicts with red context some of the most significant places for birds in Greece, among which are distinguished those of the whole area of Kassos and of the north part of Karpathos. These sites are of vital importance for the maintenance of threatened with extinction birds, vulnerable birds etc. Also, the Figure 29 represents with yellow context the wildlife refuges and the Figure 30 illustrates with green context the sites of «Natura 2000».

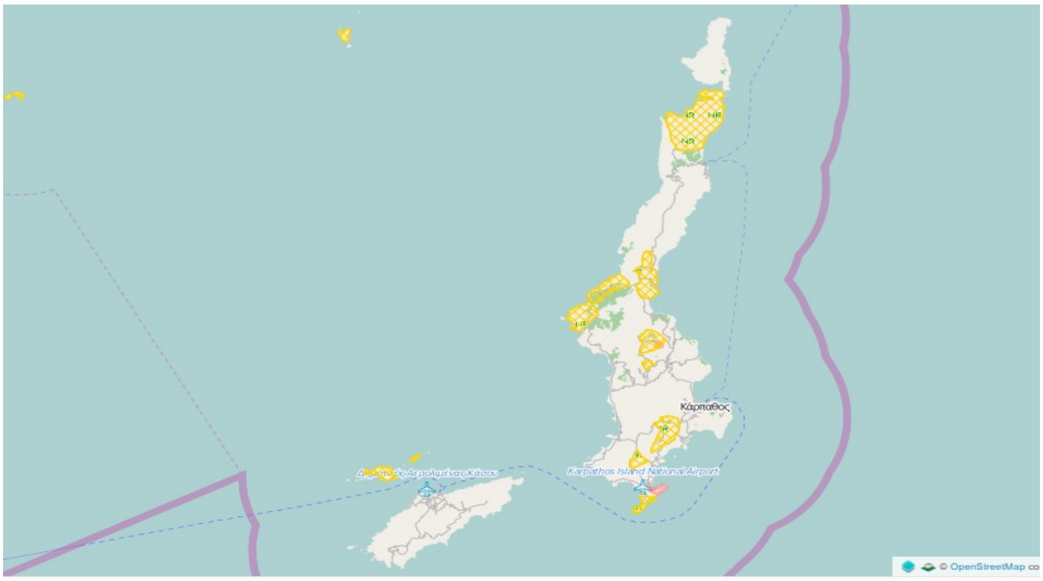
Consequently, the examined by this thesis area, for the installation of an OWF, is, in general, sensitive and for that the study should be environmental responsible, in order for the nature to be protected. Of course, the reason for which the author did not select any place in the wider area of Kassos is, after all the above mentioned, absolutely comprehensible. The whole area of Kassos is integrated in «Natura 2000» and this is prohibitive for the implementation of such a project.

Figure 28: With red context some of the most significant areas for birds in Greece are distinguished, in Kassos and in Karpathos



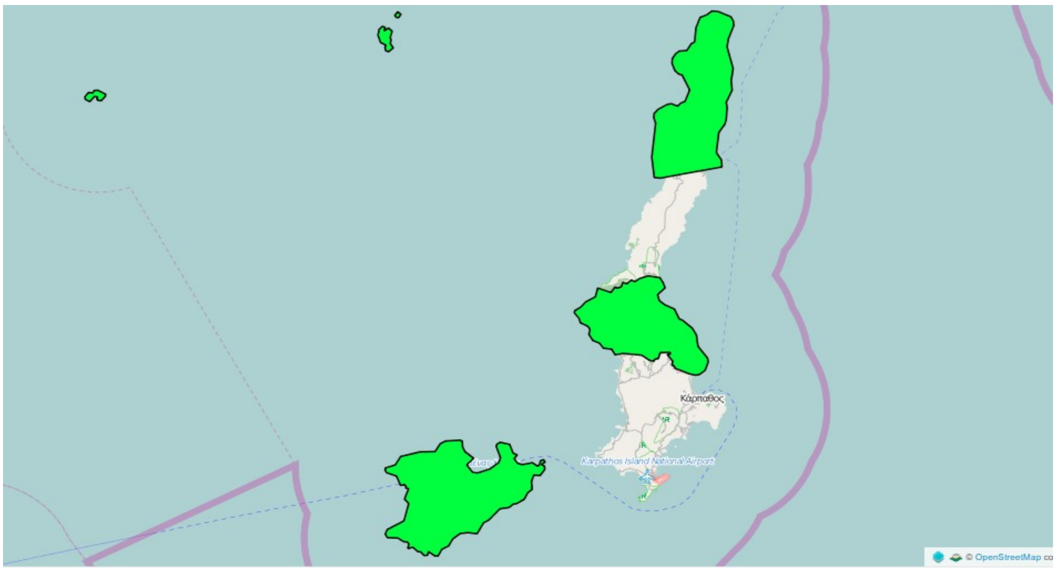
Source: Ornithological – Hellenic Ornithological Society, n.d.

Figure 29: With yellow context the wildlife refuges are illustrated, in Kassos and in Karpathos



Source: Hellenic Republic, 2015a

Figure 30: With green context the sites of «Natura 2000» are represented, in Kassos and in Karpathos



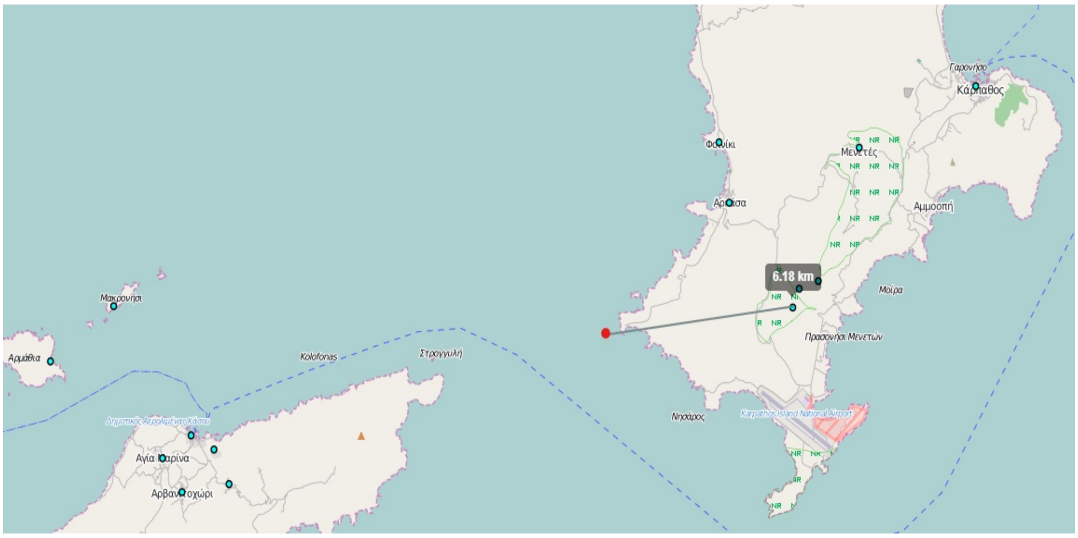
Source: Hellenic Republic, 2015b

4.2.5 Distance from settlements and distance from ship routes

Restrictions are settled, also, regarding the distance from traditional or not settlements, as well as concerning the distance from ships connections.

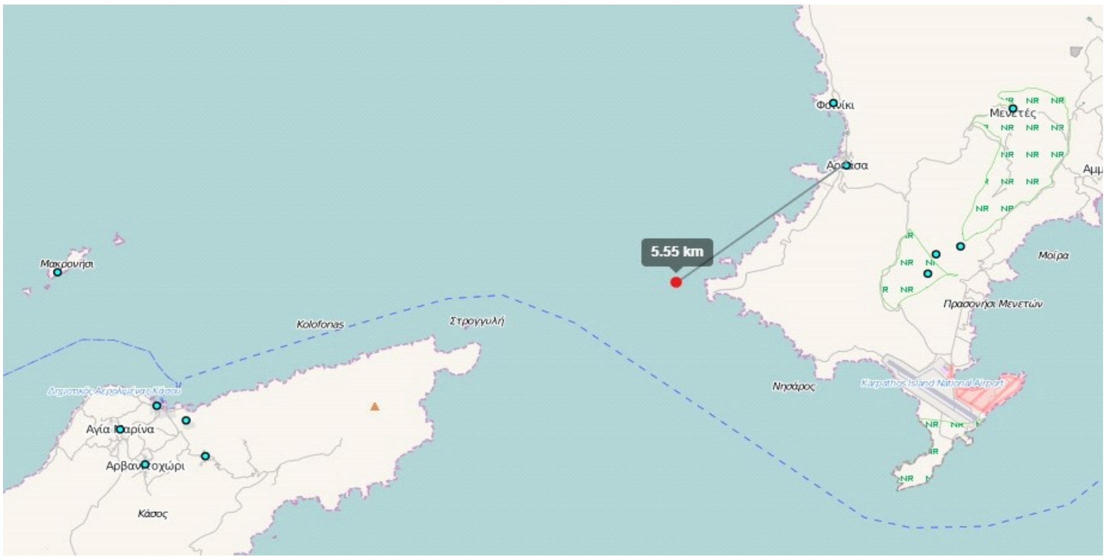
First of all, minimum distances from residential networks are different between traditional and not traditional settlements. The minimum distance from the OWF to residential network is 1 km and 1.5 km from the OWF to traditional settlements (Hellenic Republic 49828/2008). In the examined area, for the potential installation of an OWF, there is not the least relative concern, since the distance from the last settlement of the south Karpathos is 6.18 km (i.e. in this area there are only old settlements, with slightest number of probably uninhabited homes, which are used mainly for the activities of stock-farmers or for rural objectives), as it is presented in the Figure 31, the distance from Arcesine is 5.55 km (Figure 32), the distance from Finiki is 6.48 km (Figure 33), while the distance from the settlement, Poli, of the east Kassos is 11.17 km, as it is showcased in Figure 34.

Figure 31: The distance (6.18 km) from the offshore wind farm, for this thesis, to the last settlement of the south Karpathos



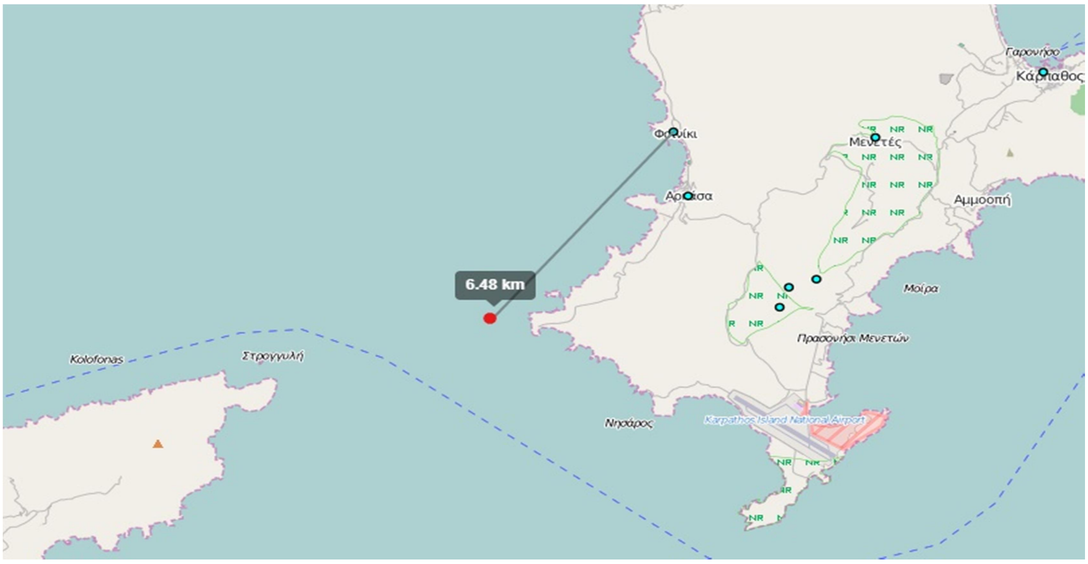
Source: Hellenic Republic, n.d., a / Edited by the author

Figure 32: The distance (5.55 km) from the offshore wind farm, for this thesis, to the settlement, Arcesine (Karpathos)



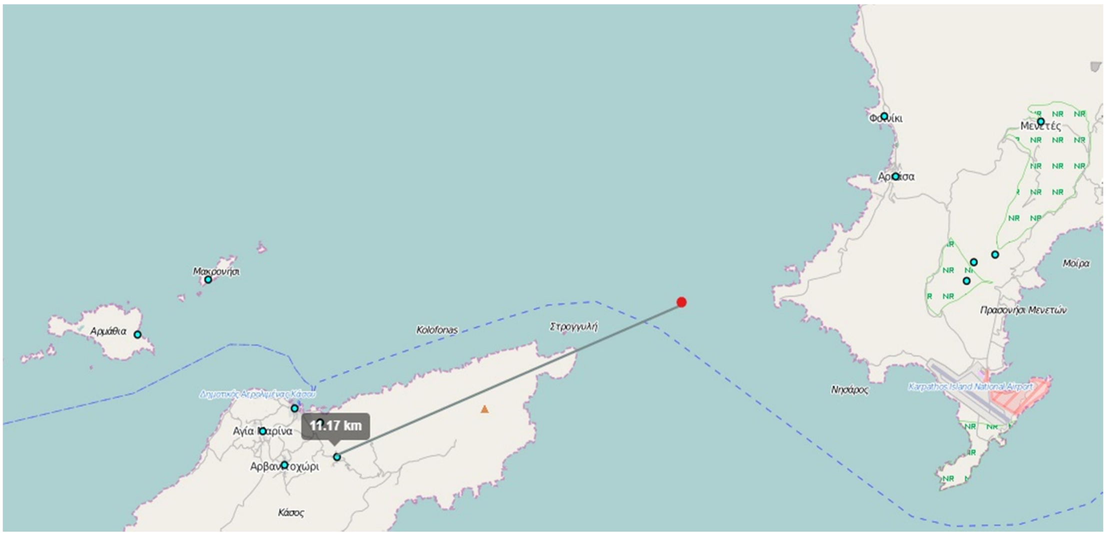
Source: Hellenic Republic, n.d., b / Edited by the author

Figure 33: The distance (6.48 km) from the offshore wind farm, for this thesis, to the settlement, Finiki (Karpathos)



Source: Hellenic Republic, n.d., c / Edited by the author

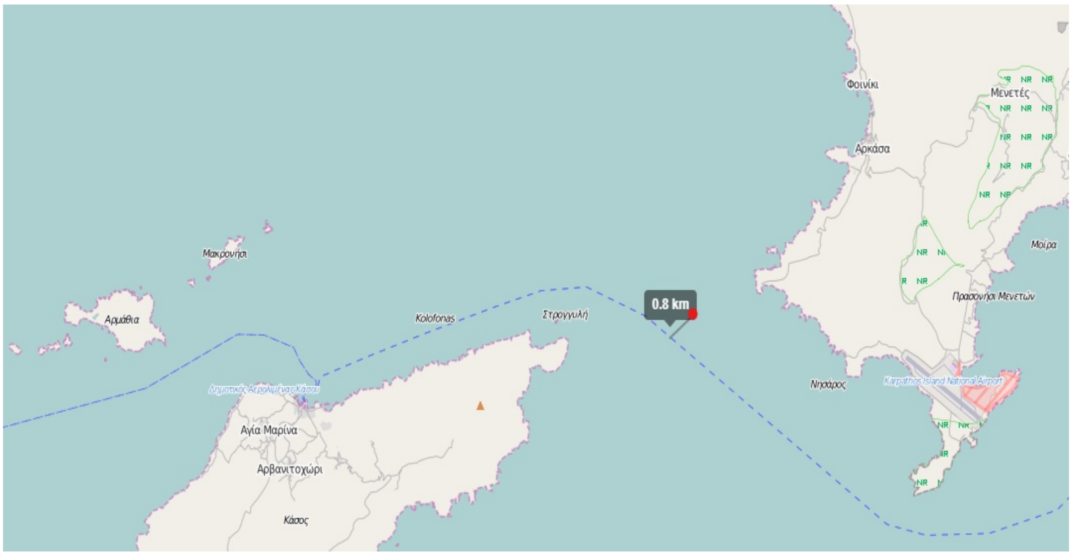
Figure 34: The distance (11.17 km) from the offshore wind farm, for this thesis, to the settlement, Poli (Kassos)



Source: Hellenic Republic, n.d., d / Edited by the author

Moreover, from the examined area passes only one shipping connection, as it is visible in Figure 35, via the intermittent line. The fewer the existing shipping connections are, the higher is the rank, during the relevant study, for the area. So, from this point of view, the examined in this thesis point has an excellent rank. In general, when an OWF is designed, there is a possibility of conflict with the shipping sector, because there is a risk for the available space for navigation to be reduced by the OWF and this affects the safety and the efficiency of shipping movement. So, it should be a priority for the possibility of collision to be eliminated (European Maritime Spatial Planning (MSP) Platform, n.d.). If the distance between an OWF and a shipping connection is 0.5 nm - 3.5 nm (0.8 km - 5.6 km), then this is tolerable (European Maritime Spatial Planning (MSP) Platform, n.d.) for an installation of an OWF. As it is concluded from the picture below (Figure 35), the relevant distance is 0.8 km. Consequently, the distance is sufficient.

Figure 35: The distance (0.8 km) from the offshore wind farm, for this thesis, to the shipping connection



Source: Hellenic Republic, n.d., e / Edited by the author

4.2.6 Distance from a shore

Nowhere is defined a sufficient distance from the shore, not even in the article 10 of the «Special framework for spatial planning and sustainable development for renewable energy sources» (Hellenic Republic 49828/2008), in which appropriate distances were taken into account. Among these distances, is the distance from organized or formed shores or other significant beaches. This distance, which is not a «distance from a shore», but a distance from a beach, is determined at 1 km.

Of course, the larger the distance from a shore, the less is the visual disturbance, which could provoke an OWF.

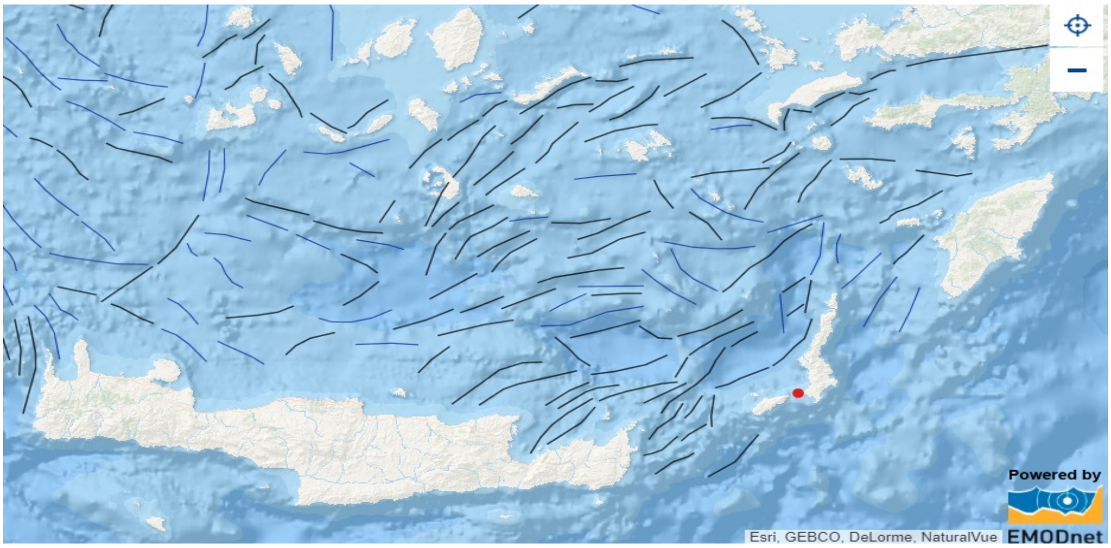
Distances from a shore are classified as short, medium and long (Badger, et al., 2018). The project of this thesis is assessed that it has a short distance from the shore. Moreover, the distance from a shore is a factor, which plays a critical role also for the cost. So, concerns about the distance from a shore are not only social and engineering, but also economic (Adelaja, et al., 2012).

4.2.7 Seabed conditions in the examined zone

The assessment of the seabed conditions of the examined area, between Karpathos and Kassos, for the installation of an OWP, for the purposes of this thesis, constitutes an essential procedure. The seabed should be evaluated in every study of such a project, since the installation of OWTs requires stable seabed conditions; otherwise there are significant geo-hazards, which include even the risk of collapse of OWTs.

The Greek area is divided into three zones of seismic risk. At the same time, it is noted that an earthquake can lead to ground acceleration. According to the Technical Chamber of Greece (Hellenic Association of Insurance Companies, 2018), in the first zone the ground acceleration is 0.16g, in the second zone is 0.24g and in the third zone is 0.36g. The total areas of the islands, Karpathos and Kassos, belong to the second zone (0.24g) (Technical Chamber of Greece, n.d.). In Greece, only the areas, which belong to the third seismic hazard zone (0.36g), are excluded for the possibility of installations of OWFs, thus the point examined between Karpathos and Kassos is appropriate (Figure 36), in terms of hazard from a possible seismic activity, for the installation of an OWF. However and in general terms, according to a relevant study (Alexandri, et al., 2017), «the Greek subduction zone is the largest, fastest and most seismically active subduction zone in the Mediterranean».

Figure 36: The tectonic lines in Greece and with the red point the examined, for this thesis, spot. In this way, it is proved that the place of the interest is not problematic.



Source: European Commission, n.d. / Edited by the author

The author interviewed (15-19/12/20) Mrs. Paraskevi Nomikou, Associate Professor of the Department of Geology and Geo-environment of the National and Kapodistrian University of Athens and among others vice-president of the Board of the Association of Greek Oceanographers and thus he ensured related information for the examined zone. Mrs. Nomikou stated that: «In the area of your interest there are not bathymetric or seismic data, but for sure this particular area is far from any active fields. Earthquakes are not observed, usually, in the site of your interest, which is possible of course to be affected by earthquakes of the surrounding areas, but not to a problematic degree. So, the seabed there is durable».

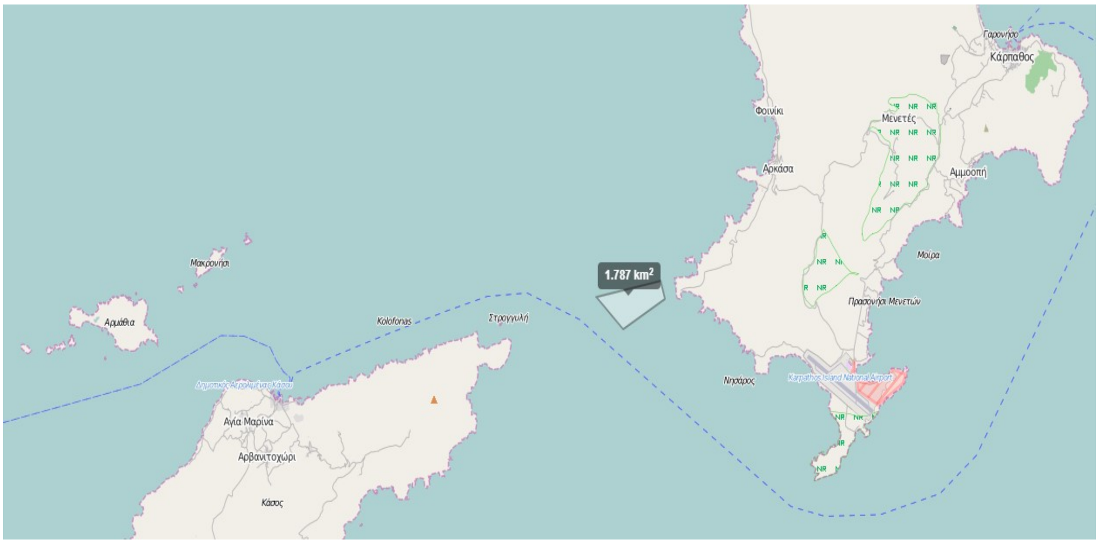
Consequently, due to all the above mentioned reasons, the examined area, between Karpathos and Kassos, is a safe -from a geological viewpoint- area.

4.3 The presentation of the offshore wind farm of the author

4.3.1 The selection of the model of the offshore wind turbines

The OWF, in this thesis, has a shape of a polygon (the total area is 1.787 km^2), since this particular shape is observed in the major part of the cases, regarding OWFs, around the world. The picture (Figure 37), which follows, is used as an indicative tool.

Figure 37: The designed by the author polygon, for the installation of the offshore wind farm, for this thesis



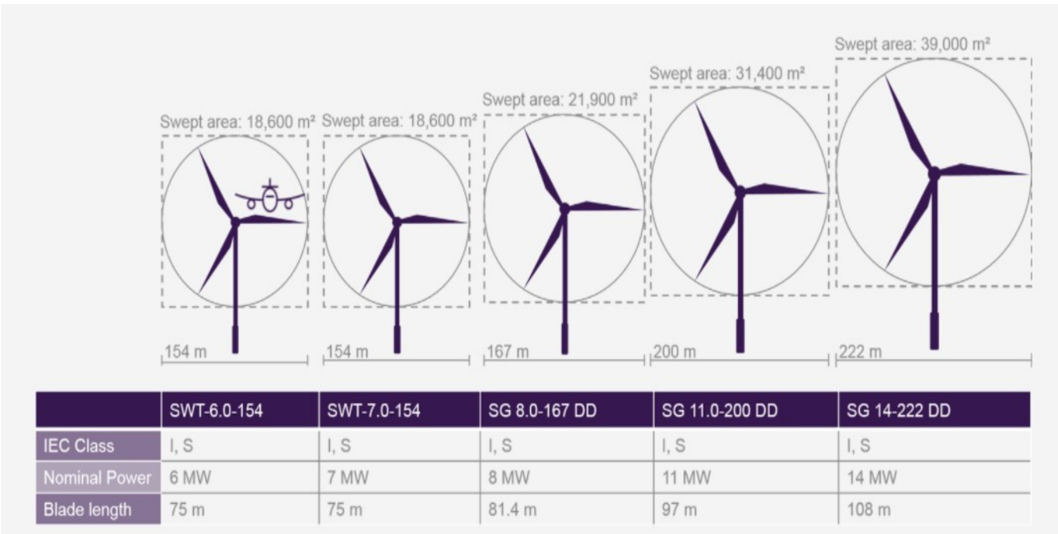
Source: Hellenic Republic, n.d., f / Edited by the author

Into this polygon the author decided to put in total, but in two phases, 9 OWTs. Three (3) OWTs will be put in January 2023, given the fact that the project development has already been done and given the fact also that there is need for a reasonable period for different procedures. Six (6) OWTs will be added in January

2028, after the expected energy interconnection (by 2027) of Karpathos and Kassos with the mainland.

The 9 OWTs will be manufactured by the German firm, Siemens Gamesa (Figure 38). Specifically, the author decided to select the model «SWT-3.6-107» (2005) (thewindpower.net, 2018). This wind turbine has a nominal power of 3.6 MW and the diameter of its rotor is 107 meters. Furthermore, it has three blades and its swept area is 8,992 m². The type of the foundation of the wind turbines was chosen by the author to be monopile, mainly due to the water depth (approximately, 10 and 32 meters), but also for all the reasons analyzed above (see pages 40 and 43-45 of this thesis).

Figure 38: Some of the models of wind turbines of Siemens Gamesa



Source: Siemens Gamesa, n.d.

The choice of the firm is not random. Siemens Gamesa, except for the fact that it is one of the most reliable companies in this sector, is also the most selected firm around the world for installations of OWFs. It is noteworthy, also, the fact that one of the largest OWFs globally, the «London Array», in the United Kingdom is based on 175 wind turbines, with the characteristic, «SWT-3.6» (but with 120 meters diameter of rotor) of the manufacturer, Siemens Gamesa. The model «SWT-3.6-107», which is this that the author chose, is used in many other projects (i.e. Gwynt y Môr – United Kingdom, Greater Gabbard – United Kingdom, Walney – United Kingdom, Sheringham Soal – United Kingdom etc).

Moreover, the author examined the Greek cases, during the process of the selection of the appropriate wind turbines for the OWF, for this thesis. In one of them, the company, «Rokas Aeoliki S.A.», proposed the installation of an OWF in a location east of the island, Lemnos, with wind turbines of the model, «SWT-3.6-107». The same selection of the model has been made by the firm, «Elliniki Energiekontor S.A.», in its proposal for an OWF north of the island, Andros. The other proposals, for the Greek area, include OWTs of the firms, Repower, Vestas, Enercon and Nordex (Regulatory Authority for Energy (RAE), n.d.).

4.3.2 The design and the total capacity of the offshore wind farm

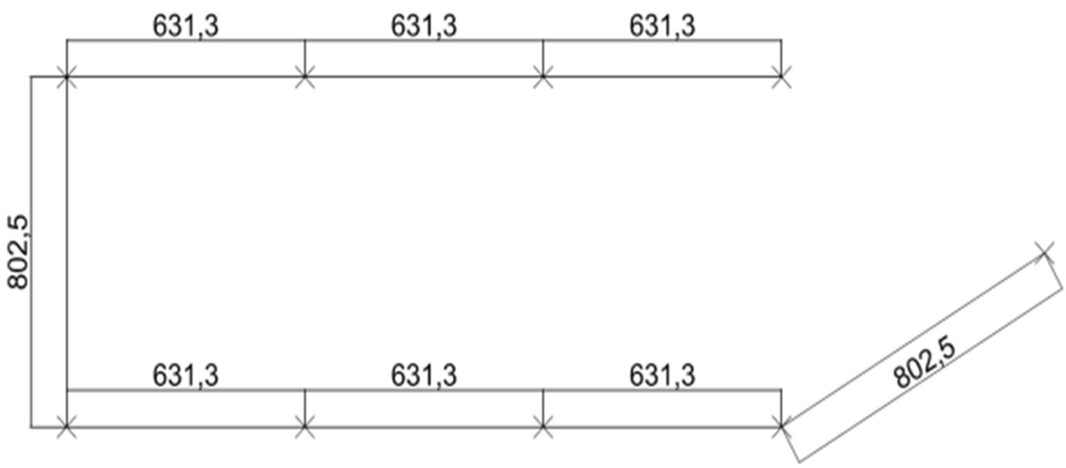
The total capacity of the OWF, for this thesis, will be shaped 3 times. The capacity of the wind farm during its first 5 years (January 2023 – December 2027) of operation will be 10.8 MW (3 wind turbines X 3.6 MW). In the period January 2028 – December 2048 and after the interconnection of Karpathos and Kassos with the mainland will operate with 9 OWTs of total capacity 32.4 MW (9 wind turbines X 3.6 MW). In the period January 2049 – December 2052, the OWF will operate with 6 OWTs of total capacity 21.6 MW (6 wind turbines X 3.6 MW), since the first 3 OWTs should be dismantled, because the lifespan of wind turbines is 25 years.

According to a study (The Renewables Consulting Group LLC, 2018), in which 27 European OWFs were analyzed, the average downwind and crosswind spacing of such a project is 7.5 D and 5.9 D respectively (i.e. D symbolizes the diameter of the rotor). Experts across all over the world, when they design the layout of wind turbines, take, also, into account the diameter of the rotor (The Renewables Consulting Group LLC, 2018). Consequently, the author took into consideration these particular downwind and crosswind spacing, in order for the area covered by the OWF between Karpathos and Kassos islands to be designed for him by the firm «Hellenic Cables S.A», with which he communicated into December of 2020 for the needs of this thesis.

For that reasons, in the area selected by the author, the installation of 9 OWTs, in total, is feasible, in order for them to be at an adequate distance from each other. Besides, the larger the power due to MW, the larger is the rotor's diameter. So, the selection of more MW would entail larger rotor's diameter and this would mean, at the same time that the author would need more space or would put less wind turbines.

Furthermore, the wind turbines were put by the author vertically in comparison with the direction of the wind (southeast), in order to be succeeded their maximum efficiency.

Graph 6: Photorealistic display of the offshore wind farm described in this thesis, between Karpathos and Kassos islands. There is a distance of 802.5 meters alongside of the southeast wind (7.5 D) and a distance 631.3 meters vertically to the southeast wind (5.9 D). At the same time, the rotor diameter is 107 meters.



Source: Hellenic Cables, 2020a / Edited by the author

However, it is essential to be underlined that wind turbines do not operate in ultimate level, since they can produce an average rate power of 40%, which means that at a percentage of 60% they produce little or not at all power (wind-watch.org, n.d.). The maximum possible conversion (kinetic energy to electricity) efficiency of a wind turbine was set to 59.26%, in 1919, by the German engineer, Albert Betz («The Betz Limit»). Nevertheless, real wind turbines have efficiency no more than 40%, since a wind turbine cannot convert the kinetic energy to electricity in absolute terms (100%) (Blackwood, 2016).

4.3.3 The selection of the cables for the offshore wind farm

Regarding the interconnection of the OWF, the author selected cables from the Greek firm, «Hellenic Cables», with which communicated on 2nd December of 2020 for the purposes of this thesis. On 28 December of the same year the company submitted a written proposal to the author regarding the installations of the cables for the OWP, between Karpathos and Kassos islands.

The Greek company announced in July of 2020 its participation in the Seagreen offshore wind project, in Scotland (27 km off the coast off the Angus Coast in the Firth of Forth - 1,075MW), with the design, manufacture, test and supply of its cables produced in its plant in Corinth, Greece (Hellenic Cables, 2020). Also, one more, among others, of the biggest successes of the firm is its presence in the construction of the OWF «Hollandse Kust Zuid», in the Netherlands, which will be, when will operate fully, in 2023, one of the biggest in the world. Moreover, the «Hellenic Cables» participated in the interconnection of Crete (Greece) with the mainland system (Ministry of the Environment and Energy, 2020).

The proposal of the «Hellenic Cables» to the author, which was adopted for this thesis, is presented below:

Table 2: The proposal of the firm, «Hellenic Cables», to the author, regarding the sizing of the cables, for the offshore wind farm described in this thesis

For the sizing of the cables, the following have been considered:	
Number of wind turbines	9
Power of each wind turbine	3.6 MW
Voltage level for the transfer of energy from the offshore wind farm to the onshore substation	33 KV
Voltage level for the interconnection of the wind turbines	33 KV
Power factor cosφ	1
Electricity per wind turbine	67 A
Power requirement for 9 wind turbines and cable carrying capacity	603 A

Source: Hellenic Cables, 2020b / Edited by the author

Table 3: The proposal of the firm, «Hellenic Cables», to the author, regarding the length of the cables, for the offshore wind farm described in this thesis

The cable lengths are:	
Total length of inter-array cables	5.392,8 m
Length of submarine cable from the last wind turbine to the grounding	1.000 m
Total length of the submarine cables	**6.392,8 m**
Distance from the grounding to the onshore substation (monopolar cable)	3.000 m
Total length of onshore cables (three monopolar cables)	**9.000 m**

Source: Hellenic Cables, 2020c / Edited by the author

Moreover, the «Hellenic Cables S.A.» informed the author about the options (aluminium and copper) of the submarine cables and about their costs. For the OWF between Karpathos and Kassos, the author selected regarding the submarine cables the material of aluminium, not only because it is cheaper, but also because it is used in the most countries of Europe in relative projects. On the other hand, the copper is used mainly in Greece and at the same time it is more expensive.

Table 4: The proposal of the firm, «Hellenic Cables», to the author, regarding the options for the submarine cables, for the offshore wind farm described in this thesis

For the submarine cables of total length 6.392,8 m, the options are the following:		
Material of the conductor	**Cross section of the conductor (mm^2)**	**Cable cost per meter (€/meter)**
Aluminium	630	165
Copper	400	220

Source: Hellenic Cables, 2020d / Edited by the author

Nevertheless, concerning the onshore cables, the firm, «Hellenic Cables S.A.», proposed to the author the material of the copper, because with this much more power could be transferred, in comparison with the aluminium. At the same time, the use of the copper is observed in the major part of the cases of onshore wind projects, in Greece, without excluding of course as a possibility the use of aluminium.

Table 5: The proposal of the firm, «Hellenic Cables», to the author, regarding the onshore cables, for the offshore wind farm described in this thesis

For the onshore cables:		
Material of the conductor	**Cross section of the conductor (mm^2)**	**Cable cost per meter (€/meter)**
Copper	400	220

Source: Hellenic Cables, 2020e / Edited by the author

As it was already mentioned (see page 70 of this thesis), 3 OWTs will be put in January 2023, before the interconnection of the islands Karpathos and Kassos with the mainland. These OWTs will be installed on the down side of the Graph 6 (see page 73 of this thesis) and from the right of it. Consequently, the first OWT will be at a distance of 1.000 meters from the shore, the second will be at a distance of 802.5 meters from the first and the third will be at a distance of 631.3 meters from the second. In addition, 6 OWTs, as it was cited above (see page 70-71 of this thesis), will be put in January 2028, after the interconnection. However, the first 3 OWTs should be dismantled, before the other 6 (see page 72 of this thesis). This fact will not cause any malfunction to the OWF, provided that the cables located before and after the OWTs, which will be removed, will be connected to each other. This is not a difficult task and it entails negligible additional costs that they are not included in the economic analysis.

4.3.4 The onshore substation and the plan after the scheduled transition to the high voltage network

The OWFs can have both an offshore substation and an onshore substation for their operation. However, they can operate only with an onshore substation, when the OWP is near to the shore. In this case, the offshore substation is unneeded and a possible its installation could increase significantly the cost, without actually being a useful action for the operation of the OWF.

Consequently and given the fact that the OWP of this thesis, between Karpathos and Kassos, is near to the shore, the author decided to not be put an offshore substation, which would be unnecessary. So, an onshore substation will be installed in Karpathos approximately 3 km far from the OWF (Figure 39), near to roads and at the same time in a flat area, without mountains. It should be noted also that regarding a potential installation of an onshore substation there are not limitations about the distance from coasts.

Figure 39: The point, where the author selected to put, for this thesis, the onshore substation, approximately 3 km (2.65 km) far from the offshore wind farm

Source: Google Maps, n.d. / Edited by the author

This onshore substation, which will be connected via cables with the OWF, will have an extent of approximately 1 acre and will be built to be in harmony with the local environment. The substation will include, among others, 2 measurement medium voltage panels, protection and control panels, the SCADA system and of course there will be access to the internet. The cables from the onshore substation should meet with the first pillar of the existing local medium voltage distribution network and if there is not one near the onshore substation, it could be constructed, after a relevant agreement between the parts. From the point that the OWF will be connected with the first pillar of the existing local medium voltage distribution network, the cost will cease to burden the energy producer (i.e. the firm, which hypothetically would assume the project). The cables and the medium voltage substation infrastructure will feed with the produced energy the medium voltage grid of Karpathos and in this way the OWF will be connected to the low and medium voltage network of the island and of course to the energy dependent from Karpathos, Kassos.

Karpathos and Kassos are currently (January of 2021) non-interconnected islands, but by 2027 is scheduled to be connected to the HETS. This fact will entail that Karpathos and Kassos will be connected via a 150 kV substation to the mainland transmission grid, through submarine cables. In this future scenario, the onshore substation described above will not serve the purposes of the project. The grid will not be of low and medium voltage, but of high voltage. For that reason, in the same point, but in an extent of 6 acres, will be created a new onshore substation (with even more equipment), because the voltage coming from the OWF should be transformed in the onshore substation at 150 kV, with the new data, after the transition to the high voltage network. The cost for this onshore substation (Figure 40) will be around 3 million Euros, in other words 2.3 million Euros more than the first (700.000 Euros) onshore substation. Nevertheless, the first onshore substation could be used as an intermediate measuring station.

Figure 40: An onshore substation in the interconnected island of Naxos, built with stone, to be in harmony with the local environment. This would be similar with the second described, in this thesis, onshore substation in Karpathos.

Source: greekcitytimes.com, 2020

For the selection of all the above mentioned information the author interviewed (21, 23/12/20) Apostolos Tzouvelekis, who is HV Substation Engineer at «Electromec S.A.», a Greek company specialized in HV/MV substations.

Table 6: A summary table of the characteristics of the OWF, between Karpathos and Kassos islands (Greece), designed by the author for this thesis

SUMMARY CHARACTERISTICS OF THE OWF OF THIS THESIS BETWEEN KARPATHOS AND KASSOS ISLANDS		
TOTAL NUMBER OF WIND TURBINES		**9**
WIND TURBINE	MANUFACTURER	**Siemens Gamesa**
	MODEL	**SWT-3.6-107**
	NOMINAL POWER	**3.6 MW**
	DIAMETER OF THE ROTOR	**107 m**
	SWEPT AREA	**8,992 m²**
TOTAL AREA		**1.787 km²**
TYPE OF FOUNDATION		**Monopile**
WATER DEPTH		**10-32 m**
SUBSTATION		**Onshore**
CABLES	OFFSHORE	**Aluminium, 6.392,8 m**
	ONSHORE	**Copper, 9.000 m**

Edited by the author

4.3.4.1 Safety measures and monitoring systems in offshore wind farms

During the construction and the operation of an OWP, guidelines about the safety and health of workers should be taken into consideration. The industry of the offshore wind follows guidelines by different sources (European, in our case, and national). The EU establishes some rules, via the EU Directive 89/391/EEC (Council of the European Union 89/391/EEC). In article 8 of paragraph 1 of this Directive there is reference about first aid, fire-fighting and evacuation of workers, as well as about serious and imminent danger. At the same time, this particular Directive is transposed in the national health and safety legislation of Member States of the EU. However, individual Member States should adopt more detailed health and safety legislation (European Wind Energy Association (EWEA), 2013). Moreover, companies execute risk assessments and it is possible to take further measures.

The objective of these policies is the mitigation of the jeopardies, as well as the prevention, in order to avoiding emergencies, during the construction and the operation of an OWF. Vessels (EWEA, 2013), which participate in these procedures, should follow also guidelines, to be limited the possibility of a threat of an accident and for that reason it is not only the training of workers mandatory, but also the existence of adequate equipment. Of course, updates of guidelines are necessary.

Offshore wind projects are more complex than onshore and thus risk assessments may be more demanding. Additional training and readiness, as well as stricter emergency plans, in comparison with onshore projects, are required, for example due to possible extreme weather, which entails potential extreme sea conditions. Furthermore, the size and the location of an OWF should be also taken into account, while the different phases may demand different plans (EWEA, 2013).

Concerning, the control and the monitor, via technology, of an offshore wind infrastructure, there are different systems for the supervision of it. These systems, which can decrease the operational and maintenance (O&M) costs and this fact could entail a more competitive price of the clean energy, have the possibility to provide reliable information for different parts of OWFs. The collected data are analyzed, mainly through algorithms, to identify and forecast malfunctions (Asanova, et al., 2017). The use of sensing and monitoring systems is still in initial steps, but the advantages that they offer lead to a further development of these. For that reason, individual researchers and companies seek to improve the conditions regarding the monitoring of offshore wind infrastructure (Asanova, et al., 2017) and the progress on wireless sensor network systems is to that direction.

Moreover, the significance of these systems is noteworthy, since the workers cannot approach OWFs for inspections with the same easiness like in inland infrastructure. Consequently, the monitoring systems should be accurate, reliable and efficient, for a potential problem to be evaluated with safety and for failure risks to be reduced.

Supervisory Control and Data Acquisition (SCADA) systems and Condition Monitoring Systems (CMSs) are extensively approved and exploited by the offshore wind industry. They are used for several parameters related to different OWT components to be monitored and for different factors to be assessed (Cai, et al., 2019). Nevertheless, the major part of CMSs is integrated into SCADA systems, because the latter offer more possibilities.

4.3.5 The examination of ports and the selection of one of them

The selection of the port, which will be used as a basis for the installation of an OWP, is of major importance, because it is a key point for the decrease of the cost (time consuming and fuels of vessels). A port is used for the transit of the components for an OWF and of course for the transportation of the crew, for the storage of the components and also as a temporary seat for the development of the project. Besides, in the port there are offices.

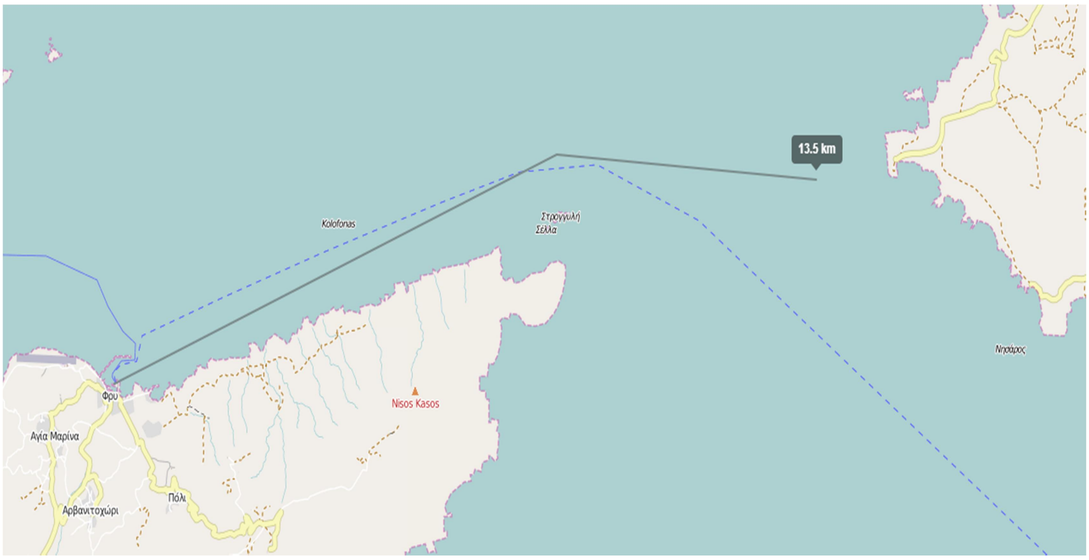
Concerning the project of this thesis, the distances from the three in total ports of the two islands to the OWP were calculated. The island of Kassos has one port, in Fry (Figure 41) and on the other side the island of Karpathos has two, which are in Pigadia and Diafani.

Figure 41: The port of Kassos

Source: Kampouris, N., 2020

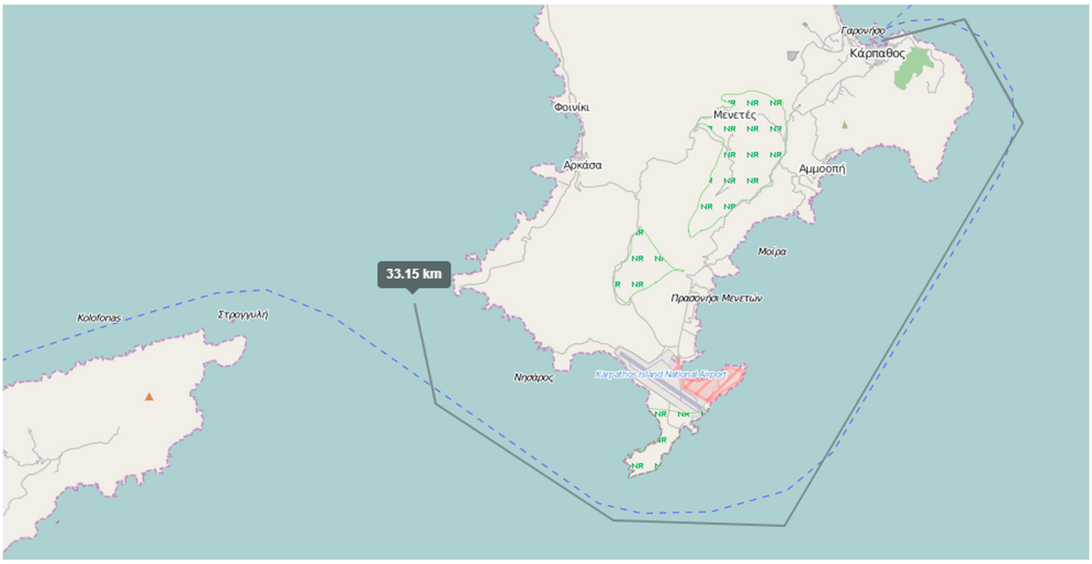
Although the fact that Kassos has a small size, it has one of the biggest ports (i.e. it has been operating since 2005 and it substituted the old port of the island) among Greek islands and bigger than the two of Karpathos. Moreover, the OWF is at a distance of approximately 13.5 km from the port of Kassos (Figure 42), while the port of Pigadia (Karpathos) is at a distance of approximately 33.15 km (Figure 43) and the port of Diafani (Karpathos) of 62 km (Figure 44). Consequently, for all the above mentioned reasons the author selected the port of Kassos, in order for the special vessels to transport faster, but also with lower energy consumption, the necessary equipment, as well as the specialized crew, for the needs of the installation of the OWF.

Figure 42: Distance (13.5 km) from the port in Fry, Kassos



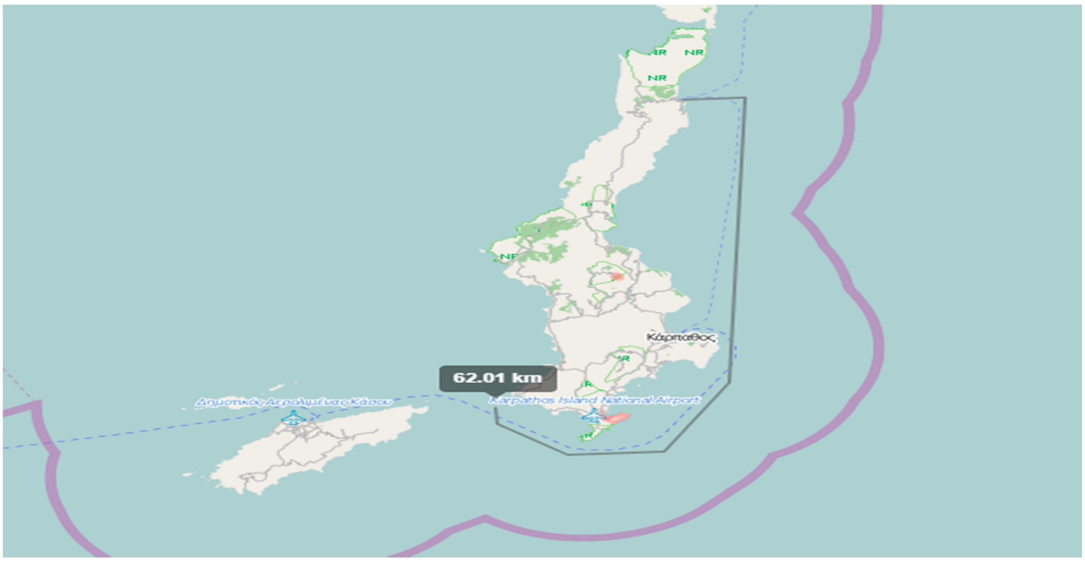
Source: Hellenic Republic, n.d., g / Edited by the author

Figure 43: Distance (33.15 km) from the port in Pigadia, Karpathos



Source: Hellenic Republic, n.d., h / Edited by the author

Figure 44: Distance (62.01 km) from the port in Diafani, Karpathos



Source: Hellenic Republic, n.d., i / Edited by the author

Nevertheless, it should be mentioned that the port of Kassos is likely to raise questions about its suitability for the purposes of an OWF, because it is near to a residential area (answer: due to the fact that the operations for the installation of the OWF will last only a few months and due to the future benefits of the Municipality of Kassos, residents of the island most probably will be tolerant), it operates as a basis for fishermen (answer: this is not an unsolvable problem, because all fishermen could be transported temporarily in their other basis, like in Mpouka and in Emporios) and the passenger ships moor there (answer: the passenger ships do not perform frequent itineraries, so the special vessels could have a lot of time to operate and also they could conduct their routes, when the passenger ships are in the port). At the same time, another possible question might be if the port of Kassos could be weight resistant regarding the components of the OWF. The answer is that most probably it could be. The hundreds extremely heavy parts of the seawall of this port were stored there, during its construction and specifically only on one side of the port. Consequently, there is already an experience about that issue.

Figure 45: The port of Kassos

Source: Diamantidis, V., n.d.

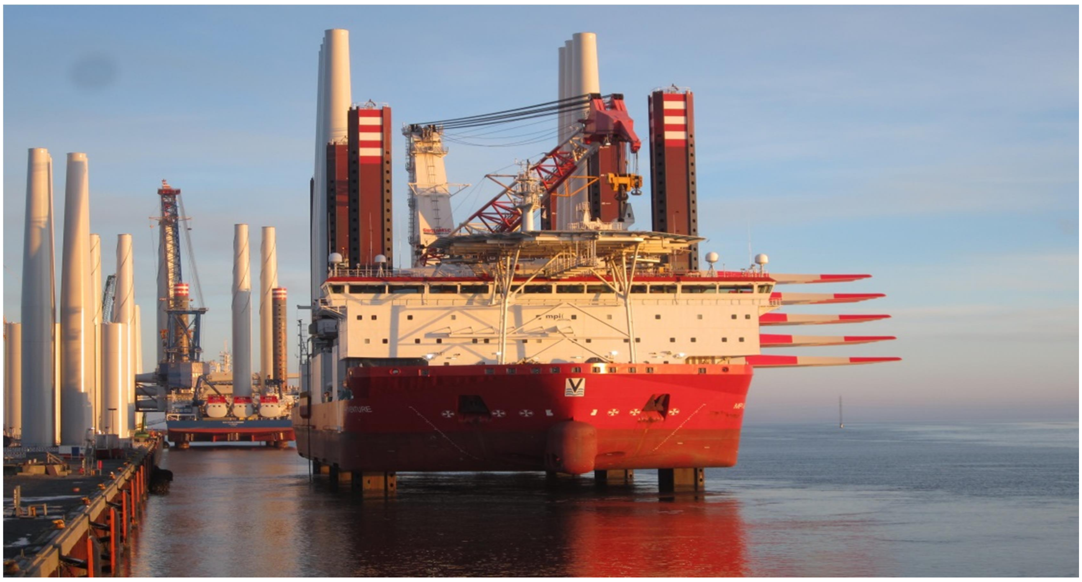
Alternatively, the port of Piraeus (Attica, mainland), which is the biggest in the Mediterranean and the ports of Laurium (Attica, mainland) and of Heraklion (Crete, island) are, most probably, sufficient for such a project. The first has a distance of approximately 410 km from the point of the interest, the second of 363 km and the third of 170 km. Such distances and even larger from ports to installation points are observed abroad, but their possible choice could increase dramatically the costs. To be concluded, in a theoretical viewpoint, all the ports in Greece are improper, currently (January of 2021), for a project of an OWF, because there is not at least one with the necessary infrastructure, due to the absence of this technology from the country.

4.3.6 Vessels

The use of vessels, which serve different objectives through their different types, is of utmost importance for the project of an OWF. As the offshore wind industry is evolving, development is observed also regarding vessels. The industry started to manufacture vessels exclusively for offshore wind purposes, with more deck space (more capabilities), less overall installation's duration (less delays) and more resistance to severe weather conditions.

There are different phases, in which vessels participate and for that reason there are different types of vessels. There is the Heavy Lift Vessel (HLV), for the transportation of the components from a port of the country of origin (in our case, Germany) to the selected port for the installation (in our case, Kassos). There is, also, the Wind Turbine Installation Vessel (WTIV), which is in our case the Jack-Up Vessel. Furthermore, there are the Platform Supply Vessel (PSV) and the Service Operation Vessel (SOV), which use is, usually, optional. Moreover, the use of the Cable Laying Vessel (CLV) and of the Fall Pipe Vessel (FPV) is necessary. The latter contributes in the rock-dumping phase (mainly for monopile foundations), in order for the foundations and for the cables to be protected. In addition, there are the Crew Transfer Vessel (CTV), which use is not mandatory and the Multi-purpose Support Vessel (MPSV), which is used for underpinning operations (D' Amico, et al., 2017), but it is not necessary for small-scale projects.

Figure 46: A vessel used for the installation of an offshore wind farm



Source: offshorewindindustry.com, 2015

Furthermore, WTIVs, which operate with a combination of hydrogen fuel cell system and a relatively small battery energy storage system (BESS), in addition to traditional fuels, are designed. According to a Norwegian firm named as «Ulstein», the cost is limited, in this way, to 5% of the total CAPEX and the vessel operates 75% of the period needed in zero-emission mode (Durakovic, 2020b). At the same time, a contract has been signed among firms for the manufacture by the end of 2022 of the largest WTIV in the world. This vessel, which will have green footprint, will be capable to transfer offshore wind turbines of the future, maybe up to 14 MW each (Buljan, 2020b).

Figure 47: A vessel into an offshore wind farm

Source: twitter.com, 2016

4.4 Energy Storage

4.4.1 Storage of energy in batteries

Wind cannot guarantee a constant production of energy, because the operation of wind turbines is intermittent. For that reason the storage of energy, mainly during times of low demand, is a key factor, in order to be ensured the channelization of energy at times of peak demand (i.e. peak period of demand in islands is, usually, the period of summer), to be limited the possibility of blackouts (power cuts) and to be provided a greater predictability, controllability (Du and Liu, 2020), reliability, responsiveness and in general to be strengthened the energy security (European Union , 2016).

Consequently, the energy storage is used, in general, in order for the surplus energy to be saved and also in order for the energy, which has previously absorbed, to be released, when the grid load is high. In this way, power grid fluctuations are avoided and the uncertainty, due to the high grade of the variability of the wind energy, is minimized.

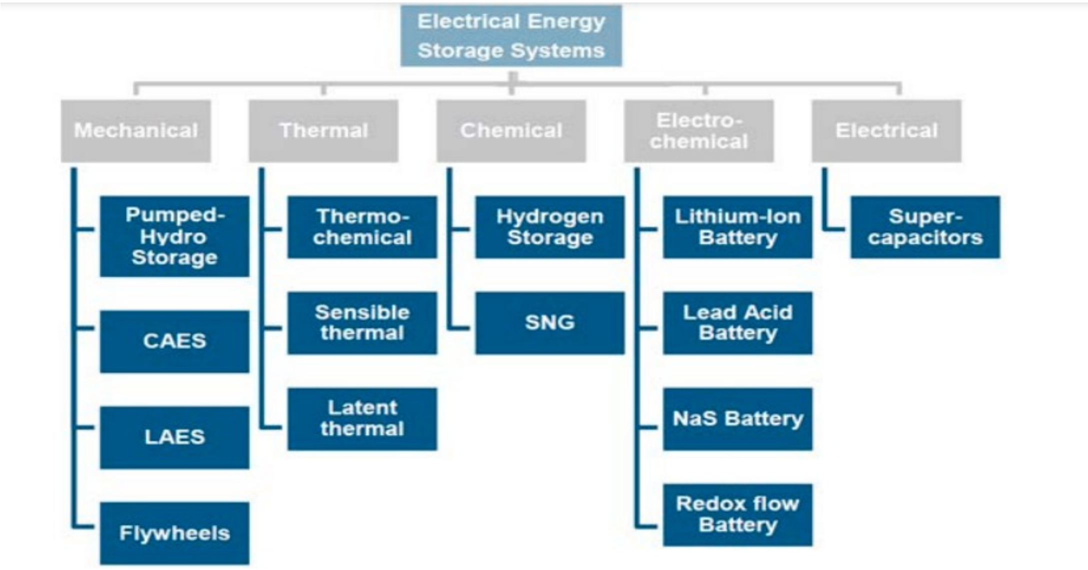
One of the manners with which the storage of energy is efficient is the use of batteries. There are many types of batteries for that objective, but lithium-ion (li-on) batteries are by far the most popular option, regarding this category and it possesses more than 90% of the global grid battery storage market.

At the same time, batteries aid to be reduced the cost of electricity mainly in isolated grids and grids without connection with the mainland (i.e. like in Karpathos – Kassos, by the time of the delivery of this thesis) (International Renewable Energy Agency (IRENA), 2020). Islands are characterized in an analysis of the European Union (TECHNOFI/Dowel Management/INTENSYS4EU/H2020, 2018, p.1) as «very attractive for deployment of batteries in combination with RES, given high cost of diesel-based electricity generation». Furthermore, the same analysis of the European Union (TECHNOFI/Dowel Management/INTENSYS4EU/H2020, 2018, p.1) underlines that in countries of the Southern Europe (i.e. Greece) is considered that batteries «make the highest economic sense».

Moreover, it is remarkable the «Tilos project», a project that took place in the Greek island of Tilos (Dodecanese complex), in order to be achieved the utmost level (100%) of energy autonomy for the island through a smart grid, based on a hybrid RES (wind and PV) system and energy storage, via the use of batteries (NaNiCl2 technology) (Tilos Horizon, n.d.).

Nevertheless, the most mature technology of storage of energy is the pumped hydro storage (PHS), which accounts for the 97% of the storage capacity globally. On the other hand, lithium-ion batteries cannot be called as mature regarding their application in electricity grids, although the fact that they are already suitable in a wide spectrum of functions (European Association for Storage of Energy (EASE) - European Energy Research Alliance (EERA), 2013).

Figure 48: The electrical energy storage systems



Source: European Commission, 2017, p.9

Moreover, according to IRENA, «globally, energy storage deployment in emerging markets is expected to increase by over 40% each year until 2025» (International Renewable Energy Agency (IRENA), 2020). Besides, the energy storage plays a determinant role in the transition to a carbon-neutral economy (European Commission, n.d., e). At the same time, according to a report of the EU about the strategic action plan on batteries (European Commission COM/2019/176, p.4), «in the 2050 perspective, storage will become the principal way of integrating renewables into the power system (…). The annual electricity storage in 2050 could increase at least tenfold compared to 2015».

The operation of batteries, concerning the charge and discharge, is very specific. The European Association for Storage of Energy (EASE) and the European Energy Research Alliance (EERA) describe it in a relative analysis: «When a battery discharges through a connected load, electrically charged ions in the electrolyte that are near one of the cell electrodes supply electrons (oxidation), while ions near the cell other electrode accept electrons (reduction), to complete the process. The process is reversed to charge the battery» (2013, p.37).

4.4.2 The lithium-ion batteries, used for the offshore wind farm of this thesis

For both phases of the project (the first phase with non-interconnected islands and the second phase with interconnected islands of Karpathos and Kassos), the author selected to use batteries of lithium-ion, for all the reasons mentioned in the paragraph 4.4.1.

The produced energy, which was also the energy consumed (there was not energy in excess), in Karpathos and Kassos (i.e. Kassos was dependent, during the writing of this thesis, in energy terms from Karpathos), in 2019, was 37.006,01 MWh (on average, 3.083,84 MWh per month), according to what Mr. Antonis Karanikolas, Electrical Engineer and resident of Karpathos, who works (January of 2021) in the autonomous production station of the Public Power Corporation (PPC) of the particular island, cited to the author on 20 October of 2020, in the context of a relevant communication between them.

For the energy purposes of Karpathos and Kassos, there are (January of 2021) 8 generators of total nominal power, approximately, 16.6 MW (Municipality of the Heroic Island of Kassos, 2020). The most powerful of them are 2 «WARTSILA W12V32», which have nominal power of 5 MW each. There is 1 «DAIHATSU 8DV-26» (1.8 MW), 1 «WARTSILA VASA 8R22MD» (0.8 MW) and 4 «MITSUBISHI» (1 MW each). All of them use mazut or diesel, leading to a total cost of production of energy, for the grid of Karpathos-Kassos, 222.13 €/MWh (i.e. the total cost for the operation and maintenance of the autonomous production station of Karpathos was 92.69 €/MWh, in 2019) (Municipality of the Heroic Island of Kassos, 2020). By installing the OWF and the lithium-ion batteries, the major part of these generators could be withdrawn. In the second phase (interconnected islands), the autonomous production station of the PPC of Karpathos will remain in reserve, in case of emergency, since the energy, which will be channelized by the HETS (the OWF of this thesis will participate in the HETS), will cover the needs of the two islands.

The batteries of lithium-ion, used for the project of this thesis, will be installed in the onshore substation and they could contribute for 10 years, on average, for the needs of the OWF, which means that for the project of this thesis will be required, after their installation, 2 times substitution of them. At the same time, it is noted that a battery of lithium-ion can maintain the stored energy even for 6 months, but there are losses of around 5% for each month. Every MWh of lithium-ion batteries costs 500.000-600.000 Euros and for the project of this thesis 2 MWh for each time (6 MWh, in total, for all the years of the OWF) were selected by the author. A cost of 550.000 Euros for each MWh it was considered, thus the overall cost is 3.300.000 Euros (550.000 Euros X 6 MWh).

For the collection of the information concerning the lithium-ion batteries, the author made an interview (11/01/20) with the Electrical Engineer, Mr. Simos Parcharidis, who works on the Greek firm, «Sunlight» that it specializes in energy storage and among others, in batteries of lithium-ion.

4.4.3 Power-to-X technology

There is an increasingly dynamic point of view that Power-to-X (PtX) technology could contribute to the world race regarding the energy transition and the decarbonisation. According to a study (Backwell, et al., 2020, p.91), «Power-to-X refers to the conversion of the surplus renewable energy into liquid or gaseous chemical energy sources through electrolysis and further synthesis processes». This technology is one of the most hopeful storage options for offshore wind and at the same time it maximizes the efficiency. The stored electricity, produced by OWFs, could be electrolyzed into hydrogen or can be combined with the carbon dioxide to make carbon-neutral liquid fuels like gasoline, diesel etc.

Power-to-X, which is at present at a very early stage and still expensive, may constitute, in the future, an economically viable model, since the advancements in this technology are continuous. Also, the costs are falling in the offshore wind projects and the policies change.

Before 2050 there is the expectation that the prices concerning the renewables powered electrolysis will fall from the current 2.06 - 5.59 Euros to 0.66 - 1.32 Euros per kilogram, in order for the Power-to-X technology to be price-appealing and competitive.

The hybrid solution of the cutting edge Power-to-X technology provides flexibility, greater energy security and lower price volatility. At the moment (January of 2021), there are two types –they are not analyzed in this thesis- of conversion of power produced by OWFs to hydrogen, which is then stored and it can be offloaded, when the energy is needed (peak periods, possible power outages etc). Finally, according to Backwell et al. (2020, p.94), «offshore wind to Power-to-X could be a game-changer within this decade considering the falling hydrogen cost and pilot projects coming online».

Two examples of the future possible coexistence of the offshore wind with the Power-to-X technology are coming from Denmark. Two energy islands, the natural island of Bornholm in the Baltic Sea and an artificial island in the North Sea, which will have a total offshore wind power capacity of 5 GW (the artificial island will have the potential to expand the offshore wind production to 10 GW in long-term), is designed to combine these two technologies (i.e. Power-to-X and offshore wind) (windeurope.org. 2020a).

Consequently, it is perceived that the Power-to-X technology constitutes one more, green, alternative solution. It could be implemented also, in the future, in the designed, in this thesis, project between Karpathos and Kassos, in order to be accomplished the power supply of the two islands and of the national energy grid, in general, with one more renewable, clean, energy source (hydrogen). Furthermore, the hydrogen could be used to serve different needs, like for example the movement of some of the Municipal (Karpathos and Kassos) vehicles (buses, garbage trucks etc) and some of trucks of individuals. In this way, the OWF could offer various alternatives regarding the energy produced by it.

Figure 49: An offshore wind farm

Source: Freeman, K., et al., 2017, p.14

4.5 Price of sale of the produced energy from the offshore wind farm between Karpathos and Kassos

Since 01/01/2017 the RES in Greece –and in all the Member States of the European Union- have been integrated in a context of State aid with the form of a differential increase in revenues from their participation in the wholesale market («Feed in Premium») and the previous RES support regime with fixed selling prices («Feed in Tariff»), through calls of interest of producers, was abandoned for the large scale projects. A Member State, through the new support scheme, which offers guaranteed premium for a number of years, could achieve the increase of new capacity for renewables mainly via auctions (competitive procedures) (European Union 2014/C 200/01). However, the regime of «Feed in Tariff» remains active for small-scale projects and for projects, which have been signed before 2016 (i.e. end of trial period of «Feed in Premium»).

For the technologies of wind farms and photovoltaics (PV), in Greece, competitive procedures were decided to be conducted, for the period 2018-20, in order to be defined the reference value. Consequently, the RES project owners was designed to have the possibility to receive State aid (premium - subsidy) on a reference value shaped from the participation of the firms in -open to all producers of electricity- competitive procedures.

In this way, through the «Feed in Premium» regime, Greece can succeed multiple goals, like the increase of the interest of potential investors, the decrease of the level of uncertainty, the increase of the level of stability, the increase of the transparency, the increase of the competitiveness in the market of the RES, the fulfillment of more investments to achieve its target climate goals, as well as the decrease of the cost for the consumers. Nevertheless, adjustments to the terms of support may be necessary in the future (European Court of Auditors, 2019).

After the completion of the first cycle of the competitive processes, in 2018, was observed that in the category of the wind farms (3 MW < P ≤ 50 MW), the reference value decreased by approximately 30%, since the starting price of the auction was posed at 90 €/MWh (i.e. the law 3468/2006 had defined the cost of electricity from OWFs at 90€/MWh), based on the previous regime («Feed in Tariff»), while the weighted average price was 66.53 €/MWh (Regulatory Authority for Energy (RAE), 2020), after the completion of the processes, with the new regime («Feed in Premium»).

On 2 April of 2020 an online auction was held (i.e. the electronic platform used for competitive processes in Greece is an innovative feature of competitive procedures) for one, among others, category of wind farms of power production greater than 3 MW and less than or equal to 50 MW (3 MW < P ≤ 50 MW). This competitive process had duration of 30 minutes, without any extension. The maximum permissible price for the common competitive process was 61.32 €/MWh (Regulatory Authority for Energy (RAE), 2020). The reference prices ranged from 49.11 €/MWh to 54.82 €/MWh and the weighted average price was 51.59 €/MWh. So, the benefit for the consumers reached to the percentage of 15.87% (Regulatory Authority for Energy

(RAE), 2020). It is realized that the weighted average price was decreased significantly in 2020 in comparison with the year 2018.

Although the fact that a competitive procedure took place, in Greece, also during July 2020, for wind farms, the author of this thesis used the auction of April 2020, in order to present an indication of prices, for wind parks, into the year 2020. Besides, in the auction of July were included the Energy Communities. In the islands of Karpathos and Kassos have not been established, yet, Energy Communities, thus they would not have the possibility to participate in this particular competitive procedure. At the same time, the OWF, for this thesis, will produce 32.4 MW, so it belongs to the category 3 MW < P ≤ 50 MW.

Nevertheless, it should be noted that the above prices constitute only an approach, given that in Greece there is not –during the time of the writing of this thesis- an OWF, but only land based wind parks and also given that the prices of OWFs differ, sometimes substantially, in relation with those of land based wind parks.

Moreover, the marginal system price in Greece, in December of 2020 (i.e. the last month, for which there were data, during the writing of this thesis), was 58.93 €/MWh (Hellenic Energy Exchange (HEnEx), 2020).

Finally, concerning Greece, the operation of the wholesale electricity market of the country was modernized in accordance with European practices and from 1st of November 2020 was organized, under the so-called «Target Model», in such a way as to allow efficient price formation, without causing distortions, fact that could entail many benefits. The ultimate aim is to be created a single, interconnected European energy market (capital.gr, 2020).

Figure 50: An offshore wind farm

Source: Moore, K., 2020

In the UK, which is the leader of offshore wind farms, worldwide, the offshore wind price in June 2020, after an auction, was shaped at 39.65 £/MWh (44.36 €/MWh) (Raval and Thomas, 2020). In Denmark the premium prices, in the last quarter of 2016, were ranged for the «near-shore projects» (OWFs «Vesterhav Nord» and «Vesterhav Syd») and Kriegers Flak offshore wind auctions, respectively, from 37.2 øre/kWh (approximately 50 €/MWh) to 47.5 øre/kWh (approximately 63.8 €/MWh) (González and Kitzing, 2019). In China, in 2016, the price for OWFs was 0.85 CNY/kWh (108.41 €/MWh) (Lin, et al., 2020).

To be concluded, the weighted average price, the marginal system price and the reference value are different values in economic terms. The price of the sale of energy in the market is defined by the weighted average price and this price was 51.59 €/MWh in April of 2020, in Greece, for wind farms (3 MW $<$ P $\leq$ 50 MW), as it was analyzed above. Nevertheless, this value is not accurate for OWFs, in Greece, because during the writing of this thesis, there was not even one in the country, as it was already mentioned. For that reason, the reference on other markets was necessary.

According to a study of the European Union (Wilson, 2020), the average selling price of the energy produced by offshore wind should be 54-65 €/MWh to be reasonable for the consumers and competitive for the producers. However, the price for this technology (i.e. specifically, this price is defined for the floating offshore wind), in Greece, is estimated to be formed in 2030 at 76 €/MWh and in 2050 at 46 €/MWh (Kielichowska, et al., 2020).

The author uses the price of 76 €/MWh for the calculations for the purposes of the economic analysis. It is not accurate to be taken into account the weighted average price (51.59 €/MWh) for a specific type of wind farms in Greece, neither to be taken into consideration the prices of other European countries that have already developed their offshore wind industry. Also, the law 3468/2006 had defined the price of electricity from offshore wind farms either in interconnected or not interconnected energy system at 90€/MWh (Hellenic Republic 3468/2006), while RAE had set the selling price for the production of energy from OWFs at 108.3 €/MWh in its decision with the number 54/2012 (Regulatory Authority for Energy (RAE) 54/2012). However, it is considered that both (90 €/MWh and 108.3 €/MWh) prices will be reformed. Consequently, the price of 76 €/MWh constitutes a more realistic choice.

4.6 Funding for the offshore wind farm between Karpathos and Kassos islands

There are many ways with which the OWF, between Karpathos and Kassos, could be funded, not only by capitals of the company that it could assume the project, but also by programs of the European Union and by the Greek State. In this section of the thesis, the author mentions some of the alternative approaches of funding of a green project by the European Union and by the Greek State, as well as the way of funding of the specific project is analyzed in this thesis.

The Sustainable Europe Investment Plan is the fundamental investment's basis of the European Green Deal. For the period 2021-2030 the budget of the EU for environmental objectives has been defined at 503 billion Euros and the parallel target is to be mobilized national investments of 114 billion Euros. The InvestEU belongs to the context of the Sustainable Europe Investment Plan and via this particular program the EU aims to dispose 279 billion Euros for environmental projects. The European Investment Bank (EIB) will support, with capitals, at a percentage of 75% the program InvestEU (Brindley, 2019). Besides, the role of the EIB is to provide aid to boost the European economy, offering financing and advisory services (Brindley, 2019). The Innovation and Modernization Fund also operates in the context of the European Green Deal. This fund «(…) will be financed with revenues from the auctioning of carbon allowances under the Emissions Trading Scheme (ETS) and will provide at least 25 billion Euros for the development of climate mitigation technologies» (Brindley, 2019, p.39).

Horizon Europe is one more program, for the research and the innovation, of the European Union and the upcoming period, 2021-2027, of its implementation is expected to be equally significant with that of the program Horizon 2020 (2014-2020), when nearly 80 billion Euros were disposed for projects (European Commission, 2019).

In addition to these ways of funding by the European Union, there are also the Green Bonds, which serve to finance projects for renewable energy, including of course the wind power (Brindley, 2019). In 2015 (September and December), for the first time, two OWFs were financed by the Project Bonds and the first from those was the OWP, Gode Wind 1, in Germany, for which 556 million Euros were approved, via the Project Bonds. Since then, approximately 2.3 billion Euros have been distributed for 1.1 GW offshore wind projects (Crédit Agricole Corporate and Investment Bank, 2019).

Moreover, regions, which are more dependent on fossil fuels, like Karpathos and Kassos, could be helped, through the Just Transition Mechanism. This mechanism could co-finance these places, into the period 2021-2030, with a total capital, which will reach approximately the 143 billion Euros, to limit their dependence and at the same time to be secured a regular transition (European Commission. 2020b). Furthermore, there is the European Fund for Strategic Investment (EFSI), which is integrated to the Investment Plan for Europe and its aim is to fund energy innovation and renewables from the year 2021 (Brindley, 2019).

The Innovation Fund is a program of the EU and it has as targets to support renewable energy and energy storage technologies. ETS of the EU has decided to finance the program via the disposal of 450 million Euros for the period 2020-2030 (windeurope.org, 2020b).

At the same time, there is a program called New Energy Solutions Optimized for Islands (NESOI), which aims to fund 60 energy transition projects in European islands, providing 100 million Euros by 2023. It offers approximately 60.000 Euros per proposal, as well as nearly 60.000 Euros for technical assistance per proposal (nesoi.eu, 2020). Moreover, a clean energy transition agenda has been published by 22 European islands, including Kassos and 7 more will follow in the near future (European Commission, 2020b).

Concerning the support of the Greek State to renewable energy projects, the Ministry of the Environment and Energy has established the Green Fund (Green Fund, n.d.), which includes also programs of renewable energy. Moreover, there is the program Greek Green Funds that it disposes 400 million Euros to the green economy and there is coordination, among others, with the Hellenic Development Investment Bank (HDBI) (Ketsietzis, 2020).

All the above cited prove that there are a lot of programs that they could fund, may –in ideal terms- in combination with each other, the OWF between Karpathos and Kassos. However, the author of this thesis selected the way of the EIB, because it is one of the leading arms of the EU and it participates in actions for the protection of the environment. At the same time, it can fund a project up to 50% of the total cost of the investment (European Investment Bank (EIB), n.d., a) and regarding OWFs there are many projects that they were half funded by the EIB. For example, the EIB provided for the «Norther» OWP, in Belgium, 438 million Euros from the total 1.112 of the investment (European Investment Bank (EIB)) and for the «Nordergrunde» OWF the EIB spent 156 million from the total amount of the 393 million Euros (European Investment Bank (EIB)). Furthermore, one more advantage is the fact that the EIB can sign long term contracts, which sometimes exceed 30 years. Also, the EIB offers competitive interest rates and project support, even on technical issues. If it is assumed that the project of this thesis would be undertaken by a medium-sized company (50-249 employees) (European Investment Bank (EIB)), which will have a turnover of less than 50 million Euros per year, then this company is included in the small and mid-size enterprises (SMEs). For that reason, the loan will be intermediate-term loan and consequently a Greek bank will participate to the funding of the project. So, the EIB will fund the OWF via a Greek bank. Under realistic and not ideal terms, the project could not be funded by other entity, because –in the case examined- the EIB, through a Greek bank, would not permit it, using relevant contract terms, in order to be ensured the payment in full of the loan by the firm. Furthermore, an interest rate of 1.5% is considered to apply for the loan payment, for the purposes of the economic analysis and also it is considered that the 50% of the cost will be coming from equity. On the other hand, apart from the loan, the contribution of a subsidy has not been considered, in the economic analysis of this thesis.

4.7 Dismantling of an offshore wind farm and dismantling of the offshore wind project of this thesis

The technology of the offshore wind is relatively new and given the fact that the major part of the OWFs has an average life expectancy of 20-25 years, the procedure of dismantling has not been analyzed yet extensively. Nevertheless, the decommissioning as a process is a very important part of any project and also it has unique characteristics for each project.

The first offshore wind project, in the world, which was disassembled, was the «Yttre Stengrund», in Sweden, in 2015, after approximately 14 years of operation. «Vindeby», the first OWP, which was installed in 1991, was decommissioned in 2017, after 26 years of operation and it was the third offshore wind project that it was dismantled (Bradley, et al., 2019).

Figure 51: A playground with pieces from a wind farm

Source: Guzzo, D., 2013

The procedure of dismantling of an OWF includes the removal of the components of it, such as wind turbines, the type of the foundation, transition pieces, offshore substation (if it exists), onshore substation, cables etc. Many of these elements are consisted of materials, which can be recycled or reused. In addition, there is a method, the method of repowering, which involves the replacement of the existing wind turbines to more powerful ones (McMillan and Topham, 2016). However, blades of wind turbines, as well as some other components of them, are currently (January of 2021) very difficult to be recycled (Bradley, et al., 2019).

Figure 52: A landfill with blades from wind turbines

Source: Rasmussen, B., 2020

It is noted that the estimated cost for the dismantling –as a procedure is calculated to be surged from 2030 at the latest- of an OWP is around 2-3% of the CapEx of the project (McMillan and Topham, 2016).

Concerning the project of this thesis, the dismantling of the first 3 OWTs, which has been designed to be installed in January 2023, will take place in December 2047 (after 25 years of operation), while the dismantling of the 6 OWTs, which has been designed to be installed in January 2028, will take place in December 2052 (after 25 years of operation).

4.8 Economic Analysis

At the following pages, the economic analysis made by the author for the OWF designed for this thesis is presented.

First of all, it should be noted that the «Cost 1» (year 0) refers to the cost, which is required for the first phase of the OWF, prior to the energy interconnection of the islands of Karpathos and Kassos with the mainland system. The period of the operation of the OWF with 3 OWTs (first phase) is considered by the author that will take place between January 2023 and December 2027. The «Cost 2» refers to the cost, which is required for the second phase (January 2028 – December 2052) of the OWF, after the energy interconnection of the two islands with the mainland system. In year 5 (January 2028) of the project 6 OWTs will be added and so the OWTs of the OWF will be, in total, 9 (3+6). However, after 25 years (January 2023 – December 2047) of the operation of the project, the first 3 OWTs will be dismantled and for that reason, the OWF will operate for a period of 5 years (January 2048 – December 2052) with 6 OWTs. Consequently, the total lifespan of the project will be 30 years.

The **Capital Expenditure (CapEx)**, via the calculation of the costs of offshore wind turbines, foundation (monopile, transition pieces), vessels, cables, meteorological mast, onshore substation, batteries, port, salaries, has been adjusted to the data of the OWF of this thesis. For the calculations regarding the wind turbines, the foundation, the vessels and the port, the author interviewed (08-23/12/20) the Civil Engineer, Mr. Joao Falcao, who is an employee of the «DEME Group», a firm which operates to the offshore wind market and consulted him. Concerning the number of occupied people needed for the project, the author also interviewed (01-03/12/20) the Engineer, Mr. Marios Papalexandou, who is founder and Director of the firm «AEOLUS», specialized to the offshore wind industry. For all the other calculations (cables, onshore substation, batteries), information about the sources could be provided in the relative parts of this thesis (4.3.3, 4.3.4, 4.4.2), in which necessary elements have been explained in detail. Nevertheless, it should be mentioned that the cost of 21.000 Euros of the «Onshore and Offshore cables connectors», in the

«Cost 1», has been occurred from the calculation 7.000 Euros X 3 pieces (one for each cable pole), which will be used for the connection of the onshore cables with the submarine cables. Furthermore, it shall be underlined that the cost (625.000 €) for the Heavy Lift Vessel (HLV) was applied to both «Cost 1» and «Cost 2».

In addition, the cost (30 €/MWh) of the **Operational Expenditures (OpEx)**, is an average cost, which has been drawn by the literature (Bela H. Buck, 2017). The selling price (76 €/MWh) has been set in paragraph 4.5.

At the same time, according to the Greek law 3468/2006, every electricity producer from RES, which is granted a production license, is burdened with a **special fee**, from the beginning of the commercial operation of the station of the produced energy. This special fee corresponds to **3%** on the pre-VAT price of sale of electricity. The special fee is attributed at a percentage of 80% to the local authority of first degree within the administrative boundaries of which the RES stations are installed and at a percentage of 20% to the local authority of first degree from the territorial region of which the line connecting the station to the System or Grid passes through. However, the author did not make allotment of the whole percentage (100%), but he took into account the special fee, 3%, as an obligatory attribution by the energy producer.

Also, the **value-added tax (VAT)** has been set by the author at 3%. In this project there has not taken into consideration any subsidy (50% equity, 50% loan) and given the fact that in reality a subsidy, most probably, will be granted by the State, the VAT, which was posed, is low, in order for this difference to be balanced.

About the **inflation** it was considered that it will be formed at 0.5%, in the year 2023, in Greece. The year 2015 (economic crisis in Greece), it was -1.7%, the year 2016 it was -0.8%, the year 2017 it was 1.1%, the year 2018 it was 0.5%, the year 2019 it was 0.3% and the year 2020 it was -1.2% (Covid-19 crisis).

The **discount rate** of 7.5% was extracted by a scientific study, which cited that the discount rate for the installed OWFs of different countries, like Germany, is 0.075

(7.5%). The same discount rate applies for Greece as well for onshore wind and photovoltaics (Alonso, et al., 2020).

The **residual value** was calculated in an approximate way, having also as direction a scientific study (McCarthy, 2015), in which the residual value per wind turbine for the model «SWT 107 - 3.6 MW», the same with this thesis, was mentioned.

The **Net Present Value (NPV)** calculation is the most important step for the economic analysis. The NPV tool shows the profitability and the feasibility of the studied project. As mentioned above, the project is consisted of two phases, so the different costs stem from this two-step investment («Cost 1» and «Cost 2») shall be taken into consideration in the NPV calculation.

The calculation of the NPV includes the present value of the cash flows. The cash flows occur from the cost of the initial investment («Cost 1»), as well as the operation of the OWF (including the loan payment, the batteries substitution cost every 10 years, the «Cost 2» of the addition of 6 more wind turbines and the dismantling costs) and the earnings from the sale of the produced energy. The wind turbines residual value at the time of the dismantling has also been taken into account.

The calculation is formed as follows:

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \frac{C_3}{(1+r)^3} + \cdots + + \frac{C_{30}}{(1+r)^{30}}$$

Where:

C_0: Initial Investment Cost (Year 0)

C_n: Cash Flow of Year n

r: Discount rate

The NPV of this investment has been calculated equal to 820,037.29 €, being positive and well above zero. This means that the project is feasible and profitable and it could be undertaken.

Furthermore, the calculation of the **Internal Rate of Return (IRR)** has been conducted. At first, it is important to be mentioned that the IRR is the annual growth rate that an investment is anticipated to generate and it is also the discount rate that makes the NPV equal to zero. If the IRR is more than the discount rate of the NPV calculation, the investment is profitable and feasible.

Actually, the IRR method concludes to the same results with the NPV method, regarding the profitability and feasibility of the project of this thesis. Indeed, in this project the IRR is calculated to be equal to 7.83%, which is more than the discount rate (7.5%) that it has taken into account in the economic analysis.

The **Levelized Cost Of Energy (LCOE)** is an economic evaluation of the average total cost to construct and operate a power-generating asset (in our case, the OWF) over its lifespan divided by the total energy production of the asset over that lifetime. Also, it is a fundamental consideration for the cost of electricity generated from a power plant during its lifetime (Duan, 2017). The global LCOE for offshore wind reached at 45-79 €/MWh, in 2019, while regarding the floating offshore wind there is a possibility to be reached at less than 100 €/MWh, in 2030 (European Commission COM/2020/741).

The LCOE formula that was used for the calculation is the following:

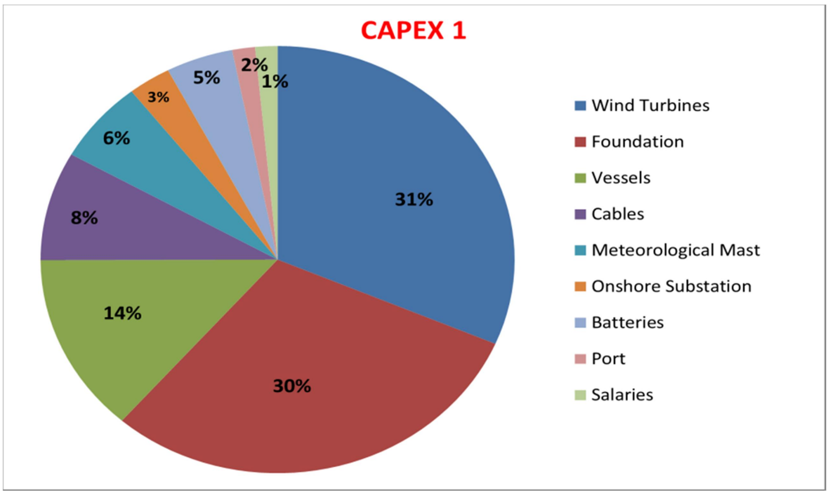
$$LCOE = \frac{Present\ Value\ of\ Costs\ (€)}{Present\ Value\ of\ Produced\ Energy\ (MWh)}$$

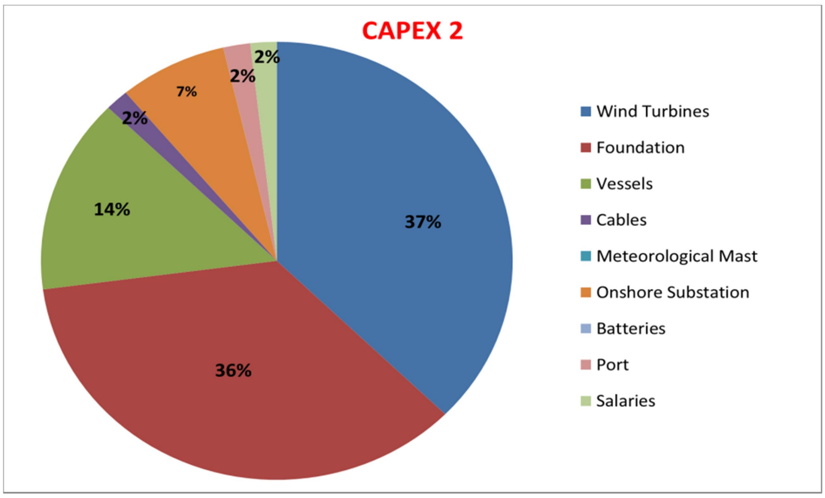
The Present Value of both costs («Cost 1» and «Cost 2») and of the produced energy has been calculated based on the discount rate of 7.5%. As for the costs that have been included, there are the initial investment cost («Cost 1»), the operating costs for the different periods, the loan payment, the batteries substitution cost every 10 years, the «Cost 2» of the addition of 6 more wind turbines and the wind turbines dismantling costs.

The LCOE of the economic analysis of this thesis was calculated equal to 97.90 €/MWh.

The detailed economic elements are following in the tables below:

CAPEX		
CATEGORIES	**COST 1 (YEAR 0)**	**COST 2 (YEAR 5)**
Wind Turbines	7,560,000.00 €	15,120,000.00 €
Foundation	7,200,000.00 €	14,400,000.00 €
Vessels	3,257,500.00 €	5,833,000.00 €
Cables	1,980,000.00 €	653,284.50 €
Meteorological Mast	1,500,000.00 €	- €
Onshore Substation	700,000.00 €	3,000,000.00 €
Batteries	1,100,000.00 €	- €
Port	375,000.00 €	750,000.00 €
Salaries	364,583.33 €	729,166.67 €
TOTAL:	**24,037,083.33 €**	**40,485,451.17 €**





WIND TURBINES					
	COST / MW	MW / TURBINE	COST / TURBINE	NUMBER OF TURBINES	TOTAL COST
COST 1	700,000.00 €	3.60	2,520,000.00 €	3.00	**7,560,000.00 €**
COST 2	700,000.00 €	3.60	2,520,000.00 €	6.00	**15,120,000.00 €**

THE FOUNDATION OF THE WIND TURBINES				
	CATEGORIES	NUMBER OF UNITS	COST / EACH	TOTAL COST
COST 1	Monopiles	3.00	650,000.00 €	1,950,000.00 €
	Transition Pieces (TPs)	3.00	1,750,000.00 €	5,250,000.00 €
			TOTAL:	**7,200,000.00 €**
COST 2	Monopiles	6.00	650,000.00 €	3,900,000.00 €
	Transition Pieces (TPs)	6.00	1,750,000.00 €	10,500,000.00 €
			TOTAL:	**14,400,000.00 €**

VESSELS						
TYPE	NUMBER / TYPE	DAYS (FOR COST 1)	DAYS (FOR COST 2)	COST / DAY	TOTAL COST 1 / TYPE	TOTAL COST 2 / TYPE
Heavy Lift Vessel (HLV)	1.00	5.00	8.00	28,500.00 €	142,500.00 €	228,000.00 €
Jack-Up Vessel	1.00	12.00	24.00	125,000.00 €	1,500,000.00 €	3,000,000.00 €
Platform Supply Vessel (PSV)	1.00	12.00	24.00	32,500.00 €	390,000.00 €	780,000.00 €
Cable Laying Vessel (CLV)	1.00	10.00	20.00	30,000.00 €	300,000.00 €	600,000.00 €
Fall Pipe Vessel (FPV)	1.00	10.00	20.00	30,000.00 €	300,000.00 €	600,000.00 €
				TOTAL:	**2,632,500.00 €**	**5,208,000.00 €**

Heavy Lift Vessel (HLV)	
For Each Installation Project	
Preparation and Mobilization	500,000.00 €
Demobilization	125,000.00 €
TOTAL:	**625,000.00 €**

CABLES					
TYPE OF CABLES	METERS (FOR COST 1)	METERS (FOR COST 2)	COST PER METER (€/m)	TOTAL COST 1	TOTAL COST 2
Offshore cables	2,433.50	3,959.30	165.00 €	401,527.50 €	653,284.50 €
Onshore cables	9,000.00	-	220.00 €	1,980,000.00 €	- €
Onshore and Offshore cables connectors	-	-	-	21,000.00 €	- €
			TOTAL:	1,980,000.00 €	653,284.50 €

METEOROLOGICAL MAST	
NUMBER OF UNITS	COST 1
1.00	1,500,000.00 €

ONSHORE SUBSTATION		
NUMBER OF UNITS	COST 1	COST 2
1.00	700,000.00 €	3,000,000.00 €

SALARIES OF THE STAFF	
Number of people	175.00
Mix Salary per person	2,500.00 €
TOTAL (per month):	437,500.00 €
TOTAL (for 25 days) (FOR COST 1):	364,583.33 €
TOTAL (for 50 days) (FOR COST 2):	729,166.67 €

BATTERIES			
	YEAR 0	YEAR 10	YEAR 20
MWh	2.00	2.00	2.00
COST PER MWh	550,000.00 €	550,000.00 €	550,000.00 €
TOTAL COST	1,100,000.00 €	1,100,000.00 €	1,100,000.00 €

PORT				
For the renting and for the using of its services				
TOTAL COST / DAY	DAYS (FOR COST 1)	DAYS (FOR COST 2)	TOTAL COST FOR 25 DAYS (FOR COST 1)	TOTAL COST FOR 50 DAYS (FOR COST 2)
15,000.00 €	25.00	50.00	375,000.00 €	750,000.00 €

OPEX			
CATEGORIES	**YEAR 0 - YEAR 5 (3 WIND TURBINES)**	**YEAR 6 - YEAR 25 (9 WIND TURBINES)**	**YEAR 26 - YEAR 30 (6 WIND TURBINES)**
Staff Salaries	30€/MWh		
Staff Insurance			
Administration & Management			
Rent for Onshore Substation			
Provisions for Repairs (incl. unplanned)			
Bills for the Use of the Whole System			
Taxes			
Depreciation			
30€/MWh*TOTAL PRODUCED MWh/YEAR			
TOTAL:	**1,135,296.00 €**	**3,405,888.00 €**	**2,270,592.00 €**

OTHER ONE TIME ACTIONS		
YEAR	**TYPE OF COST**	**COST**
10	BATTARIES REPLACMENT	1,100,000.00 €
20	BATTARIES REPLACMENT	1,100,000.00 €
25	DISMANTLING OF 3 WIND TURBINES (2,5% of COST 1)	600,927.08 €
25	RESIDUAL VALUE OF 3 WIND TURBINES	170,000.00 €
30	DISMANTLING OF 6 WIND TURBINES (2,5% of COST 2)	1,012,136.28 €
30	RESIDUAL VALUE OF 6 WIND TURBINES	340,000.00 €

INCOME CALCULATION			
	INCOME 1 (YEAR 0 - YEAR 5)	**INCOME 2 (YEAR 6 - YEAR 25)**	**INCOME 3 (YEAR 26 - YEAR 30)**
Price (€/MWh)	76	76	76
	37843.2	113529.6	75686.4
76 €/MWh * Total MWh/Year			
Income/Year	**2,876,083.20 €**	**8,628,249.60 €**	**5,752,166.40 €**

PRODUCED ENERGY CALCULATION			
	YEAR 0 - YEAR 5 (3 WIND TURBINES)	**YEAR 6 - YEAR 25 (9 WIND TURBINES)**	**YEAR 26 - YEAR 30 (6 WIND TURBINES)**
Total Installed Power (MW)	10.8	32.4	21.6
Days	365	365	365
Hours	24	24	24
Efficiency of the Wind Turbines	40.0%	40.0%	40.0%
TOTAL INSTALLED POWER (MW)*365DAYS*24HOURS*40%			
TOTAL PRODUCED MWh/YEAR:	**37,843.20**	**113,529.60**	**75,686.40**

LOCAL COMMUNITY COMPENSATORY PORTION			
	3% OF INCOME/YEAR (YEAR 0 - YEAR 5)	3% OF INCOME/YEAR (YEAR 6 - YEAR 25)	3% OF INCOME/YEAR (YEAR 26 - YEAR 30)
TOTAL:	**86,282.50 €**	**258,847.49 €**	**172,564.99 €**
INCOME*LOCAL COMMUNITY COPENSATORY PORTION			

REMAINING INCOME/YEAR (EXCL. LOCAL COMMUNITY COMPENSATORY)		
2,789,800.70 €	**8,369,402.11 €**	**5,579,601.41 €**
INCOME-LOCAL COMMUNITY COMPENSATORY		

VAT			
	VAT 1 (YEAR 0 - YEAR 5)	**VAT 2 (YEAR 6 - YEAR 25)**	**VAT 3 (YEAR 26 - YEAR 30)**
	3.00%	3.00%	3.00%
TOTAL final income after VAT	**2,706,106.68 €**	**8,118,320.05 €**	**5,412,213.37 €**
(1-VAT)*REMAINING INCOME/YEAR			

LOAN 1	
Interest Rate	1.50%
Loan Amount (50% of COST 1)	12,018,541.67 €
Years of Loan	25

LOAN 2	
Interest Rate	1.50%
Loan Amount (50% of COST 2)	20,242,725.58 €
Years of Loan	25

LOAN 1				
YEAR	INTERESTS	CAPITAL INSTALLMENT	REMAINING CAPITAL	ANNUAL LOAN PAYMENT
0	- €	- €	12,018,541.67 €	- €
1	180,278.13 €	480,741.67 €	11,537,800.00 €	661,019.79 €
2	173,067.00 €	480,741.67 €	11,057,058.33 €	653,808.67 €
3	165,855.88 €	480,741.67 €	10,576,316.67 €	646,597.54 €
4	158,644.75 €	480,741.67 €	10,095,575.00 €	639,386.42 €
5	151,433.63 €	480,741.67 €	9,614,833.33 €	632,175.29 €
6	144,222.50 €	480,741.67 €	9,134,091.67 €	624,964.17 €
7	137,011.38 €	480,741.67 €	8,653,350.00 €	617,753.04 €
8	129,800.25 €	480,741.67 €	8,172,608.33 €	610,541.92 €
9	122,589.13 €	480,741.67 €	7,691,866.67 €	603,330.79 €
10	115,378.00 €	480,741.67 €	7,211,125.00 €	596,119.67 €
11	108,166.88 €	480,741.67 €	6,730,383.33 €	588,908.54 €
12	100,955.75 €	480,741.67 €	6,249,641.67 €	581,697.42 €
13	93,744.63 €	480,741.67 €	5,768,900.00 €	574,486.29 €
14	86,533.50 €	480,741.67 €	5,288,158.33 €	567,275.17 €
15	79,322.38 €	480,741.67 €	4,807,416.67 €	560,064.04 €
16	72,111.25 €	480,741.67 €	4,326,675.00 €	552,852.92 €
17	64,900.13 €	480,741.67 €	3,845,933.33 €	545,641.79 €
18	57,689.00 €	480,741.67 €	3,365,191.67 €	538,430.67 €
19	50,477.88 €	480,741.67 €	2,884,450.00 €	531,219.54 €
20	43,266.75 €	480,741.67 €	2,403,708.33 €	524,008.42 €
21	36,055.63 €	480,741.67 €	1,922,966.67 €	516,797.29 €
22	28,844.50 €	480,741.67 €	1,442,225.00 €	509,586.17 €
23	21,633.38 €	480,741.67 €	961,483.33 €	502,375.04 €
24	14,422.25 €	480,741.67 €	480,741.67 €	495,163.92 €
25	7,211.13 €	480,741.67 €	0.00 €	487,952.79 €
26	- €	- €	- €	- €
27	- €	- €	- €	- €
28	- €	- €	- €	- €
29	- €	- €	- €	- €
30	- €	- €	- €	- €

LOAN 2				
YEAR	INTERESTS	CAPITAL INSTALLMENT	REMAINING CAPITAL	ANNUAL LOAN PAYMENT
	- €	- €	- €	- €
	- €	- €	- €	- €
	- €	- €	- €	- €
	- €	- €	- €	- €
	- €	- €	- €	- €
5	- €	- €	20,242,725.58 €	- €
6	303,640.88 €	809,709.02 €	19,433,016.56 €	1,113,349.91 €
7	291,495.25 €	809,709.02 €	18,623,307.54 €	1,101,204.27 €
8	279,349.61 €	809,709.02 €	17,813,598.51 €	1,089,058.64 €
9	267,203.98 €	809,709.02 €	17,003,889.49 €	1,076,913.00 €
10	255,058.34 €	809,709.02 €	16,194,180.47 €	1,064,767.37 €
11	242,912.71 €	809,709.02 €	15,384,471.44 €	1,052,621.73 €
12	230,767.07 €	809,709.02 €	14,574,762.42 €	1,040,476.09 €
13	218,621.44 €	809,709.02 €	13,765,053.40 €	1,028,330.46 €
14	206,475.80 €	809,709.02 €	12,955,344.37 €	1,016,184.82 €
15	194,330.17 €	809,709.02 €	12,145,635.35 €	1,004,039.19 €
16	182,184.53 €	809,709.02 €	11,335,926.33 €	991,893.55 €
17	170,038.89 €	809,709.02 €	10,526,217.30 €	979,747.92 €
18	157,893.26 €	809,709.02 €	9,716,508.28 €	967,602.28 €
19	145,747.62 €	809,709.02 €	8,906,799.26 €	955,456.65 €
20	133,601.99 €	809,709.02 €	8,097,090.23 €	943,311.01 €
21	121,456.35 €	809,709.02 €	7,287,381.21 €	931,165.38 €
22	109,310.72 €	809,709.02 €	6,477,672.19 €	919,019.74 €
23	97,165.08 €	809,709.02 €	5,667,963.16 €	906,874.11 €
24	85,019.45 €	809,709.02 €	4,858,254.14 €	894,728.47 €
25	72,873.81 €	809,709.02 €	4,048,545.12 €	882,582.84 €
26	60,728.18 €	809,709.02 €	3,238,836.09 €	870,437.20 €
27	48,582.54 €	809,709.02 €	2,429,127.07 €	858,291.56 €
28	36,436.91 €	809,709.02 €	1,619,418.05 €	846,145.93 €
29	24,291.27 €	809,709.02 €	809,709.02 €	834,000.29 €
30	12,145.64 €	809,709.02 €	0.00 €	821,854.66 €

NPV CALCULATION	
Equity 1 (50% OF COST 1)	12,018,541.67 €
Equity 2 (50% OF COST 2)	20,242,725.58 €
OPEX 1 (YEAR 0 - YEAR 5)	1,135,296.00 €
OPEX 2 (YEAR 6 - YEAR 25)	3,405,888.00 €
OPEX 3 (YEAR 26 - YEAR 30)	2,270,592.00 €
Total final income after VAT (YEAR 0 - YEAR 5)	2,706,106.68 €
Total final income after VAT (YEAR 6 - YEAR 25)	8,118,320.05 €
Total final income after VAT (YEAR 26 - YEAR 30)	5,412,213.37 €
Inflation	0.50%
Annual loan payment (Loan and Loan 2)	

Lifespan of whole project (Years)	30

Discount Rate	7.50%

PERIOD	CASHFLOWS	PERIOD	CASHFLOWS	PERIOD	CASHFLOWS
0	- 12,018,541.67 €	11	3,070,902.83 €	22	3,664,658.54 €
1	914,339.85 €	12	3,090,259.60 €	23	3,704,691.44 €
2	926,194.96 €	13	3,109,616.36 €	24	3,745,033.06 €
3	938,145.77 €	14	3,128,973.13 €	25	3,297,533.19 €
4	950,192.93 €	15	3,148,329.90 €	26	2,585,651.31 €
5	- 19,791,542.66 €	16	3,167,686.66 €	27	2,612,476.02 €
6	3,064,464.27 €	17	3,187,043.43 €	28	2,639,504.33 €
7	3,099,831.09 €	18	3,206,400.19 €	29	2,666,737.62 €
8	3,135,474.96 €	19	3,225,756.96 €	30	1,913,558.12 €
9	3,171,397.77 €	20	2,145,113.72 €		
10	2,051,347.29 €	21	3,264,470.49 €		
NPV			**820,037.29 €**		
IRR			**7.83%**		

	ROI 1	ROI 2	ROI 3
TOTAL final income after VAT	2,706,106.68 €	8,118,320.05 €	5,412,213.37 €
CAPEX	24,037,083.33 €	64,522,534.50 €	64,522,534.50 €
ROI = TOTAL FINAL INCOME AFTER VAT/CAPEX			
ROI	**11.26%**	**12.58%**	**8.39%**

YEAR	COST	COST - PRESENT VALUE	PRODUCED MWh	PRODUCED MWh - PRESENT VALUE
0	24,037,083.33 €	24,037,083.33 €	0.00	0.00
1	1,796,315.79 €	1,670,991.43 €	37,843.20	35,202.98
2	1,789,104.67 €	1,548,170.61 €	37,843.20	32,746.96
3	1,781,893.54 €	1,434,354.04 €	37,843.20	30,462.28
4	1,774,682.42 €	1,328,883.13 €	37,843.20	28,337.01
5	1,767,471.29 €	1,231,147.39 €	37,843.20	26,360.01
6	45,629,653.24 €	29,566,259.40 €	113,529.60	73,562.81
7	5,124,845.31 €	3,089,025.63 €	113,529.60	68,430.52
8	5,105,488.55 €	2,862,658.83 €	113,529.60	63,656.30
9	5,086,131.79 €	2,652,842.28 €	113,529.60	59,215.16
10	6,166,775.03 €	2,992,081.80 €	113,529.60	55,083.87
11	5,047,418.27 €	2,278,117.86 €	113,529.60	51,240.81
12	5,028,061.51 €	2,111,052.39 €	113,529.60	47,665.87
13	5,008,704.75 €	1,956,209.65 €	113,529.60	44,340.35
14	4,989,347.99 €	1,812,697.33 €	113,529.60	41,246.83
15	4,969,991.23 €	1,679,688.15 €	113,529.60	38,369.15
16	4,950,634.47 €	1,556,415.09 €	113,529.60	35,692.23
17	4,931,277.71 €	1,442,167.05 €	113,529.60	33,202.07
18	4,911,920.95 €	1,336,284.75 €	113,529.60	30,885.65
19	4,892,564.19 €	1,238,156.98 €	113,529.60	28,730.84
20	5,973,207.43 €	1,406,171.56 €	113,529.60	26,726.36
21	4,853,850.67 €	1,062,939.78 €	113,529.60	24,861.73
22	4,834,493.91 €	984,838.01 €	113,529.60	23,127.19
23	4,815,137.15 €	912,460.31 €	113,529.60	21,513.67
24	4,795,780.39 €	845,388.13 €	113,529.60	20,012.71
25	5,377,350.71 €	881,772.92 €	113,529.60	18,616.48
26	3,141,029.20 €	479,128.39 €	75,686.40	11,545.10
27	3,128,883.56 €	443,977.40 €	75,686.40	10,739.63
28	3,116,737.93 €	411,399.05 €	75,686.40	9,990.35
29	3,104,592.29 €	381,205.46 €	75,686.40	9,293.35
30	4,104,582.94 €	468,829.69 €	75,686.40	8,644.98
TOTAL:	-	93,917,857.87 €	-	959,289.84

LCOE= TOTAL COST PRESENT VALUE/ TOTAL PRODUCED MWh PRESENT VALUE	
LCOE (€/MWh)	**97.90**

ECONOMIC ANALYSIS SUMMARY		
CAPEX	COST 1	**24,037,083.33 €**
	COST 2	**40,485,451.17 €**
OPEX	YEAR 0 - YEAR 5 (3 WIND TURBINES)	**1,135,296.00 €**
	YEAR 6 - YEAR 25 (9 WIND TURBINES)	**3,405,888.00 €**
	YEAR 26 - YEAR 30 (6 WIND TURBINES)	**2,270,592.00 €**
OTHER ONE TIME ACTIONS	BATTARIES REPLACMENT (YEAR 10)	**1,100,000.00 €**
	BATTARIES REPLACMENT (YEAR 10)	**1,100,000.00 €**
	DISMANTLING OF 3 WIND TURBINES (2,5% of COST 1) (YEAR 25)	**600,927.08 €**
	RESIDUAL VALUE OF 3 WIND TURBINES (YEAR 25)	**170,000.00 €**
	DISMANTLING OF 6 WIND TURBINES (2,5% of COST 2) (YEAR 30)	**1,012,136.28 €**
	RESIDUAL VALUE OF 6 WIND TURBINES (YEAR 30)	**340,000.00 €**
TOTAL FINAL INCOME AFTER VAT	YEAR 0 - YEAR 5	**2,706,106.68 €**
	YEAR 6 - YEAR 25	**8,118,320.05 €**
	YEAR 26 - YEAR 30	**5,412,213.37 €**
LOAN	LOAN 1	**12,018,541.67 €**
	LOAN 2	**20,242,725.58 €**
NPV		**820,037.29 €**
IRR		**7.83%**
ROI	ROI 1	**11.26%**
	ROI 2	**12.58%**
	ROI 3	**8.39%**
LCOE		**97.9 (€/MWh)**

5. Socioeconomic impact

5.1 Benefits for Karpathos – Kassos islands and for the Greek State

It is crucial to specify in our analysis about the OWF, between Karpathos and Kassos, designed by the author for the purposes of this thesis, not only the benefits that the two islands could have from this project (they participate to the development of it), but also the benefits of all the Greek State.

First of all, both the Municipalities (Municipality of Karpathos – Municipality of the Heroic Island of Kassos), as well as the inhabitants of the islands, should claim and should attribute to them benefits. Besides, this project should function as a chance for the two islands and by extension for the Greek State itself for the accomplishment of the further development in the energy sector.

In this context, the author interviewed (02/11/20) the Mechanical Engineer and Deputy Mayor of Tilos, Spyros Aliferis, in order to collect useful information about the benefits of the Municipality of the first green Mediterranean island, Tilos and of its inhabitants by the «Tilos project». Through the telephonic communication, Mr. Aliferis, who is also administrative of the hybrid system in Tilos on behalf of the company «Eunice Energy Group», which is the investor of the project, referred to a series of actions that they already are or are expected to be proven positive both for the Municipality of Tilos and for the residents of the island. These actions inspired the author of this thesis.

According to the statements of Mr. Aliferis to the author, «At the moment (November of 2020), in Tilos, due to the ''Tilos project'', one local person has covered a permanent job and also there was an agreement between the Municipality and the company (Eunice) for compensatory projects, two of which are the afforestation and road construction. Moreover, during the four years of the implementation of the project, the island obtained 1 million Euros, since there was an increased economic movement in the market, due to all these people who worked for this project. Also, tourists were attracted via the promotion of the island and at the same time people from the academic field visited Tilos in the context of their researches for Universities of England, Spain, the USA etc».

The public acceptance for the installation of an OWF between Karpathos and Kassos islands could be succeeded, mainly, not only through the limitation of the ignorance of the majority of people for the advantages of RES, but also through the presentation of the benefits for the Municipalities and for the residents themselves of these two islands, which as it has been already mentioned will participate in the project.

The benefits proposed (of course, they couldn’t be realized all of them), for the two islands, in this thesis, are related to their participation in the development of the project and to the fact that during the first phase (January 2023-December 2027) is considered that the interconnection of them with the mainland will not have been activated. So, the proposed benefits are recorded as follows: 1) jobs covered by local people (exploitation of human resources), 2) compensatory projects of any form - depending on the needs of the two islands- could be taken into consideration, 3) the promotion of the two islands, due to such a project, could entail, indeed, positive results, for example it could increase the tourism, 4) roads of the two islands could be lightened with the use of «smart» lamps, which will draw energy by the OWF, 5) installation of charging stations for electric vehicles (the Municipalities can replace some of their vehicles with electric vehicles), which will be charged with energy coming from the OWF, 6) an amount of money (the Municipalities can agree with the company on the amount) could be attributed annually to the Municipalities, 7) through the development of Energy Communities, the participation of the beneficiary residents to the share capital, concerning the particular project, could be claimed, 8) the operation of the OWF will almost eliminate the production of energy from fossil fuels by these two islands.

After the energy interconnection of Karpathos and Kassos islands with the mainland, many benefits will also occur for them, as well as for the Greek State in general: 1) the limitation of blackouts, mainly due to damages to the old submarine cables that they connect Karpathos and Kassos or due to damages to the autonomous production station of the PPC of Karpathos, could be a really essential profit for entrepreneurs of the two islands, because power cuts provoke significant losses (i.e. electrical devices are «burned», products stored in refrigerators spoil etc), 2) the limitation of blackouts could decrease the risk for those who make use of oxygen supply devices, in the two islands. In the past, people's lives were endangered due to power outages and because an emergency generator there was not found directly, 3) the OWF will contribute to the increase of the share of RES to the Greek energy mix and consequently to the effort of the accomplishment of the national green targets, 4) the increase of the contribution of RES will entail lower electricity prices for all the residents of Greece, 5) the pace of the climate change can be significantly slowed down through RES, with the aid of which the protection of the environment can be succeeded.

Consequently, a socioeconomic assessment, which consists of a social benefit analysis and may incorporate an economic impact analysis, is valuable, in order for the locals to comprehend better how impacts from a green project can influence a community (AECOM, 2017). At the same time, the information, provided in different ways, of the inhabitants is also crucial to limit the unfamiliarity with RES and specifically with the technology of the offshore wind and convince them, with arguments, for the benefits coming from an OWF. In any case, the author adopts the opinion that «the public should have some involvement in the decisions that shape the places in which they live» (Ellis and Ferraro, 2016, p.40).

It is noticeable, also, the fact that the Municipality of the Heroic island of Kassos composes its «Energy Transition Plan» (Social Cooperative Enterprise (SCE), 2020). It is a strategic plan, in which are determined and specified the basic axes for the energy transition of the island. Representatives of the Municipality have been in discussions for almost a decade (approximately from 2011) with the company, «Energy Electromechanical Works S.A. - ENET S.A.», for the installation of a hybrid power plant, consisting of a wind farm and a reversible hydroelectric plant, as an energy storage unit. The project received the license by RAE in March 2020, but the company declares to representatives of the Municipality, according to information selected by the author, through an inteview (03/11/20) with the Mayor of Kassos, Michalis Erotokritos that the price of the sale for the kWh should be defined, in order for a progress regarding the procedures to be observed. Also from this project the Municipality could have many benefits, similar with those from the OWF.

However, in Karpathos two wind turbines, one owned to PPC and one to an individual, 500 kW each, operate, located in the south part of the island.

5.2 Possible social reactions

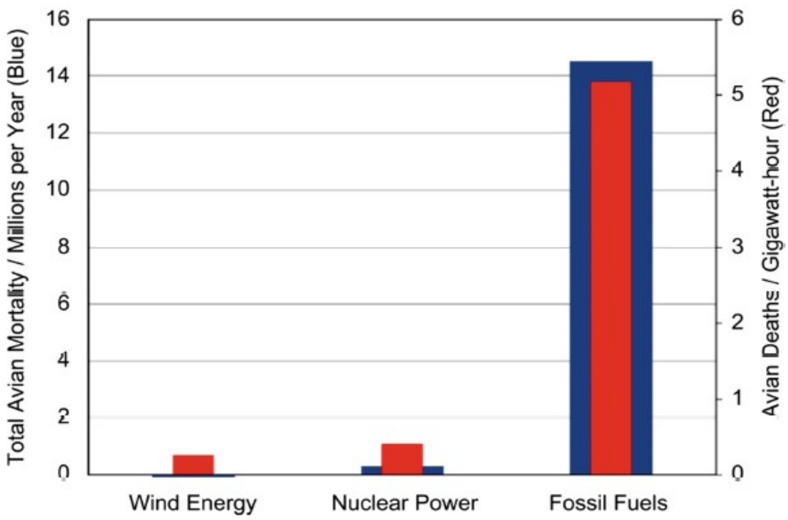
During the process of the design of the project of the OWF in Karpathos - Kassos islands it is a given that there will be reactions from categories of people, who will be negative to such a prospect.

Organizations, informal groups of people and individuals are expected to resist regarding the installation of an OWF. However, the majority of those people is assessed that it will come from Karpathos, which will be influenced at a higher level, mainly due to the unavoidable visual impact caused by the OWF, despite the fact that it is designed by the author in a very limited area and with a small number of wind turbines, exactly for making the OWF less disturbing visually.

Reactions are, also, possible to be focused on the «negative impact of OWFs on the environment». First of all, the marine environment is very different in comparison with the inland and of course an OWF does not disturb animals on land. Indeed, noise, toxic effects and electromagnetic fields may affect negatively the marine species, although the knowledge from possible results is limited, since the technology of offshore wind projects is relatively new. Nevertheless, there are, also, beneficial ecological outcomes about the sea species. For example, the artificial reefs, developed on the wind turbines foundations, provide support to the marine ecosystem (Apostolou, et al., 2016).

With the aid of techniques like radars, Thermal Animal Detection Systems (TADS), acoustic detection, cameras, sensors and computational collision model, can be studied the bird flight and behavior in relation to wind farms. Moreover, it is noticeable the fact that there are systems of artificial intelligence, like the IdentiFlight and the DTBird, which can detect, using different techniques, birds. Blades of the turbine, which is in the flight path of a bird, cease their operation automatically, when a bird owned at protected species (i.e. it must be owned, also, in the relative classification input by the operator of the system of the particular type of artificial intelligence) is identified, and in this way a possible collision is avoided. Contrary to the dominant opinion, the rate of mortality (collision fatalities) of avian species due to wind farms has been studied that it is quite low (Apostolou, et al., 2016) and lower than due to fossil-fueled power plants (coal, natural gas and oil-fired power stations), as well as nuclear power plants (Figure 53) (Ting and Vasel-Be-Hagh, 2020).

Figure 53: The total avian mortality by different causality



Source: Ting, D. and Vasel-Be-Hagh, A., 2020, p.114

«Fossil-fueled facilities are about 17 times more dangerous to birds on a per GWh basis; while wind energy accounts for 7,193 total bird kills per year, fossil fuels account for 14.5 million and nuclear power plants for 327,483», is highlighted in the book, «Complementary Resources for Tomorrow» (Ting and Vasel-Be-Hagh, 2020, p.115). The authors of the particular book point out, also: «(…) domestic cats kill billions of birds annually and collisions with communications towers kill about 6.5 million birds each year; this is about 18 times more than wind power technology» (Ting and Vasel-Be-Hagh, 2020, p.114). Of course, although the low levels of bird deaths due to wind turbines, even greater reduction of the collision fatalities caused by wind turbines is important to be achieved. Especially for OWTs there is a wide space of improvement on bird tracking technologies.

One other potential concern of people, apart from the visual impact which was analyzed in the paragraph 4.2.3 of this thesis, is the noise, regarding its potential effect on residents. In onshore projects, the noise impact creates a field of disagreements (in Greece, the minimum noise level set at 45 db should be ensured (Hellenic Republic 49828/2008), but in offshore projects this concern is extremely limited, since OWFs are located farther from inhabited areas and the noise, which distinguishes (Anon., 2001) to the aerodynamic noise and to the mechanical noise, cannot be –normally- audible from shore, especially if it is considered that the sound is overshadowed by natural sounds (e.a. sound of sea). In our case, the noise impact is impossible to influence the settlements, because the most close-range settlement of Karpathos is at a distance of approximately 5.50 km (Figure 32) and the one of Kassos of approximately 11 km (Figure 34). In onshore projects, wind turbines should be, usually (i.e. this depends on the national legislation), at a distance of 500 meters from settlements (Hellenic Republic 49828/2008).

Concerning the marine life, the noise impact is more disturbing during the construction of OWFs than during any other stage. However, «reported noise levels from operating wind turbines are rather low and are unlikely to damage the hearing of marine species» (Apostolou, et al., 2016, p.550). In any case, the industry «experiments» with techniques that they are possible to reduce the underwater noise levels, during the installation process (Durakovic, 2020a).

Fishermen also may react to a possible installation of an OWF, but compensation could be offered to them, in order to be offset potential losses. The author interviewed (17/12/20) Mr. Giannis Filippidis, who is a professional fisherman from Kassos (i.e. in Kassos and Karpathos there are about 35-40 professional fishing licenses), and he mentioned that: «In the place of your interest, in the southeast part of Karpathos, there are different species of fishes and fishermen from the islands, Kassos, Karpathos, Kalymnos, Leros, Crete work there. Besides, there is not any fishing zone in our areas, so we are not limited regarding the sites, which we select. Nevertheless, if an OWF would put in the southeast part of Karpathos, this fact would not be catastrophic for these fishermen, for us, because there are many alternatives for fishing in our places».

At the same time, it is significant the fact that OWTs cannot provoke any disturbance in agricultural or livestock activities and that there is not any discussion about land acquisitions, as in onshore wind farms.

In general, the public acceptance can be achieved with the provision of motives, which were described in the paragraph 5.1 of this thesis, as well as with the information of people.

6. SWOT Analyzes

Two (2) different SWOT analyzes, for the two phases examined in this thesis, are presented below:

1st phase: The offshore wind farm is installed, while the islands of Karpathos and Kassos are not interconnected in energy terms with the mainland:

Strengths	Weaknesses
• Favorable location, high wind resource • Protection of the environment and low impact, in general, to the everyday life (respect to the local daily life) • Many benefits for the two local communities • Provision for the future energy interconnection of the two islands (transition)	• The selection of the port of Kassos may raise questions about its appropriateness. However, the choice of this port occurred after examination and was based on reasons, which have been analyzed in detail in the paragraph 4.3.5 of this thesis. • Lack of subsidy from the specific plan
Opportunities	**Threats**
• «Turn» to the clean energy • Achieving goals with low cost, mature technology (monopile foundation) and a few wind turbines • Use of batteries and prospect for the use of hydrogen • Exploitation of the Greek ports, shipyards, industry of cables, industry of concrete etc	• Absence of such a project in Greece → no experience • Lack of specific legislative framework and methodology by the Greek State • Strong bureaucracy - Unknown required times, with accuracy • Lack of infrastructure (e.g. appropriate ports) • Possible social reactions

Edited by the author

2nd phase: The offshore wind farm is installed, while the islands of Karpathos and Kassos are interconnected in energy terms with the mainland:

Strengths	Weaknesses
• Favorable location, high wind resource • Protection of the environment and low impact, in general, to the everyday life (respect to the local daily life) • Many benefits for the two local communities and for the Greek State	• The selection of the port of Kassos may raise questions about its appropriateness. However, the choice of this port occurred after examination and was based on reasons, which have been analyzed in detail in the paragraph 4.3.5 of this thesis. • Lack of subsidy from the specific plan
Opportunities	**Threats**
• «Turn» to the clean energy • Achieving goals with low cost, mature technology (monopile foundation) and a few wind turbines • Use of batteries and prospect for the use of hydrogen • Exploitation of the Greek ports, shipyards, industry of cables, industry of concrete etc	• Absence of such a project in Greece → no experience • Lack of specific legislative framework and methodology by the Greek State • Strong bureaucracy - Unknown required times, with accuracy • Lack of infrastructure (e.g. appropriate ports) • Possible social reactions

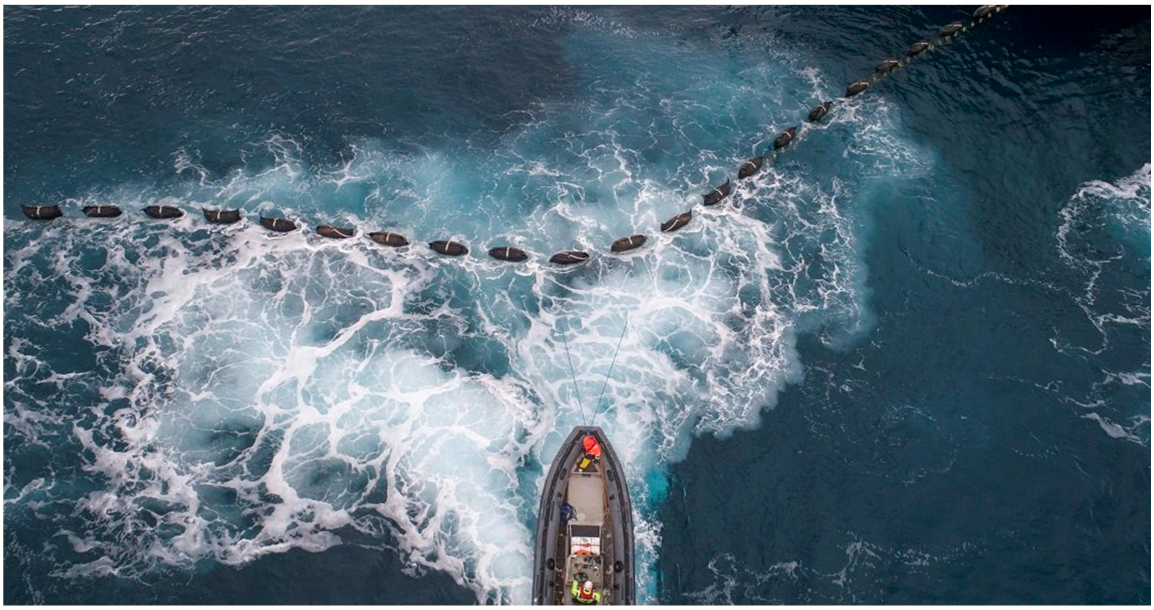
Edited by the author

7. The energy interconnection with the mainland of the non-interconnected islands and the benefits

The energy interconnection with the mainland of the non-interconnected island, Karpathos, which powers the also non-interconnected island, Kassos, has been integrated by the IPTO in its planning for the period 2020-2029 (Independent Power Transmission Operator (IPTO, 2019). This period includes the project of the interconnection of the Dodecanese, in the context of the ten-year (2021-2030) energy transmission system development program of the IPTO. At the same time, it is made provision for the interconnection of Crete, Cyclades and of the islands of the north Aegean Sea, in different phases and with different timetables.

It is noted that on 23 December 2020 completed successfully the electrification of the first submarine cable that connects Crete with the mainland system (Figure 54). This is the largest (174 km) submarine AC interconnection in the world and is characterized as the interconnection of records (Ministry of the Environment and Energy, 2020).

Figure 54: A picture from the energy interconnection of the island of Crete (Greece) with the mainland, via submarine cables



Source: Hellenic Ministry of the Environment and Energy, 2020

The project of the interconnection (via submarine cables) of the Dodecanese with the HETS incorporates 6 autonomous electric systems, among which this of Karpathos and the goal for the project is to be delivered by 2027 (Liaggou, 2020). The island of Kos was proposed as a connection point for Karpathos, in order for the connection of it with the national electricity transmission system to be achieved. Consequently, two new substations (GIS 150 kV) are expected to be constructed, one in Karpathos and one in Kos (IPTO, 2019). The overall cost for the interconnection of the non-interconnected islands of south Aegean Sea (Dodecanese and Cyclades) is calculated to 900 million – 1 billion Euros (Hellenic Republic 4428/2019).

Figure 55: The plan of the IPTO for the future energy interconnection of the Dodecanese complex, in Greece, with the mainland

Source: Independent Power Transmission Operator, 2020, p.136

There will be many benefits from the interconnection of the non-interconnected islands with the national electricity transmission system. First of all, by tackling the «electric isolation» of these islands, the reliability of the transmission of the produced energy into their grids will be increased and at the same time, the amount spent by citizens of the country for Services of General Interest will be led to a decrease, due to the decline in the energy produced by local, costly, stations. Moreover, there will be environmental benefits, since, via the greater possibilities due to the interconnection with the mainland, a breeding ground for the further development of RES in these islands (IPTO, 2019) will be created and the use of fossil fuels will be limited. Furthermore, the old power plants, with low rates of efficiency, will be replaced by new infrastructure, in these islands (Hellenic Republic 4428/2019).

All the above could create, when the project of the interconnection is completed, an even more positive environment for the development of an OWF between Karpathos and Kassos islands (second phase of this thesis). The fulfillment of the project of the interconnection will entail not only economic benefits for the residents of the islands and in general for the inhabitants of Greece, as well as greater reliability, but also environmental benefits, since the expansion of RES will be fostered due to the greater possibilities of the system and consequently the country could be favored concerning the accomplishment of its environmental objectives.

8. The Covid-19 crisis and its impact in the offshore wind industry

The global crisis due to the Covid-19 is not only a health crisis, but also an economic and social crisis, since it provokes negative implications in many different fields. This thesis developed during the pandemic and although the fact that the full footprint of the Covid-19 had not been assessed by its completion (January of 2021), the author collected data about the consequences on the renewable's sector and specifically on the offshore wind industry.

Renewable energy adjusted quickly to the new global environment, due to the coronavirus and responded to challenges of the crisis demonstrating resilience and reliability. For the first time in history, renewable's electricity generation exceeded fossil fuel's electricity generation, concerning the 27's Member States of the EU. Renewables generated, in the first semester of 2020, 40% of the electricity, while fossil fuels generated 34% (Brindley, et al., 2020b).

Nevertheless, Europe's new additions in renewables were decreased by one-third in 2020, fact that means that it was their largest annual decline since 1996. Only a partial recovery, in new additions, is expected into 2021.

Countries should accelerate significantly the deployment of renewables to meet energy goals. Even before Covid-19 this need was essential. The challenges due to coronavirus crisis should not disorientate governments from the transition to cleaner sources of energy (International Energy Agency (IEA), 2020c).

In the first wave of the pandemic, renewables were the only source of energy, in which a growth in demand (International Energy Agency (IEA), 2020a) was observed. On the other hand, the demand for oil, natural gas and coal was struck the hardest, due to the sharp fall of it. However, the general uncertainty influenced also the development of renewable's projects (International Energy Agency (IEA), 2020b). Some investors curtailed amounts, which were destined for renewable's projects and also the supply chain was disrupted, having delays as one of the results.

Nevertheless, the offshore wind sector had been predicted that it would be shielded, since the projects in this field have a long term horizon (Backwell, et al., 2020), which means that their timelines for their design and construction would not been affected significantly due to the Covid-19 crisis, albeit some cutbacks and delays, as it was already cited, were unavoidable. Consequently, the industry of the offshore wind manifested strong resilience (Backwell, et al., 2020).

Even though 2020 had been forecasted, at first, to be a record year in the global wind history, it recorded finally a 19% decrease, due to the Covid-19 crisis, in comparison to the pre-Covid estimation. Nevertheless, the onshore wind industry was hit much more than the offshore (Backwell, et al., 2020). In any case, the Covid-19 crisis changed the world, in total, forever.

Conclusion

In this thesis, an offshore wind farm between the non-interconnected islands of Karpathos and Kassos (the latter was energy dependent, until the delivery of this thesis, by the first), in Greece (Dodecanese complex), was developed by the author, in realistic terms and it was designed to operate in two different phases.

In the first phase (January 2023 - December 2027), the two islands was considered that they will not be energy interconnected, yet, with the mainland system, fact that is expected to take place by 2027, according to the plan of the Independent Power Transmission Operator (IPTO).

In the second phase (January 2028 – December 2052), the author considered that Karpathos and Kassos will be energy interconnected with the mainland system and for that reason some elements were modified in comparison with the first phase. The transition from the first to the second phase, for the same offshore wind project, was predicted.

The author described all his decisions about the selection of the point of the installation, the foundation type, the offshore wind turbines, the cables, the onshore substation and the port. Furthermore, he analyzed why the area of the interest, for this thesis, is one of the best in Greece for such a project, presenting step by step all the criteria that they should be examined. At the same time, the technology of the energy storage, through the use of batteries of lithium-ion, was exploited for the purposes of the particular offshore wind farm. In addition, a price of sale of the produced energy and a way of the funding of the project were, also, mentioned.

The benefits for the two islands, which were decided to participate for the development of the project, as well as the benefits for the Greek State, via this offshore wind farm, were underlined. However, social reactions are possible to be created.

A financial analysis, adapted to the specific offshore wind park, proved that an investment for this project would be sustainable, although the fact that it is a small-scale project. Nevertheless, even a small-scale project of such a kind could have a positive –in economic terms- sign, since the technology of the offshore wind has many advantages.

It should be noted, also, that for the needs of this project, the author communicated with a number of people, who were included in the thesis and provided useful information.

Concerning the conclusion, after the completion of this study, the offshore wind farm created by the author, for this thesis, was designed to not disrupt significantly the everyday life of the local people and also with respect to the environment. For that reason, small number of offshore wind turbines was selected, as well as an area less inhabited, less touristy and in general less developed than others of the islands of Karpathos and Kassos. Besides, the aim of the author was to prove that there are solutions with gains for all the parties (State, companies and local communities) and of course with the smallest possible disruption, as it was already cited, to the environment.

The Greek State has no experience on the offshore wind, but it makes efforts for the development of the first offshore wind farm in its marine area. Greece is considered by experts as an ideal place for such an installation and it should exploit, among others, its big ports, its shipyards, the industry of cables and the industry of concrete, in order to make a progress in the sector of the offshore wind. For the beginning, a small-scale project, like that of this thesis, may be a good option. Furthermore, Greece has many challenges to face, since there are many fields, in which it suffers undoubtedly (e.g. legislative framework, bureaucracy) and at the same time there are the challenges of the offshore wind, which is a promising technology, but not so widespread yet, fact that entails high costs.

In any case, further research on this issue, regarding possible opportunities in Greece, as well as its strengths and weaknesses on the offshore wind, is always welcome.

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Annex I

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Annex II

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