Proceedings of the Twenty-sixth (2016) International Ocean and Polar Engineering Conference
Rhodes, Greece, June 26-July 1, 2016
Copyright © 2016 by the International Society of Offshore and Polar Engineers (ISOPE)
ISBN 978-1-880653-88-3; ISSN 1098-6189

www.isope.org

Offshore Wind Turbines: An Overview of the Effects on the Marine Environment

Luigia Riefolo[1], Caterina Lanfredi[1], Arianna Azzellino[1], Giuseppe R. Tomasicchio[2],
D'Alessandro Felice[2], Valery Penchev[3], Diego Vicinanza[4]

[1] Department of Civil and Environmental Engineering DICA, Politecnico di Milano, Milan, Italy.
[2] Dipartimento di Ingegneria dell'Innovazione, Università del Salento, Lecce, Italy.
[3] Black Sea - Danube Coastal Research Association (BDCA), Coastal Research and Engineering (CORES), Varna, Bulgaria.
[4] Dipartimento di Ingegneria Civile, Design, Edilizia e Ambiente DICDEA, Seconda Università degli Studi di Napoli, Aversa, Italy.

ABSTRACT

The wind energy industry is growing worldwide. Recently, a number of physical and numerical modeling studies have been carried out in Europe to implement the offshore wind turbine technology, as well as the wind resource. Accordingly, the consideration of the possible environmental impacts of this technology on the marine environment, already affected by several anthropogenic pressures (e.g. fishery, maritime traffic) becomes increasingly important. Main goal of this paper is to provide an overview of the offshore wind farm developments and the associated environmental impacts at European level. The Italian state of the art is also presented.

KEY WORDS: Offshore wind farms, wind turbines; environmental impacts; marine environment.

INTRODUCTION

The use of renewable energy is a key point to reach the objectives of United Nations Climate Change Conference COP21, held in Paris on December 2015. In the framework of recent COP21, each State published its own Intended Nationally Determined Contribution, (INDC) or rather than its commitment to reduce greenhouse gas emissions by 2025-2030 in order to mitigate global warming. 195 countries signed an agreement to limit global temperature rise to well below 2°C above pre-industrial levels, and to undertake efforts to meet a 1.5°C goal (http://www.cop21.gouv.fr). Among the possible energy alternatives (e.g. solar, hydro, wave), wind represents one of the most promising renewable energy resource which aims to reduce gas emissions. While onshore wind is in continuous development, offshore wind is attracting people attention and is moving faster than the other renewable resources (Leung & Yang, 2012). Therefore, it is necessary to consider the potential effects on the environment due to the development of this technology. Even if the environmental monitoring of such effects are rapidly developing, it remains a high degree of uncertainty regarding the environmental implications of construction, operation and decommissioning activities (Leeney et al., 2014). The present review gives an overview of the offshore wind energy technologies and the environmental impacts of the existing European offshore wind farms (hereafter OWFs). The effects on the different marine ecosystem components such as benthic or pelagic habitats, large marine vertebrates (i.e. sea birds, marine mammals) are described.

Up to now at Italian level offshore wind energy projects are still at proposal or planning stage. Therefore, an overview of the current Italian regulatory processes and the Italian presented projects is given. Knowledge gaps that could be addressed by future research are also outlined.

GLOBAL AND EUROPEAN STATUS OF WIND ENERGY

The wind energy resource exploitation is rapidly growing globally. According to Global Wind Energy Council (GWEC), the 2015 registered a record in term of global wind industry annual installations (inshore and offshore) crossing the 60 GW mark for the first time from 2000 (Fig. 1).

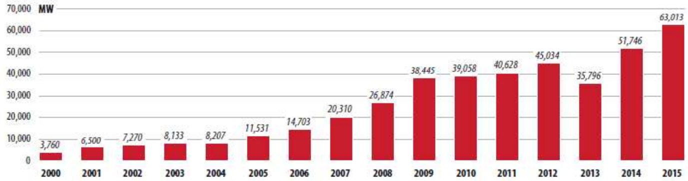

Figure 1. Global annual installed wind (onshore and offshore) capacity 2000-2015 (GWEC, 2016).

To implement the wind energy industry in Europe, it is necessary to identify the optimal sites where the wind energy (onshore and offshore) source is highly suitable. This requires a careful study of the resource characteristics and wind energy potential. Bett et al. (2015) mapped 142-year mean wind speed (1871-2012) giving an overview of the geographic distribution of wind speed over Europe (Fig. 2). There is a noticeable contrast between the northern and southern European areas. Higher values are reached in the northern areas where the mean daily wind speed is between 8-12 m/s. On the other hand, the southern areas present considerably lower values. However, despite some areas are less windy, the new improved turbines are still feasible economically and the technology can be successfully developed anyway (Bett et al., 2015). In fact, it is very relevant to examine the power or the rotor thrust variation depending on the wind speed. To better understand this concept the wind velocities should be considered at the nacelle position, as reported on the curve of the National Renewable Energy Laboratory (NREL) 5MW turbine (Jonkman et al., 2009). According to Ling Wan et al. (2015), when the wind speed is larger than the cutout speed 25 m/s, the wind turbine will be parked and the blades will be feathered into the wind, so there is only wind drag on the blade, and there is no centrifugal force and gyro moment. Instead, at the rated wind speed of 11.4 m/s, the thrust force on the rotor reaches the maximum value (Fig. 3).

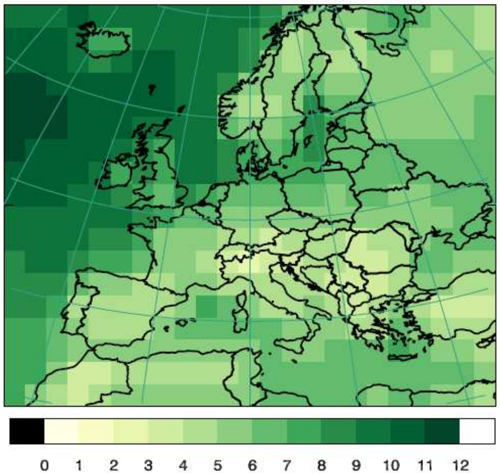

Figure 2. Long-term mean wind speed over Europe (Bett et al. 2015).

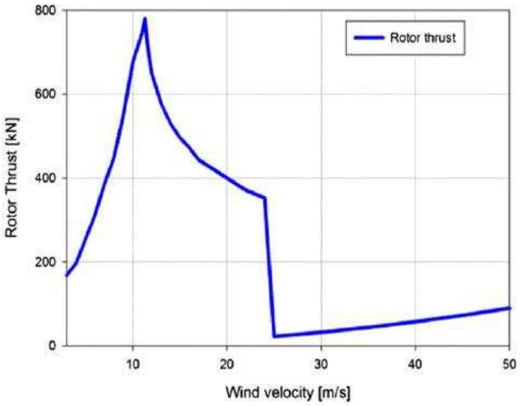

Figure 3. Wind thrust curve of NREL 5MW turbine (Ling Wan et al., 2015).

Wind velocity is a key point for the installation of the offshore wind turbines at sea. Although average wind speeds vary considerably by location, valuable technical potential exists in most areas of Europe to enable significant wind energy deployment (IPCC, 2011). European wind energy capacity increased 10.5% year on year from 2013 (GWEC, 2014). Currently, in the North of Europe (Germany, Spain, UK) the installed wind power capacity is between 45000-14000 MW (Table 1) (GWEC, 2016).

Table 1. European installed wind (inland and offshore) power capacity in MW (GWEC Global Wind Energy Council, 2016).

Country	until 2014	2015	Total
Germany	39.128	6.013	44.947
Spain	23.025	-	23.025
UK	12.633	975	13.603
France	9.285	1.073	10.358
Italy	8.663	295	8.958
Sweden	5.425	615	6.025
Poland	3.834	1.266	5.100
Portugal	4.947	132	5.079
Denmark	4.881	217	5.063
Turkey	3.738	956	4.694
Netherlands	2.865	586	3.431
Romania	2.953	23	2.976
Ireland	2.262	224	2.486
Austria	2.089	323	2.411
Belgium	1.959	274	2.229
Rest of Europe*	6.564	833	7.387

*Bulgaria, Cyprus, Czech Republic, Estonia, Finland, Faroe Islands, FYROM, Hungary, Iceland, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Norway, Romania, Russia, Switzerland, Slovakia, Sloven, Ukraine.

OFFSHORE WIND ENERGY STATUS

The number of the offshore wind farms installed in Europe is growing. The total installed offshore wind capacity for Europe in 2015 stands at 11,028 MW. This capacity is related to the offshore wind farms installed in different European countries. The UK has the largest offshore wind capacity in the European waters with 5,061 MW, Germany follows with 3,295 MW. Denmark is third with 1,271 MW (GWEC, 2016) (Table 2). Rodrigues et al. (2015) presented the current status of the offshore wind industry and identified trends in Offshore Wind Projects OWPs (Table 3). Denmark commissioned the first OWFs with capacities exceeding 100 MW, the Horns Rev1 and Nysted1, in 2002 and 2003 respectively. Currently, UK has OWPs with the highest installed capacities: London Array1 and Gwynt y Môr in operation off the North Wales coast from June 2015 (www.rwe.com).

Table 2.Offshore wind capacity in Europe (GWEC, 2016).

	UK	Germany	Denmark	Belgium	Netherlands	Sweden	Others*
MW	5061	3295	1271	712	427	202	60

*Finland, Ireland, Spain, Norway, Portugal.

Due to this growing number of wind farms and the consequent lack of space available for the future developments, wind installation are moving further out in deeper waters. Furthermore, the relocation in deeper water makes the wind farms more economical and reduce their carbon footprint per unit energy generated (Caduff et al., 2012).

At the end of 2014, the average water depth of online offshore wind farms was 22.4 m and the average distance to shore 32.9 km. (EWEA, 2014). Projects under construction, consented and planned confirm that average water depths and distances to shore are likely to increase (Fig. 4). Therefore it will be necessary to consider the potential environmental effects of this future development on marine deeper water ecosystems.

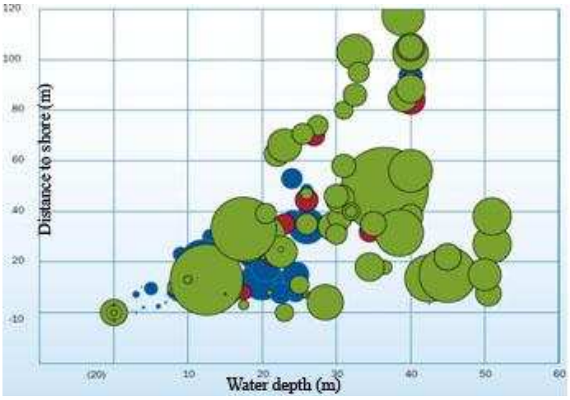

Figure 4. Average water depth and distance to shore of online (blue), under construction (red), consented (green) wind farms (EWEA, 2014).

Table 3. Projects of the main OWF in Europe (modified from Rodrigues et al., 2015).

Project (Year)	Country	Capacity (MW)	# turbines	Water depth (m)
Horns Rev 1 (2002)	Denmark	160	80	10
Nysted (2003)	Denmark	166	72	8
Lillgrund (2008)	Sweden	110	48	7
Prinses Amalia (2008)	Netherlands	120	60	22
Horns Rev 2 (2009)	Denmark	209	91	13
Belwind 1 (2010)	Belgium	165	55	29
London Array1 (2013)	UK	630	175	13
Riffgat (2014)	Germany	108	30	21
Gwynt y Mor (2015)	UK	576	160	20

OFFSHORE WIND TURBINES: TECHNOLOGY

According to European Wind Energy Association (EWEA, 2015), during the first semester of 2015, a total number of 15 OWFs was installed in Germany, Netherlands and United Kingdom. A number of 138 foundations were erected (Table 4). Furthermore, Germany met the expectations expressed at the beginning of the year thanks to the catch-up effects of grid connection. In fact, 546 offshore wind turbines, with a total capacity of 2,282.4 MW went on grid. This brings the total number of turbines connected to the grid by 31 December 2015 up to 792, with a combined capacity of 3,294.9 MW. One hundred twenty two foundations were built offshore in 2015, for offshore wind turbines to be installed in the German waters in 2016 (http://www.gwec.net/).

Table 4. Numbers of offshore wind farms, turbines and total of MW connected to the grid between January and June 2015 (EWEA, 2015).

Country	# farms	# foundations installed	# turbines erected	MW fully connected to the grid
Germany	9	75	218	1706.3
Netherlands	2	48	43	114
UK	4	15	52	522.6
Total	15	138	313	2342.9

A focal point in the understanding of the potential environmental impacts of the offshore wind farms is the knowledge of the size and type of used technology. Offshore wind turbines are typically mounted on tubular towers that range from 60 to 105 meters above the sea surface. Foundation technology is designed according to site conditions. Maximum wind speed, water depth, wave heights, currents and soil properties are parameters that affect the type and design of the foundations. The foundations typology are: "gravity" "monopile", "jacket/tripod", "tri-pile" and "floating" structures (Fig. 5, EWEA, 2013). Currently, the mostly used types are "monopile" (74% of the cases) and "gravity" (26%). Monopile foundation consists of a long hollow steel pole that extends from below the seabed to the base of the turbine and is used in water with a maximum depth around 25 meters. Gravity foundations are used preferably in waters with a maximum depth around 30 meters, are made of precast concrete and are ballasted with sand, gravel or stones.

For waters more than 30 m in depth, "tri-pile" or "tripod" foundations could allow the installation in water up to 50 meters of depth. The "floating" foundations are installed for deep water areas where the water depth is greater than 50 m within 300 m (Fig. 5). Since wind farms will move further from shore and into deeper waters, the floating structures will probably be employed in the future. Furthermore, according to Sun et al. (2012), there is the potential to reach water depths of up to 700 m. Floating structures use 3 main types of foundations: the Tension Leg Platform (TLP), semi-submersible (Semi-sub), and Spar Buoy (Spar). In the Spar Buoy concept, ballast is used to get the center of gravity well below the center of buoyancy, providing stability; catenary mooring lines are used to keep the system in place. In particular, recent studies on this type of technology have been carried out in order to examine the hydrodynamic behavior under combined action of wind and waves (Damiani et al., 2015; Tomasicchio et al., 2014; Vorpahl et al., 2014). In the TLP Platform the corners are connected to mooring lines anchored to the seabed, instead in Semi-sub concept the wind turbine stand on a platform floating near to the surface, and held in place by mooring lines. The mooring lines in this concept primarily have the role of keeping the structure in place (Wayman et al., 2006).

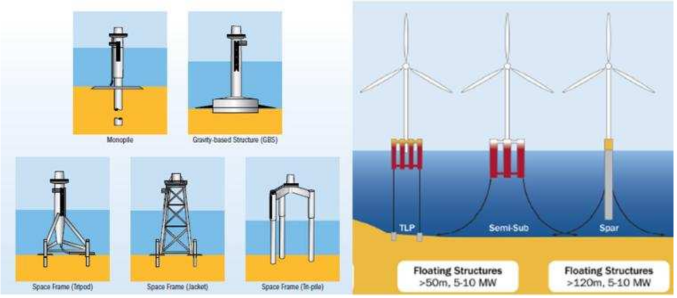

Figure 5. Types of offshore wind turbine foundations and floating structures (EWEA, 2013).

ENVIRONENTAL IMPACTS OF OFFSHORE WIND FARMS

Renewable energy deployments can provide environmental benefits by reducing greenhouse gas emissions and mitigating adverse climate change impacts. However, these installations can adversely affect marine species and features of conservation importance, including those protected by European Law.

All the renewable installations can affect the marine environment through negative and positive effects. For example, in a recent review benefits and disadvantages due to the construction, operation and decommissiong of the wave energy converters are described, enhancing the importance to monitor them (Riefolo et al., 2015). The major environmental issues related to OWFs deployment concern the increase of the noise level, risk of collision (e.g. bird and bat fatalities), the changes to benthic and pelagic habitat and the introduction of additional electromagnetic fields into the ocean.

Noise

Human generated noise is now considered an important form of pollution and both scientists and stakeholders are aware about the environmental impact that anthropogenic underwater noise may have on the marine ecosystem (Table 5). For instance, this is demonstrated by its coverage by international agreements and conventions, in the framework of the European Union, such as EU Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC), the Convention on Migratory Species and ASCOBAMS and ACCOBANS recommendations (www.ascobans.org; www.accobans.org).

One of the major concerns in the development of OWF is the introduction of underwater noise during installation, operation and decommissioning of the wind turbine array. Negative direct or indirect impacts for several marine species such as cetaceans (whales, dolphins and porpoises), fish, marine turtles and invertebrates have been reported to date (CBD, 2012). In particular, the construction phase is likely to have the greatest impact on marine fauna. The activities of greatest concern are pile driving and increase in vessel traffic. Pile driving is the most common method used to secure the turbine foundation to the seafloor. Harbor porpoises are the most critically affected species from piling inducing noise (Madsen et al., 2006; Tougaard et al., 2009b; Dähne et al., 2013, Bruns et al., 2015). Effects also on fish stocks, turtles, and invertebrates have been observed. According to Thomsen et al. (2006), at the site of construction, the sound pressure level of pile driving a monopile for a 1.5 MW turbine is 228 dB and the sound produced may travel tens of kilometres underwater. The sound emitted during this activity could cause effects on marine mammals at different levels from temporal to permanent hearing damages, behavioural changes (escape from the area to avoid the noise and masking the communication, masking the calls) (Southall et al., 2007). Evidence of injury for pile driving sounds has been reported for several fish species (Casper et al., 2012, 2013; Halvorsen et al., 2012). It is important to know that also the nature of the foundations (Fig. 4) affects the noise transmission from the operating turbines into the oceans (Ødegaard and Danneskiold – Samsøe A/S 2000). Noise can be also produced by offshore wind turbines in operation. In fact, the noise and the consequent vibration produced by the turbines can produce negative effects to fish, masking their communication and orientation signals (Wahlberg and Westerberg, 2005) and other marine species such as sea turtles (Bailey et al., 2014).

To date no international agreements on the methods for the protection of adverse effect on marine habitat exist as guidelines and regulations controlled by individual countries (Bruns et al., 2015). Explicit guidelines have only been issued for certain operations, such as pile driving but with regards to impacts on marine mammals, particularly cetaceans. Therefore, there is the need to better understand the potential physiological and behavioural impacts on the marine life due to introduction of underwater noise during the construction, operation and decommissioning of the offshore wind turbines.

Table 5. Overview of the acoustic properties of some anthropogenic sounds (modified form OSPAR, 2009).

Sound	SL (dB)	Bandwidth (Hz)	Major amplitude (Hz)
Pile driving	228 Peak / 243 - 257 P-to-P	20 -> 20000	100 - 500
Dredging	168 - 186 rms	30 -> 20000	100 - 500
Drilling	145 - 190 rms	10 – 10000	< 100
Wind turbine	142 rms	16 – 20000	30 - 200

Collision risk

The construction and operation of the OWFs may impact birds causing effects at different levels, from mortality due to collision with the moving turbine blades, creating barriers to movement, inducing avoidance responses that may results in displacement form key habitat or increase energetic costs (Bailey et al., 2014).

The nature and magnitude of these effects are site- and species-specific (Drewitt and Langston, 2006). In particular, the factors that can heighten collision risk of birds are the characteristics of turbines, and geometry of arrays formed by the turbines, weather conditions, bird species diversity and abundance. Species-specific risks are a function of flight altitude, flight maneuverability, percentage of time spent in flying and habitat specialization (Tabassum-Abbasi et al., 2014; Furness and Wade, 2013; Schwemmer et al, 2011).

Birds may however respond to these effects through fleeing, activity shifts or changed habitat utilization; usually termed avoidance. An increasing number of empirical studies have improved the understanding of avoidance (Roel 2015) where geometry of the array is an important concern. In fact, turbines constructed linearly in long strings may cause more avian collisions than turbines that are constructed in clusters. The heights, blade lengths, tip speeds and blade appearances to birds are the main factors that determine the collision probability. This risk is increasing since the wind turbines are becoming much larger. Actually, the turbines consist in taller towers and larger blade lengths with slower tip speeds (Tabassum-Abbasi et al., 2014; Morrison and Karin, 2009).

Adverse weather conditions also increase the probability of the seabirds hitting the wind turbines. Even if migrating birds generally fly at altitudes higher than 150 m, they descend to lower altitudes during high winds, low clouds and rain (Tabassum-Abbasi et al., 2014; Montevecchi 2006).

Knowledge of bird vulnerability and mortality from wind farms has largely been based on those on land. Direct measurements of mortality from offshore wind farms are much rarer because of the difficulty of finding corpses at sea. The lack of direct measurements of flight height distributions and avoidance responses for many seabird species means there is still considerable uncertainty in the mortality estimates.

Furthermore, there are doubts on the consequent energetic costs of avoidance behaviors for offshore wind farms, even though modeling approaches developed for terrestrial wind farms have provided a robust framework to begin the assessments (Bailey et al., 2014; Band et al., 2012; Band W. et al., 2005).

Ruben et al. (2015) assessed the impacts of avian collisions with wind turbines estimating avian flight intensities and altitudes, to allow accurate estimation of collision rates, avoidance rates and related effects on populations. At sea, obtaining such estimates visually is limited not only by weather conditions but, more importantly, because a high proportion of birds fly at night and at heights above the range of visual observation. A vertical radar with automated bird-tracking software overcome these limitations and can provide bird movements data and seasonal migration, as support tool for the understanding of the impacts on birds (Ruben et al, 2015; Desholm Mark & Johnny Kahlert, 2005).

Collision events were registered also for bats. However, very poor studies have been conducted on the offshore distribution of the migrating bats, their collision risk and potential displacement caused by offshore wind farms. Despite bats have also been found to occur offshore, their occurrence is less frequent with respect to that concerning inland wind farms (Sjollema et al., 2014; Bailey et al., 2014; Pellettier et al., 2013; Kunz et al., 2007).

Artificial reef effect

During the OWF deployment, foundations and piles installation alters the sea bottom. This can create positive and negative effects. Wind turbine foundations may act as artificial reef, providing additional habitat available for marine life. An increase of biodiversity and habitat complexity (increasing abundance of species and biomass) has been observed in the offshore wind farm area due to the colonization of new substrate and the attraction of fish species (Inger et al., 2009; Linley et al., 2007; Gill, 2005).

Besides, in recent studies the opportunity to combine offshore wind energy installations and marine aquaculture has been suggested in terms of environmental sustainability. In fact, the turbine foundations can serve as anchor points (Wever et al., 2015; Langhamer 2012).

However, few deployments mention the risk of disturbing natural habitats and introducing invasive species, promoting the establishment and spread of alien species and harmful algal blooms (Tabassum-Abbasi et al., 2014; Vaissière et al., 2014). According to Mangi (2013) and Hiscock et al. (2010), changes in benthic and epibiotic communities appear when rocky substrata and artificial structures are placed on the seabed at depth higher than 15 m. It is also known, floating structures, which are anchored to the seabed by a mooring line, facilitate the aggregation of fish (Tabassum-Abbasi; 2014; Fayram and De Risi, 2007; Wilhelmsson et al., 2006; Vella et al., 2001).

Electromagnetic fields

During the OWF operation, cables transmit the produced electricity emitting as well electromagnetic fields (EMF). Fishes use their perception of magnetic and electric fields for orientation and prey detection (Lozano-Minguez et al., 2011; Tricas T and Gill AB, 2011; Wilson et al., 2010; Snyder and Kaise, 2008). According to Bailey et al. (2014) during operation's activities, EMFs sent out by cables could affect the movements and navigation of marine animals.

Particularly elasmobranchs and some teleost fish, decapod crustaceans and sea turtles are sensitive to electro- or magnetic fields. The impact on marine life due to the exposure of EMF varies from minor to harmful. Different studies suggest chronic exposure to electromagnetic radiation could impact nervous, cardiovascular, reproductive and immune systems of the marine species (e.g. fish, marine mammals). EMFs could also disrupt species orientation affecting animals that use geomagnetic cues during migration (Lovich Jeffrey E. and Joshua R. Ennen, 2013; Balmori A., 2010; Lohmann et al., 2008; Petersen and Malm, 2006).

Furthermore, it is predicted that electricity production at the offshore wind farm site will increase the temperature in the surrounding sediment and water. This thermal effect could increase the temperature within a few centimetres from the cable and could produce negative effects on benthic communities (Tabassum-Abbasi et al., 2014). However, additional studies need to be conducted to better understand the long term impacts of electromagnetic fields on the marine ecosystem.

ITALIAN STATE OF ART

Legislation

Across the European countries, the development of wind farms is affected by the environmental legislation which includes the Environmental Impact Assessment (EIA) Directive (85/337/EEC), the Strategic Environmental Assessment (SEA) Directive (2001/42/EC) and the Birds and Habitat Directive (2009/147/EC) built around the Natura 2000 network.

In particular, in Italy the consenting process for the development and installation of wind farms is regulated by the legislative decree 152 (“Norme in materia ambientale”, 2006) commonly called “Single Environmental Text” as it regroups in a single legislative text the environmental laws previously contained in several decrees. Particularly, it specifies the projects that need to be subjected to Environmental Impact Assessment EIA study.

OWFs were included in the list of those projects through the Directive 99/2009, (art.27 paragraph 43 “modification of Directive 152/2006”). Within the framework of this Directive is clearly mentioned the management of the environmental impacts study of the offshore wind farms is under the National authority (Attachment 2, art. 7-bis).

Italian Offshore Wind Projects

Up to now no offshore wind installations are operating in the Mediterranean waters, even though projects are under authorization for the Italian coasts. Most of the offshore wind projects presented were rejected or are still under revision by Region and Municipality.

These projects are mostly located in the south of Italy (Puglia, Molise, Sardegna and Sicilia) where the wind availability is suitable for the development of OWFs (Legambiente, 2015). The majority of these projects, except that withdrawn and rejected, has planned to install monopile foundations in shallow water ranging depth between 10 and 50 m (green bathymetric as shown in Figure 6). Floating foundation has been proposed at 20 Km off the coast of Tricase city (Puglia), whereas tripile foundation 26 and 35 miles far from the southern coast of Pantelleria (Sicily) (in according to the Figure 6 sites number 7 and 13).

In Table 6 for each offshore wind farm project is reported the foundation's type such as "M" for the monopile, "F" for the floating and "T" for the tripile, respectively. Moreover, the proposed number of turbines and water depth for OWF deployments are also reported.

To understand the potential impacts of these proposed projects, the presence of areas of special environmental interest (i.e. Important Bird Areas IBAs) and protected species presence (i.e. marine mammal and seaweed) need to be considered.

Since OWFs may impact birds (from avoidance to mortality due by collision) IBA presence is investigated by using the marine IBA-e atlas (maps.birdlife.org/marineIBAs/default.html). These areas are based on specific criteria and include the appearance of globally threatened species (IUCN Red List) seabird breeding colonies, foraging areas around breeding colonies, non-breeding concentrations (usually coastal), migratory bottlenecks and feeding areas for pelagic species.

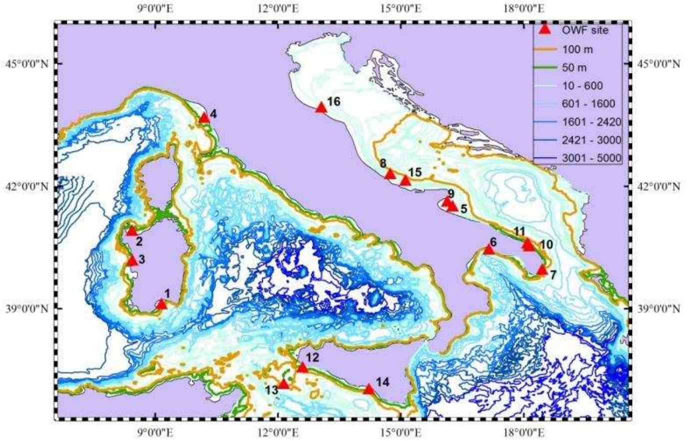

Figure 6. Location of the Italian offshore wind farm projects (red triangle with related number). The 50 (green line), 100 (orange line) and between 10-5000 depth contours are shown (depth in meters).

Table 6. Location, technology type ("M" monopile, "F" floating and "T" tripile) turbine's number, water depth (m) and status of the EIA studies of the OWF projects (modified from Legambiente, 2015).

	Location (Project year)	Type / # turbines	Depth (m)	Project status
1	Sardegna, Cagliari (2013)	n.a/300	n.a.	withdrawn
2	Sardegna, Porto Torres (2012)	n.a/26	n.a.	withdrawn
3	Sardegna, Oristano (2009)	M /80	13-36	*
4	Toscana, Pisa, Vecchiano, San Giuliano (2012)	M /38	10-20	*
5	Puglia, Mattinata, Margherita di Savoia, Manfredonia (2008)	n.a/100	n.a.	rejected
6	Puglia, Taranto (2010)	M /10	30-35	EIA completed
7	Puglia, Tricase (2010)	F /24	108	EIA completed
8	Puglia, Chieuti, Campomarino,Serracapriola (2008)	n.a/50	17-24	rejected
9	Puglia, Manfredonia (2012)	M /95	14-23	*
10	Puglia, Brindisi, Torchiarolo, San Pietro, Vernotico, Lecce (2008)	M/ 50	17-30	negative EIA
11	Puglia, Brindisi, Torchiarolo, San Pietro, Vernotico (2013)	M/ 36	20-35	*
12	Sicilia, Petrosino, Mazara del Vallo (2013)	M /48	<50	*
13	Sicilia, Pantelleria (2009)	T /38	20-50	negative EIA
14	Sicilia, Gela, Butera (2007)	M /38	10-30	EIA completed
15	Molise, Termoli (2006)	M /45	12-20	EIA completed
16	Emilia Romagna, Rimini (2013)	n.a.	n.a.	Feasibility study ongoing

* OWF not yet installed. EIA study still under revision.

Figure 7 shows the distribution of the marine IBAs along the Italian coast. Most of the locations, selected as suitable sites for the OWF developments, are located within or close to a confirmed IBA. Furthermore, it is important to consider the potential noise impact that these OWFs may cause to marine mammals. Most of the sites are located within the 100 m of water depth that is considered in literature a suitable habitat for marine protected species such as coastal dolphins (i.e. bottlenose dolphins Tursiops truncates Montagu 1821) (Gnone et al., 2005; Bearzi et al., 2008; Azzellino et al., 2011; 2012; 2014). The regular presence of bottlenose dolphin along the Italian coasts is also confirmed by the strandings data available from the Italian Stranding Network data (mammiferimarini.unipv.it). In addition, it is known the presence of a protected species of seaweeds (Posidonia oceanica) widely distributed in the Mediterranean Sea. Posidonia occurs typically at a depth of about 10-50 meters, in extensive beds along open shores and bays (SI.DI.MAR database sidimar.tutelamare.it).

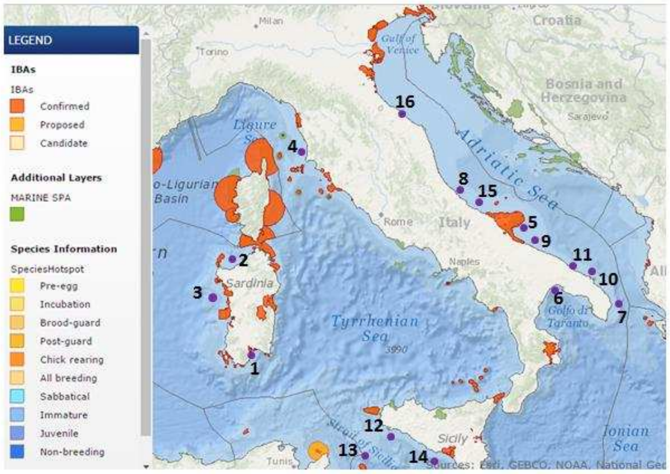

Figure 7. Distribution of the marine IBA (orange) along the Italian coasts (modified from maps.birdlife.org/marineIBAs/default.html). Numbers and purple dots indicate the OWF projects proposed for the Italian seas.

FINAL REMARKS

Offshore wind farms development can impact marine life during the entire life process. In particular, marine mammals appear to be the most impacted marine species because of their vulnerability of underwater sounds emission emitted during all the three phases of OWF life (Table 7). Offshore wind farm construction, operation and decommissioning processes should follow a standard Before-After/Control-Impact (BACI) approach to understand the impact of OWF on the marine environment (Wilson et al., 2010; Gray and Elliott, 2009). Additional studies and monitoring programs should be addressed to better figure out the environmental effects on marine life caused by the OWFs deployment. The research should be focused to assess the impacts of the different type of foundations (e.g. monopile vs. floating) on the different components of the marine ecosystem. Predefined protocols should be developed for environmental impact studies, monitoring and data collection regarding the European waters. Furthermore, the use of numerical models for the simulation of the possible changes on the marine environment could help the development of standard procedure to develop the environmental impact assessment.

This review describes the main OWF environmental impacts identified in Europe. In Italy there is a burgeoning interest on the OWF deployments and the consequent potential environmental impacts. Most of the proposed projects are located in areas with acceptable wind energy potential and a rich marine ecosystem. The monopile foundations are largely proposed at marine sites where the habitat losses could be the most probable impacts. Also the noise impact should be taken into account since the shallow water proposed for the OWFs development could represent a suitable habitat for marine mammals. Finally, the presence of important seabird areas need to be taken in consideration in order to minimize the collision risk. In addition, it is necessary to consider the environmental impact of OWFs in the context of the existing pressures (maritime traffic, chemical pollution, aquaculture development, fishery). The identification of the optimal sites for the development of future OWFs though a Marine Spatial Planning MSP (as the one proposed by Azzellino et al., 2013) could represent an effective tool for balancing between energy production necessities, existing pressures and environmental sustainability. Therefore, a common feature of EIA studies is the need to compare alternative scenarios, and this may be done by using a simulation approach or using the information derived from different marine renewable energy projects (Azzellino et al., 2013).

Table 7. Environmental impacts and receptors assessed on the base of the construction "C", operation "O" and decommissioning "D" activities of the offshore wind farm.

		Receptors		
		Marine mammals	Birds	Fish
Impacts	Noise	C-O-D	O	C-O-D
	Collision	C-O-D	O	C-D
	Artificial reef	-	-	O
	Electromagnetic fields	O	-	O

REFERENCES

Azzellino A., Fossi MC, Gaspari S, Lanfredi C, Lauriano G, Marsili L, Panigada S, Podestà P (2014). "An index based on the biodiversity of cetacean species to assess the Environmental Status of marine ecosystems" Marine Environmental Research Vol 100, pag 94–111.

Azzellino A, Panigada S, Lanfredi C, Zanardelli M, Airoldi S. and Notarbartolo di Sciara, G. (2012). Predictive Habitat Models For Managing Marine Areas: Spatial And Temporal Distribution Of Marine Mammals Within The Pelagos Sanctuary (Northwestern Mediterranean Sea). Ocean and Coastal Management 67:63-74.

Azzellino A., Ferrante V., Kofoed J.P., Lanfredi C., Vicinanza D. (2013) "Optimal siting of offshore wind-power combined with wave energy through a marine spatial planning approach", International Journal of Marine Energy 3–4 e11–e25.

Azzellino A, Conley D, Vicinanza D, Kofoed JP (2013)"Marine Renewable Energies:Perspectives and Implications for Marine Ecosystems"Special Issue The Scientific World Journal, 1537-744X.

Azzellino A, P Contestabile, V Ferrante, Lanfredi C, D Vicinanza. 2011)"Strategic Environmental Assessment to evaluate WEC projects in the perspective of the environmental cost-benefit analysis"ISOPE Conference.ISBN978-1-880653-96-8 (Set) 584-589.

Bailey H, Brookes KL, Thompson PM, (2014) "Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future"Aquatic Biosystems, 10:8.

Balmori A (2010) "The incidence of electromagnetic pollution on wild mammals:a new poison with a slow effect on nature?" Environmentalist; 30:90–7.

Band B, Band B. (2012) "Using a collision risk model to assess bird collision risks for offshore windfarms". Norway: SOSS report for The Crown Estate.

Band W, Madders M, Whitfield DP (2005) "Developing field and analytical methods to assess avian collision risk at wind farms". In Birds and Wind Power. Edited by De Lucas M, Janss G, Ferrer M. Barcelona, Spain: Lynx Edicions.

Bearzi G, Fortuna C, Reeves RR (2008)"Ecology and conservation of common bottlenose dolphins Tursiops truncatus in the Mediterranean Sea" Mammal. Rev. 39, 92e123.

Bett PE, HE Thornton, RT Clark (2015)"Using the Twentieth Century Reanalysis to assess climate variability for the European wind industry",Theoretical&Appl Climatol.,doi10.1007/s00704-015-1591-y.

Bruns C, Braunova V, Jorgensen P (2015) "Offshore Wind Construction Sound Hazards and Hierarchy of Control Measures"Proceedings ISOPE Conference Kona(Hawaii)June 21-26,ISBN978-1-880653-89-0.

Caduff M, Huijbregts MAJ, Althaus HJ, Koehler A, Hellweg S. (2012) Wind power electricity: the bigger the turbine, the greener the electricity? Environmental Science&Technology; 46:4725–33.

Carstensen J, Henriksen OD, Teilmann J(2006)"Impacts of offshore wind farm construction on harbour porpoise" Marine Ecology 321, 295–308.

Casper BM, Halvorsen MB, Matthews F, Carlson TJ, Popper AN (2013) "Recovery of barotrauma injuries resulting from exposure to pile driving sound in two sizes of hybrid striped bass" PLoSONE, 8:e73844.

Casper BM, Popper AN, Matthews F, Carlson TJ, Halvorsen MB (2012) "Recovery of barotrauma injuries in Chinook salmon, Oncorhynchus tshawytscha from exposure to pile driving sound" PLoSONE, 7:e39593.

Convention on Biological Diversity (CBD, 2012). "Scientific Synthesis on the Impacts of Underwater Noise on Marine and Coastal Biodiversity and Habitats". Subsidiary Body on Scientific, Technical and technological Advice, Sixteenth meeting, Montreal.

Dähne, M., Gilles, A., Lucke, K. et al. (2013). Effects of Pile Driving on Harbour Porpoises (Phocoena Phocoena) at the First Offshore Windfarm in Germany. Environmental Research Letter 8:025002.

Damiani, L., Musci, E., Tomasicchio, G.R., D'Alessandro, F. (2015), "Spar buoy numerical model calibration and verification". Proceedings VI International Conference on Computational Methods in Marine Engineering MARINE, Roma.

Desholm Mark and Johnny Kahlert, (2005), "Avian collision risk at an offshore wind farm", Biology Letters doi:10.1098/rsbl.2005.0336.

Directives 85/337/EEC, 2001/42/EC, 2009/147/EC, 152/2006, 99/2009, 2008/56/EC.

Drewitt Allan L, Rowena H W. Langston (2006)"Assessing the impacts of wind farms on birds" Ibis Special Issue: Wind, Fire and Water: Renewable Energy and Birds, Vol 148, Issue Supplement s1, pg29–42.

EWEA European Wind Energy Association, (2013), "Deep Water: The Next Step for Offshore Wind Energy". Brussels, Belgium: A report by the European Wind Energy Association.

EWEA European Wind Energy Association, (2014) "The European offshore wind industry - key trends and statistics". Report EWEA.

EWEA European Wind Energy Association, (2015), "The European offshore wind industry - key trends and statistics 1st half 2015", A report by the European Wind Energy Association - July.

Fayram AH, de Risi A. (2007) "The potential compatibility of offshore wind power and fisheries: an example using bluefin tuna in the Adriatic Sea". Ocean Coastal Manage;50:597–605.

Furness RW, Wade HM (2013) "Assessing vulnerability of marine bird populations to offshore wind farms". J Environ Manag;119:56–66.

Gill AB (2005)''Offshore renewable energy:Ecological implications of generating electricity in the coastal zone''J.Appl. Ecol, vol42,605-615.

Gnone G,Caltavuturo G, Tomasini A, Zavatta V, Nobili A, (2005) "Analysis of the presence of the bottlenose dolphin (Tursiops truncatus) along the Italian peninsula in relation to the bathymetry of the coastal band" Sci. nat. Museo civ. Stor. nat. Milan,146 (I):39-48.

Gray JS, Elliott M(2009) "Ecology of Marine Sediments: Science to Management", Oxford University Press: Oxford, UK.

GWEC (2014) "Global wind report. Annual market update". Report of Global Wind Energy Council.

GWEC (2016) "Global Wind Statistics 2015". Report of Global Wind Energy Council.

Halvorsen MB, Casper BM, Woodley CM, Carlson TJ, Popper, AN (2012)'Threshold for Onset of Injury in Chinook Salmon from Exposure to Impulsive Pile Driving Sounds'. PLoS ONE Vol 7 Issue 6.

Hiscock K, S Sharrock, J Highfied, D. Snelling (2010) ''Colonization of an artificial reef in south-west EnglandVEx HMS Scylla'' J. Mar. Biol. Assoc. U.K., vol. 90, pp. 69–94.

Inger R., M. J. Attrill, S. Bearhop, A. C. Broderick, W. J. Grecian, D. J. Hodgson, Mills, E. Sheehan, S. C. Votier, M. J. Witt, and B. J. Godley (2009) ''Marine renewable energy: Potential benefits to biodiversity? An urgent call for research,'' J. Appl. Ecol., vol. 41, pp. 821–833.

IPCC. Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, Zwickel T, Eickemeier P, Hansen G, Schlömer S, von Stechow C. (2011) "IPCC special report on renewable energy sources and climate change mitigation" Cambridge, United Kingdom and New York, NY,USA:Cambridge University Press.

Jonkman J, Butterfield S, Musial W, Scott G. (2009) "Definition of a 5-

MW reference wind turbine for offshore system development". Technical Report. NREL/TP-500–38060, National Renewable Energy Laboratory (NREL), Golden, CO, USA.

Kunz TH, Arnett EB, Erickson WP, Hoar AR, Johnson GD, Larkin RP, Strickland MD, Thresher RW, Tuttle MD (2007) "Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses". Front Ecol Environ, 5:315–324.

Langhamer O. (2012) "Review Article. Artificial Reef Effect in relation to Offshore Renewable Energy Conversion: State of the Art". The Scientific World Journal Volume 2012, Article ID 386713, 8 pages.

Leeney RH., D Greaves, DConley, AM O'Hagan (2014) "Environmental Impact Assessments for wave energy developments e Learning from existing activities and informing future research priorities", Ocean & Coastal Management, doi.org/10.1016/j.ocecoaman.2014.05.02.

Legambiente (2015), "L'assurdo stop all'eolico off-shore in Italia. Da Taranto a Termoli, da Gela a Manfredonia tutte le barriere all'eolico in mare", 15 June 2015, Wind Day.

Leung Dennis YC, Yuan Yang (2012), "Wind energy development and its environmental impact: A review", Renewable and Sustainable Energy Reviews 16 1031– 1039.

Ling W., Zhen G., Torgeir M(2015)"Experimental and numerical study of hydrodynamic responses of a combined wind and wave energy converter concept in survival modes", Coastal Engineer. 104, 151-169.

Linley EAS, Wilding TA, Black K, Hawkins AJS, Mangi S., (2007) ''Review of the reef effects of offshore wind farm structures and their potential for enhancement and mitigation'' Report PML Applications Ltd. and Scottish Association for Marine Science to BERR.

Lohmann KJ, Lohmann MF, Endres CS. (2008) "The sensory ecology of ocean navigation" J Exp Biol; 211:1719–28.

Lovich Jeffrey E., Joshua R. Ennen, (2013) "Assessing the state of knowledge of utility-scale wind energy development and operation on non-volant terrestrial and marine wildlife", Applied Energy 103 52–60.

Lozano-Minguez E, AJ Kolios, FP Brennan (2011) "Multi-criteria assessment of offshore wind turbine support structures" Renewable Energy 36, 2831e2837.

Madsen, P., Wahlberg, M., Tougaard, J. et al. (2006). "Wind Turbine Underwater Noise and Marine Mammals: Implications of Current Knowledge and Data Needs". Marine Ecology Progress Series.

Mangi Stephen C., (2013) "The Impact of Offshore Wind Farms on Marine Ecosystems: A Review Taking an Ecosystem Services Perspective", Proceedings of the IEEE 101, No. 4, Vol. 0018-9219.

Montevecchi WA. Influences of artificial light on marine birds. In: Rich C, Longcore T, (2006) "Ecological consequences of artificial night lighting" Washington, DC: Island Press; p. 94–113.

Morrison ML, Karin S. (2009) "Wind energy technology Environmental impacts" in. Encyclopedia Energy:435–48.

Ødegaard & Danneskiold–Samsøe A/S(2000)"Underwater noise measurements, analysis and predictions. Rødsand Offshore Wind farm EIA technical background report:underwater noise"Report 00.792rev1.

OSPAR (2009) "Overview of the impacts of anthropogenic underwater sound in the marine environment OSPAR Convention for the Protection of the Marine Environment of the North- East Atlantic". Biodiversity and Ecosystems Series, Publication N. 441/2009, 134 pp.

Pelletier SK, Omland K, Watrous KS, Peterson TS. (2013) "Information Synthesis on the Potential for Bat Interactions with Offshore Wind Facilities" Final Report. Herndon, VA: U.S. Department of the Interior, Bureau of Ocean Energy Management, Headquarters; OCS Study BOEM 2013–01163.

Petersen JK, Malm T. (2006) "Offshore windmill farms: threats to or possibilities for the marine environment". Ambio; 35:75–80.

Riefolo L, Lanfredi C, Azzellino A, Vicinanza D, (2015) "Environmental impact assessment of wave energy converters: a review", International Conference on Applied Coastal Research SCACR. 29th September-1 October Florence, Italy.

Rodrigues S,C.Restrepo E,Kontos R, T. Pinto, P.Bauer(2015) "Trends of offshore wind projects"Renewable&Sustain Energ.Rev.49,1114-1135.

Roel F. May, (2015) "A unifying framework for the underlying mechanisms of avian avoidance of wind turbines", Biological Conservation 190 (2015) 179–187.

Ruben C. Fijn, Karen L. Krijgsveld, Martin J. M. Poot & Sjoerd Dirksen, (2015) "Bird movements at rotor heights measured continuously with vertical radar at a Dutch offshore wind farm", Ibis, 157, 558–566.

Schwemmer P, Mendel B, Sonntag N, Dierschke V, Garthe S. (2011) "Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning" Ecol Appl; 21:1851e1860.

Sjollema AL, Gates JE, Hilderbrand RH, Sherwell J(2014)"Offshore activity of bats along the Mid-Atlantic Coast"Northeast Nat,21:154-163.

Snyder B, Kaise MJ. (2008) "Ecological and economic cost-benefit analysis of offshore wind energy". Renewable Energy; 34:1567e78.

Southall BL, Bowles AE, Ellison WT, Finneran JJ, Gentry RL, Greene CR, Kastak D, Ketten DK, Miller JH, Nachtigall PE, Richardson WJ, Thomas JA,Tyack PL(2007)"Marine Mammal Noise Exposure Criteria:Initial Scientific Recommendations"Aquatic Mammals 33(4), 412-522.

Sun X, Huang D, Wu G, (2012), "The current state of offshore wind energy technology development". Energy, 41:298–312.

Tabassum-Abbasi, M. Premalatha, Tasneem Abbasi n, S.A. Abbasi, (2014), "Wind energy: Increasing deployment, rising environmental concerns", Renewable and Sustainable Energy Reviews 31 270–288.

Thomsen F, Lüdemann K, Kafemann R, Piper W. (2006) "Effects of offshore wind farm noise on marine mammals and fish". Biola, Hamburg: Germany on behalf of COWRIE Ltd.

Tomasicchio GR, D'Alessandro F, Musci E, Fonseca N, Mavrakos Spyros A, Kirkegaard J, Katsaounis GM, Penchev V, Schüttrumpf H, Wolbring J, Armenio E, (2014) "Physical model experiments on floating off-shore wind turbines", Proceedings of the HYDRALAB IV.

Tougaard, J., Carstensen, J., Teilmann, J., Skiv, H., and Rasmussen, P. (2009b)." Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena phocoena (L.))". Journal of the Acoustical Society of America 126, 11–14. doi:10.1121/1.3132523.

Tricas T, Gill AB.(2011)"Effects of EMFs from undersea power cables on Elasmobranchs and other marine species".Camarillo:U.S.Dept.of the Interior,Bureau of Ocean Energy Manag.,Regulation Enforcement.

Vaissière Anne-Charlotte, Harold Levrel, Sylvain Pioch, Antoine Carlier, (2014) "Biodiversity offsets for offshore wind farm projects: The current situation in Europe", Marine Policy 48 172–183.

Vella G; Rushforth I; Mason E; Hough A; England R; Styles P; Holt T; Thorne P(2001)"Assessment Of The Effects Of Noise And Vibration From Offshore Wind Farms On Marine Wildlife".Report Centre for Marine and Coastal Studies Ltd, Environ Research&Consultancy, 51.

Vorpahl, F, Strobel, M, Jonkman, J.M., Larsen, T.J., Passon, P., Nichols, J. (2014) "Verification of aero-elastic offshore wind turbine design codes under IEA Wind Task XXIII Wind Energy Vol 17-4, 519-547.

Wahlberg M, Westerberg H. (2005) "Hearing in fish and their reactions to sounds from offshore wind farms" Mar Ecol Prog Ser, 288:295-309.

Wayman E, Sclavounos PD, Butterifeld S, Jonkman J, Musial W. (2006) "Coupled dynamic modeling of floating wind turbine systems". Offshore Technology Conference Houston, Texas.

Wever L,Krause G,Buck B.H.(2015)"Lessons from stakeholder dialogues on marine aquaculture in offshore wind farms:Perceived potentials, constraints and research gaps"Marine Policy Vol 51, pg.251-259.

Wilhelmsson D, Malm T, Ohman MC. (2006) "The influence of offshore windpower on demersal fish". ICES J Mar Sci; 63:775–84.

Wilson Jennifer C., Mike Elliott, Nick D. Cutts, Lucas Mander, Vera Mendão, Rafael Perez-Dominguez and Anna Phelps, (2010) "Review Coastal and Offshore Wind Energy Generation: Is It Environmentally Benign?" Energies, 3, 1383-1422; doi:10.3390/en3071383.