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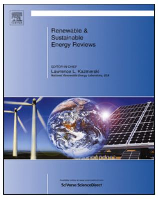

Offshore floating wind parks in the deep waters of Mediterranean Sea

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ABSTRACT

Offshore wind is mainly exploited for electricity production in Northern European countries where shallow waters exist. Although technology has been progressed to provide the offshore wind sector with many pioneering projects, there are still several interesting subjects for investigation, such as the very high costs of fixed-bottom offshore wind facilities in deep waters, constraining the implementation of offshore wind parks only in swallow waters. The exploitation of the vast wind resources in larger water depths is very significant for the offshore wind sector expansion, thus floating wind turbines are needed. This paper explores the feasibility of the, still immature, floating wind technology in deep waters, such as the Mediterranean Sea and under which conditions offshore wind farms can be implanted. The techno-economic study of the project, estimating the complete payback period, the net present value and the internal rate of return, revealed the conditions needed for its profitability. In addition, the social benefits from the floating wind park operation, which are related with the reduction of the oil imports, the savings from carbon dioxide emissions and other externalities, are compared with the applied feed in tariffs, in order to provide their break even values.

Contents

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1. Introduction

The wind power generation industry has seen significant growth during the last two decades [1–6] with the majority of wind farm installations to take place onshore [7,8]. Although this development of renewable energy sources across Europe has the support of the society and State policy, reluctance to invest and public opposition remain significant obstacles to the expansion of renewable energy sources (RES). Studies showed [9] that negative opinions regarding wind turbines are closely linked with beliefs that they are inefficient, unprofitable, noisier and more visually intrusive. Apart from issues though, such as visual and noise impacts, land space limitations, disturbance of flora and fauna habitat and constraints on natural reserved areas that were created with the onshore wind farm installations, led to the investigation of offshore site locations, where most of these issues are eliminated [10–13].

The available energy power in the European coasts, considering the Mediterranean and the Atlantic is 350 GW [14]. Europe has widely developed offshore wind parks [15–20] with the majority of installations implemented by Denmark and the United Kingdom, where shallow waters exist [21]. The experience gained from the research and the implementation of offshore wind turbines offers the opportunity to countries with deep seas, to reconsider their hesitation about developing offshore wind farms.

European countries are the leading players in the offshore wind energy market. The first offshore wind farm was installed in Denmark in 1991. The energy authorities of Denmark and the UK supported experimental projects (Vindeby and Blyth in Denmark and the UK, respectively) that proved successful and led them to utility-scale projects, through an attractive policy regime [22]. Nowadays the offshore capacity is growing with a rate of 40% per year. In the UK the projected offshore installed capacity by the year 2016 is 8 GW, while in the US 3.824 MW offshore projects are under development [6].

Currently, offshore wind farms are built primarily in shallow waters less than 30 m and close to shore [8,10,16,20,23], as offshore wind turbine foundations are considerably affected by sea floor soil properties, water depth, wave heights and currents. Although the Mediterranean Sea has high wind potential, no offshore wind farms have been implemented due to its deep waters.

Most of the conducted researches refer to wind parks that are implemented in shallow waters no more than 30 m depth. The existing challenges and opportunities in the development stages of an offshore wind farm project are discussed in [5]. Furthermore, a comparison between a high voltage direct current and high voltage alternating current transmission for integration of large scale offshore wind farm with onshore grid is also presented [5]. The work [6] researches the current situation of UK and US offshore wind industries and analyses the proper direction and pathways of the industry in India. The combination of offshore wind and wave systems is introduced in [14], based on the degree of integration between the technologies, and the type of substructure. The article [20] investigates the investment cost, employment, industry and installation of offshore wind energy in Europe and also in comparison to its onshore counterpart. A comparison between onshore and offshore wind energy is provided in [21], which also assesses whether offshore wind development potential has been exploited through further differentiation of the electricity market. In [23] the potential for development offshore wind power plant in the Croatian part of the Adriatic Sea is analyzed, with likely implication on the environment and economy of the country. In [24] an analysis of hypothetical offshore wind park scenarios in Belgium, Denmark, Germany, France, and the UK, for different water depths and distances to shore are presented, as these factors influence costs, whereas available wind resources determine the amount of electricity produced. The work [25] reviews some important factors and techniques for wind turbine installations such as the wind energy resource assessment techniques, environmental and grid integration factors, control strategies, impact of offshore wind turbines, feed-in tariff mechanism, modeling of wind turbine components including generators and performance improvement techniques. In [26] a detailed overview of the offshore wind power industry in the UK is presented, in terms of market growth, policy development and offshore wind farm costs. The work [27] provides a survey of previous regional-economic assessments of wind power projects, as well as a

Table 1
Specifications of NREL offshore 5 MW wind turbine [35].

Wind turbine characteristics	Value
Rated power	5 MW
Rotor orientation	Upwind
Control	Variable speed. Collective pitch
Drivetrain	High speed. Multiple stage gearbox
Rotor/hub diameter	126 m/3 m
Hub height	90 m above mean sea level
Cut-in; rated; cut-out wind speed	3 m/s; 11.4 m/s; 25 m/s
Cut-in; rated; rotor; generator wind speed	6.9 rpm; 12.1 rpm; 670 rpm; 1173.7 rpm
Rated tip speed	80 m/s
Overhang; shaft tilt; precone	5 m; 5°; 2.5°
Rotor mass	110 000 kg
Nacelle mass	240 000 kg
Tower mass	347 460 kg

quantitative assessment of the employment impacts of an ongoing wind farm investment in northern Sweden under different benefit-sharing scenarios.

A few researches of economic viability of offshore wind projects (floating) in European deep seas can be found. In [28] the feasibility of spar-type wind turbine at a moderate water depth is presented. The analysis for different load cases showed that the implementation of the spar-type wind turbine in moderate water depth is feasible. The work [29] investigates hollow cylindrical floating substructure and the tension of mooring cables with respect to the total length and the connection position of mooring cables. In [30] a comprehensive analysis and comparison of the levelised cost of energy, for different offshore floating wind turbine concepts, is presented. The development of coupled model of dynamics regarding vertical axis floating wind turbines as well as suitable semi-analytical hydrodynamic models are presented in [31].

The majority of the installed offshore wind turbines are in shallow waters with no more than 30 m depth, whereas few are installed in medium waters, with depth ranging between 30 and 60 m [26,32,33]. As most of the conducted researches refer to wind parks are implemented in shallow waters, effort is being made to deductions regarding floating offshore wind farms taking into consideration factors that have significant contribution to the total investment cost such as the distance from the shore, the depth of the waters and the weather conditions. Hence, it is very crucial for a developer to have knowledge about the selected sitting depth and distance from the shore. These two important parameters determine, most of the times, the feasibility of a wind park implementation.

This paper presents a feasibility study of offshore floating wind park in Aegean Sea, located in the East Mediterranean Sea. The Greek island of Santorini is used, with autonomous power system, which is not connected to the mainland power system. The coastal line in Greece is about 16 500 km long and contains a very sensitive aquaculture. The sea area of the island of Santorini was selected to be investigated because of the high wind potential and the depth of the seabed that exist in the area. It is considered that the wind turbines are installed on floating platforms, which are appropriate for offshore wind projects in deep waters and on a long distance from the shore.

2. Offshore wind turbine technology

2.1. Offshore wind power advantages and disadvantages

The growth in the development of offshore wind parks is driven by a number of advantages of offshore wind energy, compared to its onshore counterpart.

Offshore wind turbines are taking the advantage of the wind resource quality in the sea, where wind speed is typically stronger and more stable, even increasing with the distance to the coast, leading to less turbulence effects and significantly higher production per unit installed. Furthermore, the characteristics of the turbulent air layer adjacent to the ground and to the sea surface, allow the use of shorter towers than the equivalent onshore machine.

The availability of large areas in the sea where offshore wind farms can be installed, leads to greater installations. The possibility of placement, far from the shore and population areas, reduces the visual impact from the coast and the noise emissions.

On the other hand, offshore wind power is more complex and costly to install and maintain. For example, the cost of wind generator turbines in onshore wind farms is around 75% of the total cost, whereas this percentage in offshore installations is approximately 33%, as the costs of the sea operations are very high. More specifically, offshore wind projects face more expensive marine foundations, construction of longer electrical networks, more expensive installation procedures and restricted access during construction due to weather conditions, as well as limited access for operations and maintenance during operation [20,34].

2.2. Offshore wind turbine technology

2.2.1. Fixed-bottom wind turbine technology

The maximum offshore wind turbine generation capacity commercially available is 6 MW [26]. The National Renewable Energy Laboratory (NREL) has created a 5 MW offshore baseline model, whose characteristics are shown in Table 1 [35]. Most of the turbine designs in the offshore wind turbine industry consist of the same components. Among all, the most expensive components are the foundation, the tower, the blades, the drive train and the substation.

The most commonly used wind turbines have asynchronous generators or high speed doubly-fed induction generators (DFIG), but a number of direct drive wind turbines, such as synchronous direct drive permanent magnet generators, is increasing. The reason for a change in generators is that direct drive generators are more reliable than the high speed DFIG gear-driven systems, although DFIG systems are lighter than direct drive systems [26].

The rotor diameter of offshore wind turbines has steadily increased from the 2 MW wind turbine with 66 m rotor diameter, to the 3.6 MW wind turbine with 120 m rotor diameter in 2013. The blades are made of carbon fibre or glass fibre and constitute the largest component cost [26].

Unlike onshore wind turbines where taller towers are needed, offshore wind turbine towers can be shorter as less height is required to achieve comparable wind speeds, due to different surface characteristics. The towers are made of tapered tubular steel sections, whereas typical tower diameter is between 3 m and 5 m for 4 MW wind turbine, up to 5 m and 7 m tower diameter for a 6 MW wind turbine [26,35].

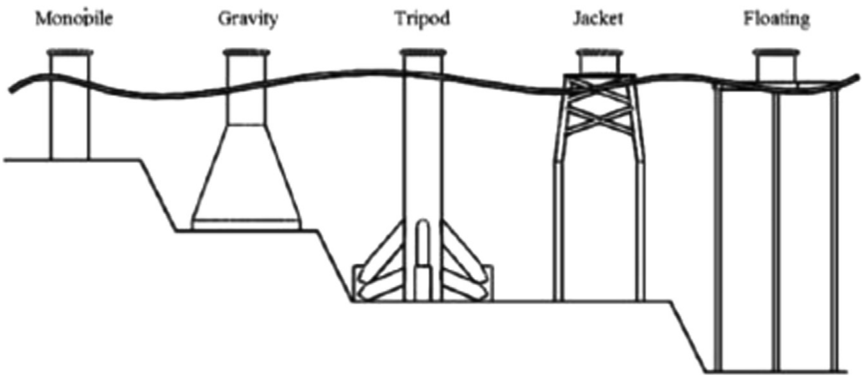


Fig. 1. Offshore wind turbines foundations [26].

The foundation types depend on the site depth. There are five different foundations types: monopile, gravity, tripod, jacket and floating, as depicted in Fig. 1 [26]. Monopile foundations account for 96% of the commissioned offshore wind turbine foundations, followed by the jacket foundations [26,35].

2.2.2. *Floating wind turbine technology*

Offshore wind turbine structures are economically viable options in shallow waters no deeper than 50 m [20,36]. For greater water depths, floating wind turbines are needed, which can be installed in the range of 100 m to 900 m depth. The foundations of these turbines are not fixed to the seabed but are floating structures [37].

There are three concepts for the floating wind turbines foundations, depicted in Fig. 2 [23]. The Semi-Submersible (Semi-Sub) where large columns are linked to each other by connecting bracings. The columns provide the ballast and flotation stability (column-stabilized) [38]. The Spar buoy platform uses steel or concrete cylinder with low water plane area in order to achieve stability keeping the center of gravity below the center of buoyancy. Finally the Tension leg platform (TLP) that uses a large center column, with three submerged “arms” to which the tension legs are attached [38]. The site characteristics, such as the water depth and the distinctiveness of the bottom soil determine the length and the type of the anchors [39]. The advantages and disadvantages of each technology are presented in Table 2 [38]. For details of the floating structures and costs, the reader is referred to [36–43].

The above three technologies are suitable for deep water installations; however, there is a variety of parameters, which will determine the type of the foundations and the size of a floating wind park. Strong wave forces occur simultaneously with large wind forces on the wind turbines, which create translational and rotational motions of the platforms and the wind turbines and should be taken into account. Furthermore, the total cost of the required equipment is an important factor for the selection of a particular floating wind turbine. The potential onshore assembly and the stability float out of the wind turbines, including foundations, may reduce the additional cost from the emerging necessity of using special purpose ships for the onsite installation.

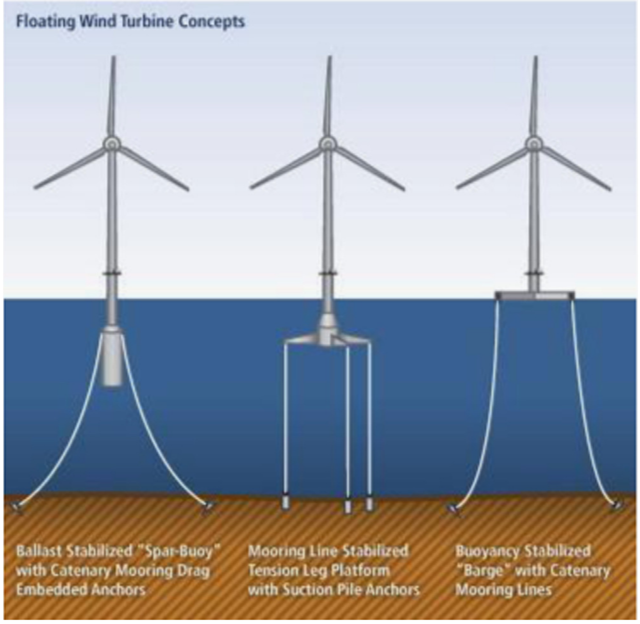


Fig. 2. Three floating wind turbine concepts [23].

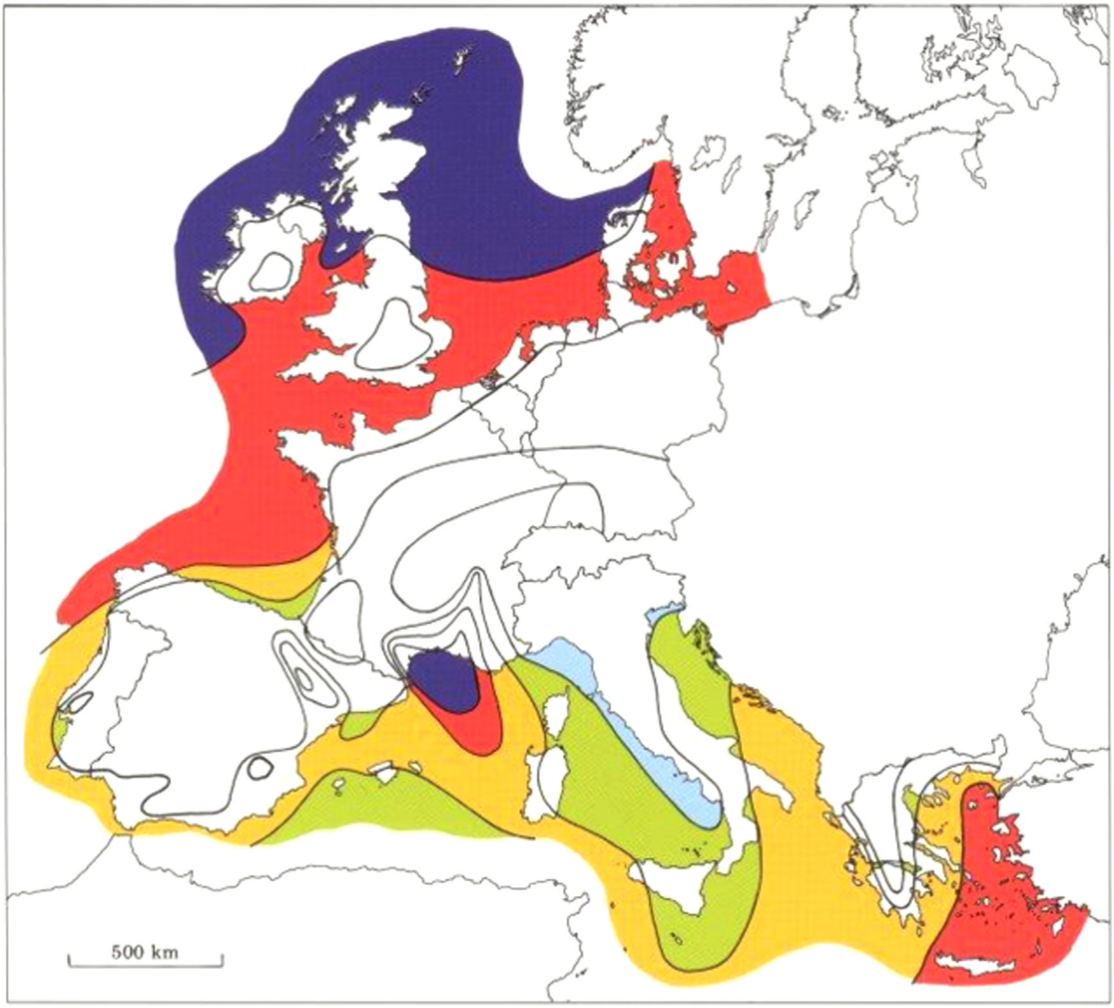
3. European offshore wind power sector

3.1. *Offshore wind potential in Europe*

The progress in the developed wind technology in combination with the high wind energy potential of the European seas has led to a significant growth of offshore wind sector in Europe the past

Table 2
Assessment of offshore wind turbine floating platforms.

Structural design	
	Semi-submersible
Pros	The most flexible design with regard to water depth with a typically low draft
Cons	Might have larger wave-induced motions that may impact the rotor, tower and blades
	Spar buoy
Pros	Inherently high stability structure
Cons	Fatigue load in tower base might be higher for spar buoys than for TLP
	TLP
Pros	Lower fatigue loads in tower and blades than semi-submersibles, and lower fatigue loads in the tower base than spar buoys
Cons	Less technological experience from offshore wind application than for spars and semi-submersibles
Fabrication & installation	
	Semi-submersible
Pros	Possibility to construct and assemble the structure on-shore or in a dry dock
Cons	Expected to be a more complex structure to manufacture
	Spar buoy
Pros	Relatively simple structure to manufacture, minimum amount of welds, and there is a possibility to use concrete instead of steel
Cons	The large draft may limit the possibility for in-shore assembly which would add several offshore operations
	TLP
Pros	Can be fully assembled in a dry-dock
Cons	Tendon tensioning and transitioning from a free-floating phase to a TLP phase could be challenging
Operation & maintenance	
	Semi-submersible
Pros	The stability and low draft enables semi-submersibles to be easily towed back to shore in case of major repairs
Cons	Might be more subject to corrosion and ice-loads since much of the structure is close to the water surface
	Spar buoy
Pros	Few active systems or complicated components
Cons	The large draft may limit the possibility for tow-back to shore in case major maintenance is required
	TLP
Pros	Simple structure to inspect. Few active systems and components. Low amount of welds that will require inspection
Cons	Can be challenging to disconnect for tow-to-shore in case of major repairs. Tendon termination points (and possibly active tensioning system) needs attention



Wind resources over open sea (more than 10 km offshore) for five standard heights

	10 m		25 m		50 m		100 m		200 m	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
🟪	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
🟥	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
🟨	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
🟩	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
🟦	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Fig. 3. European offshore wind resources for five different heights above the sea level [44].

several years. An offshore wind energy potential map for the European seas is presented in Fig. 3. This map shows the available wind resources over open sea for five different standard heights. It can be observed the high wind potential of the Aegean Sea in the eastern Mediterranean Sea. The potential area for offshore wind energy generation is limited to sea depths less than 50 m due to the foundations structure. The available offshore area for wind energy farms according to the distance from the coast, for the European countries is depicted in Fig. 4.

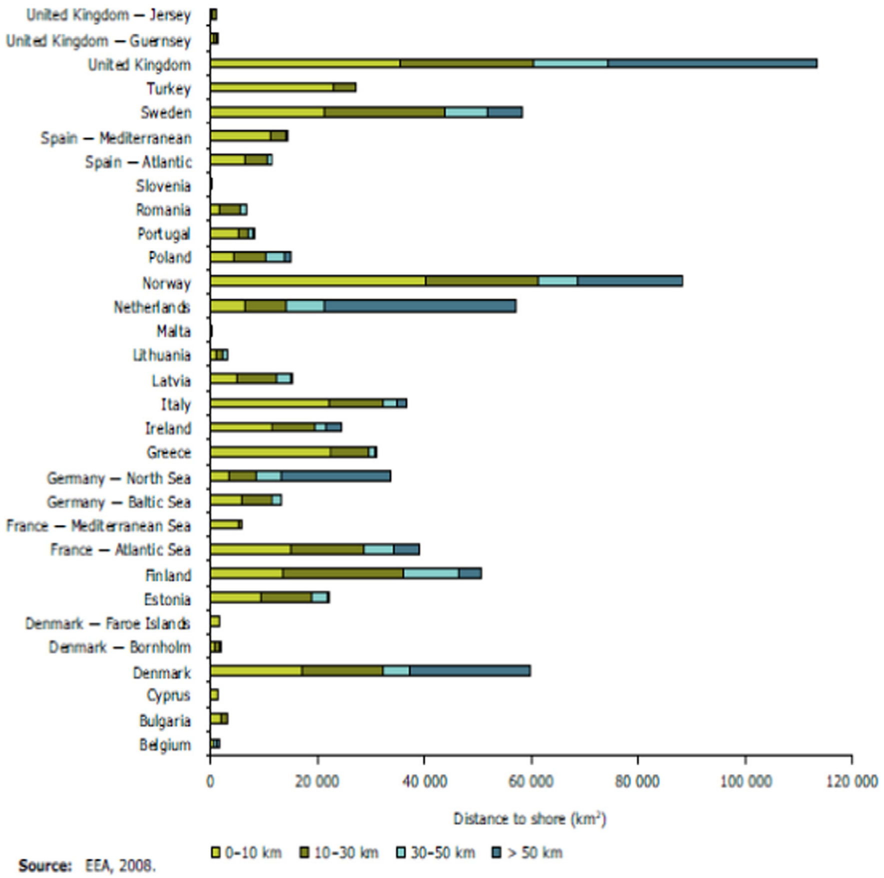
3.2. Offshore wind parks

Europe is leading the deployment in offshore wind energy sector, presenting 74 offshore wind farms by the end of 2014. These farms are extended in eleven countries with a total 8045.3 MW installed capacity of offshore wind turbines. The pioneers in offshore wind exploitation are Denmark and the UK with 1271 MW and 4494.4 MW, respectively [32,45,46].

The deepest offshore wind park is constructed in the UK, in Beatrice, with jacket foundation type at 40 m deep in the water, 25 km from the shore. It comprises two wind turbines with total capacity of 10 MW. Another offshore wind park at the same depth is constructed in Germany, in western North Sea, with triple foundation type at 100 km from the shore. It comprises four wind turbines with total capacity of 20 MW [32].

Regarding wind turbine manufacturers with grid connected turbines, in 2014 Siemens continues to be the top offshore wind turbine supplier in Europe, with 1278 MW of new capacity connected, accounting 86.2% of the market, followed by MHI Vestas with 141 MW (9.5%), Areva with 45 MW (3%) and Senvion with 12.3 MW (0.8%). Samsung connected a demonstration 7 MW (0.5%) turbine to the grid in Fife, UK.

The most popular foundation in 2014 remains the monopile type, with 406 installations, representing 91% of all newly installed substructures. 36 jacket foundations (8.1%) were also installed, followed by tripods (0.9%).



Source: EEA, 2008.

Fig. 4. Available offshore area (km^2) for wind energy farms according to the distance to the coast [33].

Table 3
Low and high investment costs variation.

Capital cost estimation (€/kW)		
	Low	High
Fixed-bottom	2600	4200
Floating	3200	4550

Table 4
Low and high average costs variation for large scale floating wind turbine deployment.

Cost (€/kW)		
	Low	High
Turbine	1280	1820
Foundation	800	1137.5
Mooring & anchoring	320	455
Installation	320	455
Grid connection	160	227.5
Other	320	455
Total cost (€/kW)	3200	4550

Table 5
Operational cost comparison between fixed bottom offshore WT at 45 m and floating WT investment costs variation of offshore wind power.

Operational costs (€/kW)	
Fixed-bottom	148
Floating	136

Table 6
Investment costs variation of offshore fixed-bottom wind power at different water depth.

	Water depth (m)			
Cost (€/kW h)	10–20	20–30	30–40	40–50
Turbine	772	772	772	772
Foundation	352	466	625	900
Installation	465	465	605	605
Grid connection	133	133	133	133
Other costs	79	85	92	105
Total	1800	1920	2227	2514

The average water depth of offshore wind farms in 2014 was 22.4 m, slightly more than in 2013 (20 m), with average distance to shore of 32.9 km, more than in 2013 (30 km) [46].

Regarding floating wind technology, the first formally inaugurated large-scale floating wind turbine was developed in 2009 by the collaboration between Statoil Hydro, a Norwegian energy company and Siemens, a wind turbine manufacturer. The 2.3 MW floating wind turbine was placed 12 km away from the western coast of Norway, anchoring at 220 m depth. Its technology uses a spar buoy anchoring system that gives feasibility in placing wind turbines at depths from 120 m to 700 m [32,39]. The second 33 kW floating wind park is implemented in 2010 in Denmark, northwest of Vindeby, 3 km from the shore in 7 m depth [32].

Several organizations (EWEA, DNV, IEA, etc.) have estimated the wind energy costs of floating and fixed-bottom wind turbines

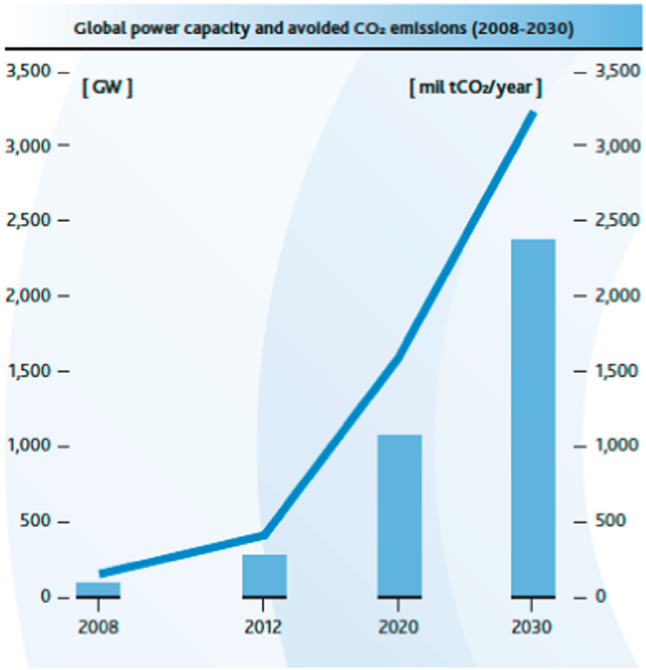


Fig. 5. Global power capacity and avoided CO_2 emissions (2008–2030) [48].

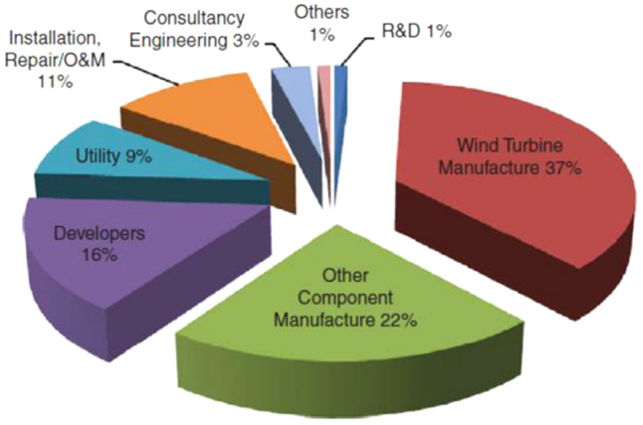


Fig. 6. Direct employment by type of company in the wind energy sector [49].

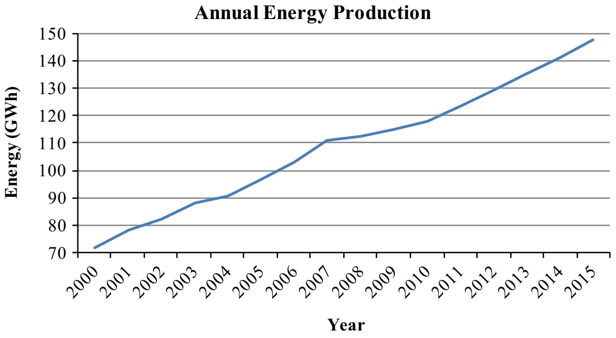


Fig. 7. Santorini projected annual energy production.

[38], although an accurate investment cost for floating wind energy is difficult to estimate as the amount of data are too limited. From these studies, the range (low and high values) of capital and operational cost, for large scale floating wind turbine deployment has been estimated, as depicted in Tables 3–5. The variation of the investment costs of the fixed-bottom offshore wind turbines at different water depths are depicted in Table 6 [10]. It is obvious the cost incensement, along with the incensement of the water depth.

It should be mentioned that cost reduction is expected as the floating technology matures, due to technical improvements, the possibility to use in the substructure concrete instead of steel, and the mass production [38,47].

3.3. *Wind projects social benefits*

One of the main social benefits of the wind energy development is the contribution to the minimization of the operation of coal and oil-fired or natural gas-based thermal power stations. More specifically, the operation of wind-based power stations first of all reduces the energy imports, while they lead to emissions reduction. In Fig. 5 the global wind power capacity and avoided CO_2 emissions for the period 2008–2030 is depicted [48]. Furthermore, the exploitation of wind energy improves the security of energy supply, since it minimizes the dependency to fossil fuel reserves or oil imports [49].

As with most business ventures, new jobs and activities are created in the areas where the wind parks are installed, thus regional development is achieved [27,49]. The sectors associated with the wind energy create direct or indirect employment that include the turbine manufacturing, the construction and installation of the wind power plant, the operation and maintenance activities, and other parallel activities such as engineering, consultancy, education, distribution network, and utilities as depicted in Fig. 6 [49].

4. Implementation of offshore floating wind park

The Aegean Sea has been mentioned as privileged wind energy territory, which constitutes of a unique seabed with great depths that can be met even in short distances from the shore. In order to study the feasibility of the floating wind technology in deep waters, as described in Section 5, Santorini island is selected as a case study, which is a representative island of the Aegean Sea.

4.1. *Santorini case study*

Santorini is a non interconnected island in the southern Aegean Sea, about 200 km southeast from Greece mainland. The total land area is 73 km^2, with population of 13 402 inhabitants. The annual electrical energy consumption is 116.56 GW h with a peak load of 34.10 MW. The thermal energy production of the island comprises 10 diesel and heavy oil units. Santorini island has a high wind energy potential especially for heights between 100 m and 200 m, where the wind speeds vary from 8.5 to 10.0 m/s and from 9.5 to 11.0 m/s, respectively. The direction of the wind is mostly north, considering a deviation that includes the winds with direction from northwest up to northeast. The potential yield energy for the corresponding heights is estimated to be 650 to 1100 W/m^2 and 900 to 1500 W/m^2, respectively.

4.1.1. *Energy profile analysis*

The maximum allowed renewable energy production in Santorini can be determined by the energy analysis of the island. Data concerning the monthly peak power demand and the total net energy production for the years 2000 to 2010 were collected from the Public Power Corporation (PPC) of Greece, in order to estimate the annual energy growth rate as follows:

$$e_{mean} = \sqrt[n]{\frac{E_{(n)}}{E_0}} - 1 \tag{1}$$

Table 7
Santorini energy analysis parameter values.

Parameter	Symbol	Value
Mean annual energy growth rate from Eq. (1)	e_{mean}	4.63%
Projected annual energy demand for the year 2015, from Fig. 7	$E_{ann2015}$	147 911.95 MW h
Mean annual load of year 2015, from Eq. (2)	$P_{meanL_{2015}}$	16.8 MW
Maximum installed capacity of the wind park	$P_{MAXinst2015}$	12.33 MW

Table 8
Bathymetry data of the area offshore of Santorini.

Distances from the shore	10 km	15 km	20 km	25 km	30 km
Direction	Bathymetry data (m)				
East	219	162	Anafi island	Anafi island	Anafi island
SouthEast	269	540	847	791	798
South	183	Navy prohibited area	Navy prohibited area	1029	988
SouthWest	380	657	700	925	1300
West	430	473	465	489	511

Fig. 8. Spatial design of the wind turbines indicating wind turbines, subsea cable and onshore connection point, using the map of the Navy Hydrographic Service.

where e_{meanE} (%) is the mean annual increase rate, E_0 (MW h) is the present energy production and $E_{(n)}$ (MW h) is the energy production of the year n.

The maximum installed capacity $P_{MAXinst}$ (MW) of the wind park is estimated, taking into account that the maximum allowed wind energy penetration limit for the Greek autonomous islands is equal to the 73% of the mean annual load [50] P_{meanL} (MW):

$$P_{meanL} = \frac{E_{ann}}{T} \tag{2}$$

where E_{ann} is the annual energy demand in MW h and T is the number of hours per year.

Based on the annual energy growth rate calculated from Eq. (1), the annual energy production E_{ann} until the year 2015 is estimated and is shown in Fig. 7. The projected values for the year 2015 resulted from Eqs. (1) and (2) are summed up in Table 7.

4.1.2. Spatial planning

The site selection for the floating wind park is based on the available wind potential, the depths of the seabed and the restrictions and regulations (protective areas) of the different directions of the island's maritime space. The investigation of the acquired bathymetry map from the Hellenic Hydrographic Navy service produced a combination of depths and distances from the shore, as shown in Table 8. The Table shows the presence of significant depths.

Taking into account the neighboring island of Santorini, Anafi island, which is very close to the examined island as well as the prohibited area of the Greek Navy, the most suitable position for the wind park is located 15 km southeast of the southern point of the island called Exomitis area, as depicted in Fig. 8, where the depths are approximately 540 m.

The selected location has to satisfy all the environmental regulatory constraints. The scope of these regulations is to protect the human and aqua environment of the investigated area as well as to provide instructions and a framework for the engineers, who are responsible for the proposed study. The limitations set by the authorities eliminate the environmental impacts during the whole implementation process.

According to the Special Framework of Spatial Planning and Sustainable Development, which was released in October 2008 by the Minister of Environment, Energy and Climate Change of Greece, the proposed location satisfies all the current restrictions. The 15 km distance from the shore is beyond the minimum distance limit, which is set at 6 km. The overland head of the cables down to the substation is less than the maximum allowed distance of 10 km, which is required for the non interconnected islands, since the distance between the connection point, Monolithos 15 kV substation, and the coast is very small and less than 1 km. Furthermore, the preferred location is out of the concern of the Natura 2000 environmental protection framework and is not an institutionalized area for sea or subsea parks neither confirmed sea transportation routes.

Fig. 9. Spar-buoy floating wind turbine [38].

4.1.3. *Floating wind park*

The offshore wind park comprises floating wind turbines due to the existence of very deep waters. The water depth makes suitable the use of spar buoy floater depicted in Fig. 9, which according to [43] is preferable due to its high stability and also its relative simple structure. The horizontal distance between the anchor and the fairlead is 4–6 times the water depth [38]. For the wind turbine, the V112-3.0 MW model is selected. It is manufactured by Vestas and has achieved the IEC IB offshore wind classification, which permits the exposure to severe weather conditions like the ones that are met at offshore sites. The height of wind turbine hub is 100 m above the sea level [51].

4.1.4. *Wind park energy production*

The climate data of the selected location were acquired from the Greek Institute of Oceanography and processed through the WAsP software, as depicted in Fig. 10. The Weibull probability density function is commonly used for wind speed distributions

Table 9
Wind park energy parameter values.

Parameter	Symbol	Value
Speed distribution parameter	C	7 m/s
Distribution shape factor	k	2.41
Mean power coefficient	$\omega(V)$	0.475
Mean technical availability factor	Δ	0.92
Installation capacity factor	CF	0.437
Number of wind turbines	z	4
Wind turbine nominal power	P_0	3 MW
Wind park's electric energy production	E_{WP}	45 937 MW h

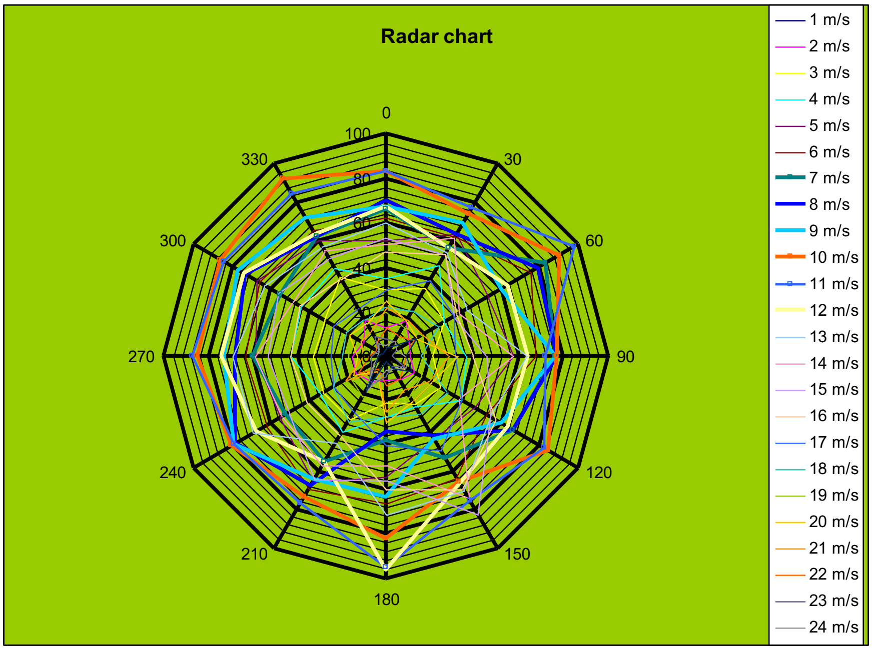


Fig. 10. Radar diagram derived from the processed climate data.

over the sea. The Weibull parameters C (wind speed distribution parameter) and k (distribution shape factor) were also estimated from the WAsP software.

The mean power coefficient of the wind turbine depends on the wind speeds of the location site and the specifications of the wind turbine, and is computed by [52]:

$$\omega(V) = \int_{V_C}^{V_F} \frac{P(V)}{P_0} \cdot f(V)dV \tag{3}$$

where V_C is the cut in speed of the wind turbine, V_F is the cut out speed of the wind turbine, $(P(V)/P_0)$ is a non dimensional power proportion estimated by the power curve chart of the wind turbine, $f(V)$ is the probability density based on Weibull distribution, calculated as [52]:

$$f(V) = \frac{k}{c} \cdot \left(\frac{V}{c}\right)^{k-1} \cdot e^{\left[-\left(\frac{V}{c}\right)^k\right]} \tag{4}$$

Using the power curve of the wind turbine, the mean power coefficient is computed by WAsP software.

The installation capacity factor of the wind turbine is estimated according to [52]:

$$CF = \Delta \cdot \omega(V) \tag{5}$$

where Δ is the mean technical availability factor of the wind turbine and $\omega(V)$ is the mean power coefficient of the installation.

The wind park's electric energy production E_{WP} (kW h) is calculated by [52]:

$$E_{WP} = z \cdot P_0 \cdot CF \cdot \Delta t \tag{6}$$

where z is the number of wind turbines, P_0 (kW) is the nominal power of each wind turbine, CF is the installation capacity factor of the wind turbine, and Δt (h) is the examined period.

The parameter values used for the calculations are summed up in Table 9.

5. Feasibility study

The feasibility of the floating wind park in the deep sea of Santorini island is investigated. As analyzed in the previous section, the wind park's capacity is estimated taking into account the maximum allowed wind energy penetration limit for the Greek autonomous islands, which resulted in a 12.33 MW wind park. The wind park is located in Exomitis area, 15 km away from the shore in 540 m water depth, with high wind potential. Four offshore wind turbines of 3 MW each were selected, manufactured by Vestas. Spar buoy floating foundation type was chosen due to water depth, while the height of wind turbine hub is 100 m above the sea level.

The cost–benefit analysis aims at identifying and assessing the investment, from both the investor's and the society's perspective, taking into consideration the national economy and the environment. For this reason the cost–benefit analysis of the floating wind park is divided into two parts. First, the economic evaluation regarding the investment is conducted, which reveals the feasibility or not of the project from the investors point of view. Next, the social benefits arising by the annual savings due to the reduced operation of the thermal station are estimated, followed by a cost–benefit revealing the profitability or not of the project from a social point of view.

5.1. *Economic evaluation*

The feasibility study is an assessment of the viability of the floating wind park. The investment evaluation is based on the yearly net cash flows calculation using the method of net present values. Thus, the annual inflation rate is taken into account. For the economic evaluation of the project, the complete payback period (CPBP), the net present value (*NPV*) and the internal rate of return (*IRR*) are estimated. The CPBP method estimates the amortization time of the investment taking into consideration the time value problem. This particular method does not account the cash flows after the payback period, thus it cannot be considered as a reliable appraisal tool. Consequently, when the cash inflows are uneven, the CPBP method could not be enough to decide on project profitability, as the method emphasizes on the capital recovery rather than on the profitability. Consequently, in order to minimize the economic risks of the offshore floating wind park project, the CPBP method is combined with the *NPV* and *IRR* methods in order to derive more reliable results.

The investment capital cost, IC_0 (€), can be allocated between the investor, the bank and the state as:

$$IC_0 = \alpha \cdot IC_0 + \beta \cdot IC_0 + \gamma \cdot IC_0 \tag{7}$$

where a (%) is the participation of the investor in the cost, β (%) is the loan participation in the cost, γ (%) is the state subsidy.

Incorporating the inflation and the wind energy selling price into the annual revenues pro taxes yields the following formula [53]:

$$R_t = E_{WT_{(t)}} \cdot c \cdot (1+g)^t \tag{8}$$

where R_t (€) are the annual revenues pro taxes, c (€/kW h) is the selling price of wind energy and g (%) is the mean annual inflation rate and $E_{WT_{(t)}}$ (kW h) is the energy production of the year $t-1$, reduced by d (%), the annual degradation factor of the wind turbines:

$$E_{WT_t} = E_{WT_{(t-1)}} \cdot (1-d) \tag{9}$$

The interest and amortization installments I_t (€) are distributed equal during the loan period and are calculated by [53]:

$$I_t = \left(k_l + \frac{k_l}{(1+k_l)^{n_l}-1}\right) \cdot \beta \cdot IC_0 \tag{10}$$

where k_l (%) is the loan interest rate and n_l is the bank loan period (years).

The amortization installments, AI_t in (€), are computed by [53]:

$$AI_t = \frac{k_l}{(1+k_l)^{n_l}-1} \cdot \beta \cdot IC_0 \cdot (1+k_l)^{t-1} \tag{11}$$

The annual net cash flows NCF_t in (€), of the investment are calculated by:

$$NCF_t = R_t - C_{OMt} - T_t - I_t \tag{12}$$

where C_{OMt} (€) is the operation and maintenance cost and T_t (€) are the taxes of the year t.

The taxes are computed by:

$$T_t = R_t \cdot t_r \tag{13}$$

where t_r (%) is the tax rate.

The net present value (NPV_n) of the examined period n (years) is estimated as [53]:

$$NPV_n = -IC_0 + \sum_{t=1}^{n} \frac{NCF_t}{(1+i)^t} \tag{14}$$

where the net cash flow, NCF_t in (€), is the difference between the investment cash inflows and outflows in the examined period n and i (%) is the demanded return index.

The *IRR* value of the investment is met when the value of the return index i makes the NPV_n equal to zero:

$$-IC_0 + \sum_{t=1}^{n} \frac{NCF_t}{(1+IRR)^t} = 0 \tag{15}$$

Table 10
Environmental impact parameter values.

Parameter	Symbol	Value
Emission cost	ec	100 €
Number of barrels	$No\_barrels$	77 080 barrels
Cost of the oil barrel	$barrel\_\cos t$	66.74 €/barrel (30/07/2011)
Efficiency of the oil-based plants in Santorini	n	35%
Calorific value of oil	H_u	12.6 kW h/kg
Mass of oil contained in a barrel	m_{oil_barrel}	135.14 kg of oil

Table 11
Electricity generation emission coefficients [55].

Electricity generation emission coefficients			
Fuel	CO_2 (kg/kW h_e)	SO_2 (kg CO_2/kW h_e)	NO_X (kg CO_2/kW h_e)
Oil	0.989	6.449×10^{-3}	2.579×10^{-3}

Table 12
External costs of existing power units (m €/kW h) [57].

Power unit type	Low external cost estimates	Mean external cost estimates	High external cost estimates
Lignite1 (Ptolemais)	108.9	135.96	584.1
Lignite 2 (Kardia)	73.92	98.67	451.44
Lignite3 (St. Dimitios)	101.97	128.04	548.79
Lignite 4 (Megalopoli A)	121.11	154.44	720.72
Lignite5 (Megalopoli B)	40.26	64.35	332.64
Lignite 6 (Amyntaio)	214.5	254.76	1118.7
Lignite 7 (St. Dimitrios V)	24.75	46.20	269.61
Fuel oil	25.41	47.19	214.17
Natural gas	4.95	14.06	80.38
Hydro	3.76	4.88	6.00

For the proper evaluation of the NPV_n and IRR in the case of the bank loan, the demanded return index i (%) should be the weighted average cost of capital (k_{tot}), computed by [53]:

$$k_{tot} = \beta \cdot k_l + \alpha \cdot k_{eq} \tag{16}$$

where k_{eq} (%) is the equity capitals return index.

5.2. Social benefits

The development of offshore wind power and other renewable energy sources (RES) installations leads to electricity substitution and hence a significant avoidance of environmental damage and its resulting costs. The economic evaluation of the previous section does not take into account the additional revenues due to social benefits resulted from the operation of the wind park. Thus, the annual savings due to the reduced operation of the thermal stations are not considered in the calculation of the cash flows. A proper evaluation of the wind park however, should also take into account the additional profit or cost coming from the substitution of part of the thermal station energy production and the associated savings in operational costs, such as fuel, lubrication and maintenance, extending the life of the equipment.

The total social benefits from the operation of the floating wind park are related with the reduction of the oil imports, the savings from carbon dioxide emissions and the external cost reduction [54]:

$$Savings_{total} = Savings_{gas\_em} + Savings_{oil\_imp} + Savings_{external} \tag{17}$$

where $Savings_{gas\_em}$ in (€) are the avoided cost due to gas emission reduction, $Savings_{oil\_imp}$ in (€) are the avoided cost due to reduction of oil imports and $Savings_{external}$ in (€) are the avoided cost due to external cost reduction.

5.2.1. Savings from the reduction of CO_2 emissions

The European Union Emissions Trading Scheme is a cap and trading mandatory program that allows operators use of compliance carbon credits from mechanisms based on Kyoto Protocol. About 12 000 emission sources are included in the regulation, such as iron, glass, ceramics, power generation, etc. Only carbon dioxide related emissions are covered by the cap, but the next years other GHG will be added. The entities that do not comply with their obligation, have to pay 100€ per metric tone of CO_2 emitted. That penalty refers to the second phase of the program that involves the period 2008–2010.

Supposing that the state does not meet its obligations concerning the CO_2 emissions, the savings from the reduction of gas emissions by the installation of the RES-based power generation plants is:

$$Savings_{gas\_em} = \left(\mathrm{CO}_{2\_savings} + \mathrm{SO}_{2\_savings} + \mathrm{NO}_{x\_savings}\right) \cdot ec \tag{18}$$

where ec (€) is the emission cost per metric tone of CO_2 emitted, and its value is given in Table 10, $\mathrm{CO}_{2\_savings}$ ($tnCO_{2(CO_2)}$),$\mathrm{SO}_{2\_savings}$ ($tnCO_{2(SO_2)}$),$\mathrm{NO}_{X\_savings}$ ($tnCO_{2(NO_x)}$) are the savings from the avoided pollutants due to the replacement of the thermal plants energy production with the wind power generation, calculated by:

$$\mathrm{CO}_{2\_savings} = E_{WT} \cdot \mathrm{CO}_{2_{emco}} \tag{19.a}$$

$$\mathrm{SO}_{2\_savings} = E_{WT} \cdot \mathrm{SO}_{2_{emco}} \tag{19.b}$$

$$\mathrm{NO}_{X\_savings} = E_{WT} \cdot \mathrm{NO}_{X_{emco}} \tag{19.c}$$

where E_{WT} (kW h) is the produced electric energy from the wind park and $\mathrm{CO}_{2_{emco}}$, $\mathrm{SO}_{2_{emco}}$, and $\mathrm{NO}_{X_{emco}}$ (kg/kW h_e) are the electricity generation emission coefficients given in Table 11.

5.2.2. Cost avoided due to reduction of oil imports

As the Greek islands use autonomous oil-based power generation plants, the reduction of the oil import due to the operation of the floating wind park is [54]:

$$Savings_{oil\_imp} = No\_barrels \cdot barrel\_\cos t \tag{20}$$

where $No\_barrels$ is the number of barrels and $barrel\_\cos t$ is the cost of the oil barrel (€/barrel), and their values are given in Table 10.

Table 13
Range of floating capital cost based on the values of Table 3.

	Investment cost IC_0 (€)
Low value	38400 000
Average value	46500 000
High value	54600 000

Table 14
Economic schemes under study.

Economic schemes	State subsidization γ (%)	Equity capitals α (%)	Bank loan β (%)
I_{LOW}	0% (0 €)	25% (9 600 000 €)	75% (28 800 000 €)
II_{LOW}	30% (11 520 000 €)	25% (6 720 000 €)	75% (20 160 000 €)
I_{AVRG}	0% (0 €)	25% (11 625 000 €)	75% (34 875 000 €)
II_{AVRG}	30% (13 950 000 €)	25% (8 137 500 €)	75% (24 412 500 €)
I_{HIGH}	0% (0 €)	25% (13 650 000 €)	75% (40 950 000 €)
II_{HIGH}	30% (16 380 000 €)	25% (9 555 000 €)	75% (28 665 000 €)

For the calculation of the number of barrels, the mass of the total amount of oil avoided is needed. Consequently:

$$No\_barrels = \frac{m_{total}}{m_{oil\_barrel}} \tag{21}$$

where m_{total} (kg) is the mass of the total fuel avoided and m_{oil_barrel} (kg) is the mass of oil contained in a barrel and its value is given in Table 10.

For the estimation of the total mass of the oil avoided, the following equation is used:

$$m_{total} = \frac{E_{out}}{n \cdot H_u} \tag{22}$$

where E_{out} is the energy output, n (%) is the efficiency of the power plant and H_u is the calorific value of the fuel and their values are given in Table 10.

5.2.3. *Cost avoided due to reduction of external costs*

Power generation plants impose external costs due to their operation, since they pollute the environment, affect public health in a negative way, affect the environment during their construction phases, etc. In order to minimize the environmental impacts, the eco taxes have been applied, with a purpose to control and reduce the external costs of pollutant activities [54,56,57]. Table 12 presents external costs related to power generation plants from different sources.

The savings from the external cost (€) from the replacement of an oil based power plant with a wind park are computed by:

$$Savings_{external} = Cost_{external-oil} \cdot E_{WT} \tag{23}$$

where $Cost_{external-oil}$ in (€/kW h) is the mean external cost of an existing oil power unit, taken from Table 12.

5.3. *Cost–benefit analysis*

Social gains or losses arising by the financial support of wind energy applications by the State and ultimately by the society, indicate the profitability of a project from a social point of view, leading to the adoption or the reformation of the State's policy. For this reason the State financial support to the wind power projects should also be investigated. According to the results, conclusions are extracted regarding the convergence between financial and social profitability showing alignment or not, of private and social interest [58].

The social cost includes the State subsidization of wind park's initial cost and the feed in tariff (FIT), which is the State compensation for the wind energy production.

The social benefits from the operation of the floating wind park, as discussed in the Section 5.2, are related with the reduction of oil imports, the savings from carbon dioxide emissions and the external costs reduction.

Thus, the social cost or benefit (Δp) from the wind park operation is calculated, if from the total support offered by the society to the RES station, the total social benefits are subtracted. The state-financial support offered to RES producers includes the subsidization of the initial cost ($\gamma \cdot IC_0$) and the feed in tariff (FIT) price [54]:

$$\Delta p = \gamma \cdot IC_0 + FIT \cdot E_{WT} - Savings_{total} \tag{24}$$

where feed in tariff (FIT) in €, is the state compensation for the wind energy production and $Savings_{total}$ in (€) are the total social benefits.

In case that Δp is negative the wind park operates in favor of the social interest, whereas in case that Δp is positive the wind park construction and operation is not paid back to society [54].

Moreover, a break-even feed-in-tariff (BEFIT) is produced [54] when the society costs due to state compensation balance the benefits from the wind park operation, i.e. when Δp is zero. Thus, considering zero Δp in Eq. (24), the BFIT is computed as follows:

$$\mathrm{BFIT} = \frac{Savings_{total} - \gamma \cdot IC_0}{E_{WT}} \tag{25}$$

If the BEFIT is greater than the existing FIT, then the operation of the RES installation examined favors the local society without being fully compensated on the basis of FITs. On the contrary, if the BEFIT is lower than the existing FIT, the State provides FITs that surcharge the local economy in favor of RES promotion [54].

6. Results

The present work focuses on the feasibility study of a 12 MW floating wind park in the deep waters of Aegean Sea. Based on the low, high and average values of floating wind turbines investment cost as depicted in Table 13, economic schemes of Table 14 are examined, concerning the funding which include state or European Union subsidization and bank loan.

Table 15
Economic evaluation parameter values.

Parameter	Symbol	Value
Participation of the investor in the cost	α	25%
Loan participation in the cost	β	75%
State amortization	γ	30%
Offshore wind energy selling price	c	108.3 €/MW h
Mean annual inflation rate	g	3.5%
Degradation factor annual	d	0.7%
Tax rate	t_r	26%
Demanded return index of the investment	i	8%
Bank loan interest rate	k_l	4–8%
Lifetime of the investment	n	25 years

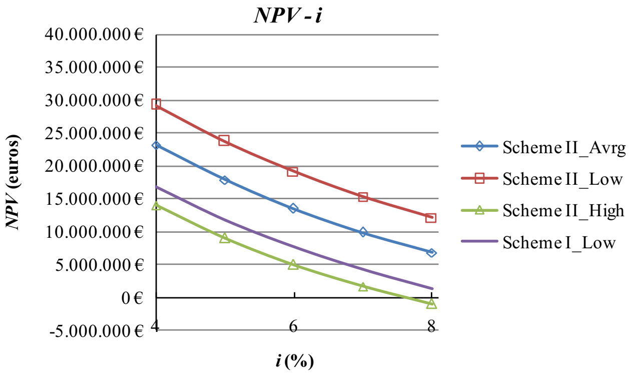


Fig. 11. Variation of the *NPV* versus the return on investment index for the economic schemes.

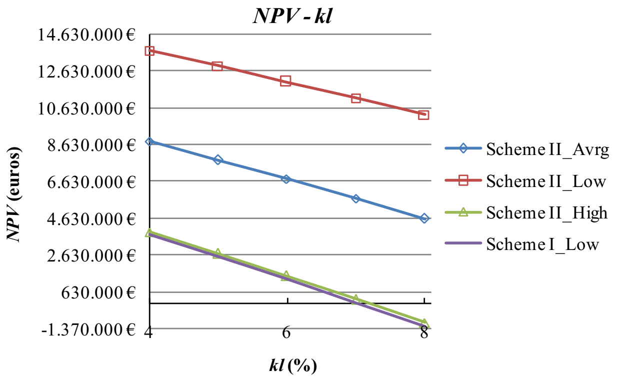


Fig. 12. Sensitivity of the *NPV* in regard to the bank loan interest rate, for the return on investment index 8%.

More specifically, in scenarios I, the investor contributes 25% of the investment cost and the rest 75% of the investment is a bank loan, whereas no subsidy is considered. In scenarios II, a 30% subsidy is considered, while the percentage of the bank loan in the remaining capital remains the same. The financing schemes, taking into account Eq. (7), are summed up in Table 14. The parameter values used for the economic evaluation in Eqs. (7)–(16) are depicted in Table 15.

The project examined lifetime is 25 years. In order for the investment to be attractive, a demanded return index of 8% or more is expected. Consequently, the scenarios resulted a lower value of *IRR* are considered unacceptable. The effect of the return index *i* on the *NPV*, for bank loan interest rate 6%, is depicted in Fig. 11. The *NPV*s of the schemes I_{AVRG} and I_{HIGH}, for return index 8%, are not depicted as they have negative values and so the two schemes are not considered profitable. The sensitivity of the *NPV*, the *IRR* and the CPBP, regarding the bank loan interest rate, for return index 8%, is depicted in Figs. 12–14, respectively.

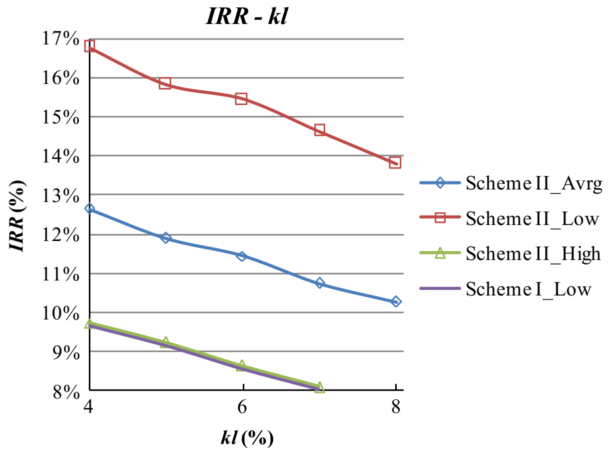


Fig. 13. Sensitivity of the *IRR* in regard to the bank loan interest rate, for the return on investment index 8%.

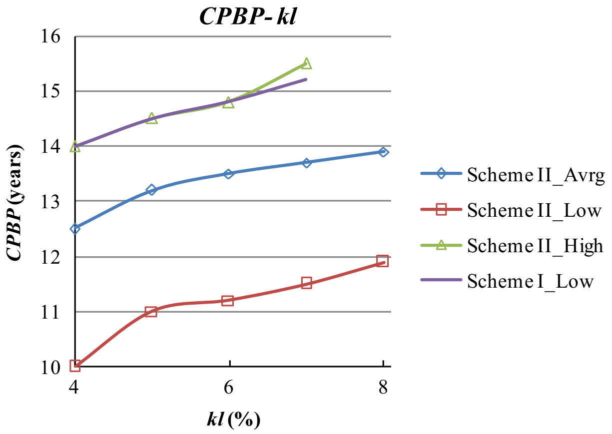


Fig. 14. Sensitivity of the CPBP in regard to the bank loan interest rate, for the return on investment index 8%.

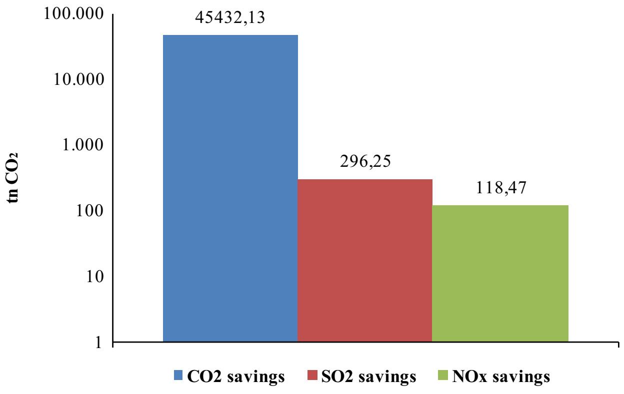


Fig. 15. Annual pollutant savings.

Given the floating wind turbines current economic status, the importance of the state subsidy for the feasibility of the project is evident. Without a state subsidy, only the low capital cost scenario (scheme I_{LOW}) is feasible, indicating the future attractiveness of the investment, based on the expected potential for cost reductions of floating structures. In the case of state subsidization, all the schemes are considered profitable having positive *NPV*s and *IRR* up to 17%, as depicted in Figs. 12 and 13. The schemes II_{HIGH} and I_{LOW} are the most sensitive in the fluctuation of the bank loan

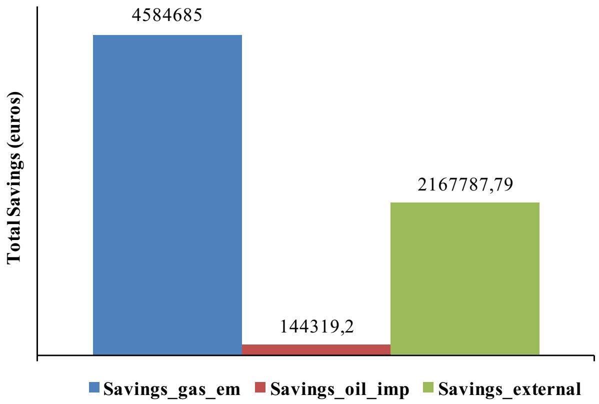


Fig. 16. Total savings from the replacement part of the oil based thermal station with RES.

interest rate, as for bank loan interest rate larger than 7%, the investment is not considered profitable.

Regarding CPBP, a 5 years period would be desirable due to the small commercialization of the technology and potential unknown risks. For this reason, the minimum resulted CPBP of 10 years and the scale of the investment might create uncertainties for the investors.

The total social benefits ($Savings_{total}$) from the operation of the floating wind park are calculated in the amount of 11 896 791.99 € and are related with the reduction of the oil imports, the savings from carbon dioxide emissions and the external cost reduction, as discussed in Section 5.2. The avoided pollutants due to the replacement of the thermal plants energy production with the wind power generation, calculated by Eqs. (19.a)–(19.c), are shown in Fig. 15, while Fig. 16 depicts the total savings distributed per category. The BFIT for the most representative economic schemes I and II_{LOW}, estimated as 0.25877 €/kW h and 0.008 €/kW h, respectively.

The Greek legislation imposes a FIT, for the compensation of the offshore wind energy of 0.1083€/kW h. This given feed in tariff price stands between the two calculated BFIT values for schemes I and II_{LOW}. It is obvious that for the first economic scheme where there is no state subsidy, the given FIT does not fully compensate the floating wind park, whereas its operation favours the society. On the contrary, the economic schemes II surcharge the economy through the state subsidy, in favor of RES promotion.

7. Discussion

The installed wind power in Greece in 2014 reached 1971 MW, out of which 1662 MW are installed in the mainland of Greece as well as in the interconnected with the electrical grid islands, while the rest 309 MW were installed into non-interconnected islands. In order for Greece to reach the goal of 7 GW of wind power installed by 2020, nearly 1000 MW of new wind turbines must by installed yearly. Unfortunately, many of new projects are delayed or eventually cancelled, due to local society reactions, provoked by the believes of noisy and more visually intrusive wind turbines.

A solution to this problem is the installation of offshore wind parks, far away from the shore. But the Aegean sea, as the Mediterranean basin in total, is characterized by large water depths even in short distances from the shore, making costly ineffective the construction of fixed-bottom wind turbines. For this reason it seems that the floating wind parks constitute the best solution for Greece and the Mediterranean countries.

The Greek Law 3851/2010 introduced a special framework of spatial planning as far as the RES is concerned, including also the offshore wind energy applications. Permission was granted for submission of offshore investment proposals in order to have the consent decision of the examination board.

The funding part of the considered project is having an important share regarding the feasibility of the investment. The economics of a full scale offshore floating wind energy project require great capital investments and need to initiate different funding schemes in order to attract the investors. The motivations of this kind of investments are mainly a subsidy controlled scheme or an incentive sell price of the produced electric energy, which will be offered in the contract with the grid operator. These funding schemes are often strategically planned and announced from the Commission of the European Union or from each individual National Government.

The subsidization of such investments is of great significance and should be promoted by all means. However, the Greek law 3851/2010 for the promotion of RES based applications does not include any subsidization scheme except from a premium attribute feed in tariff price. There is an argument if it is social fair for the RES to be subsidized when there is high wind potential. The authors opinion is that since there are differentiations in the social benefits coming from the operation of RES, especially in small islands, there should also be differentiations in social support to these applications, taking into consideration that clear energy coming from wind, has also social benefits that should be always promoted.

8. Conclusions

Recently, floating wind turbines have been proposed as a complementary solution for offshore wind energy production. The main disadvantage of the fixed-bottom offshore wind turbines is that there are economically viable options in water depths of only up to 50 m. For greater water depths, floating wind turbines are needed. The floating wind turbines can be installed in the range of 100 m to 900 m depth and thereby in a large distance from the shore.

In this paper, the offshore wind parks advantages and disadvantages compared to onshore wind parks are presented, revealing the attractiveness of the offshore projects. The current offshore technology development regarding fixed bottom wind turbines and floating concepts are analysed. Regarding the fixed bottom wind turbines, the monopile and jacket type foundations are the prevailing structures, whereas the basic floating foundation types are the tension leg platform, the Semi-Submersible and the Spar-buoy platform.

The social benefits, arising from the contribution of wind energy in the minimization of the operation of coal and oil-fired or natural gas-based thermal power stations, result in the reduction of energy imports, the increase of energy supply security and the reduction of CO_2 emissions. Furthermore, new jobs and activities are created in the areas where the wind parks are installed.

The feasibility of a 12 MW floating offshore wind park at 15 km distance from the shore, in the deep waters of Santorini island was investigated. The floating wind park's capacity is estimated taking into account the maximum allowed wind energy penetration limit for the Greek autonomous islands. The examined scenarios for the economic evaluation were based on low, high and average investment cost estimation, since an accurate investment cost for floating wind energy is difficult to estimate. The examined scenarios for two cases of state subsidy showed that the complete payback period, the net present value and the internal rate of return are very sensitive on the subsidization schemes and the bank loan interest rate. In order for the offshore floating wind park to be feasible, state subsidy is necessary or a smaller amount of bank loan. Without a state subsidy, only a low investment cost scenario is feasible, although cost reductions of floating structures are expected in the future.

The social benefits, resulted from wind park operation (as it substitutes part of the power produced by the thermal station), were also calculated. The social benefits include the reduction of the oil imports, the savings from carbon dioxide emissions and the external cost reduction.

The State financial support to the wind power projects was also investigated. Social gains or losses arising by the financial support of wind energy applications by the State and ultimately by the society, indicate the profitability of a project from a social point of view, and may lead to the adoption or the reformation of the State's policy.

When the social benefits from the wind park operation balance the societal costs due to state compensation, a break-even feed-in-tariff is produced. The current feed in tariff price, which was established by the new law, stands between the calculated break-even feed-in-tariff values for 0% and 30% state subsidy, concluding that in the case of no state subsidy exists, the given FIT does not fully compensate the floating wind park, whereas its operation favours the society. On the contrary, the 30% state subsidy surcharges the economy, in favor of RES promotion. If the state contributes to the investment holding 30% then it could offer lower feed in tariff price, however due to the investment uncertainty resulting from new technology, further investigation is needed.

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