Environmental concerns related to the construction of offshore wind parks: Baltic Sea case

L. Rostin, G. Martin & K. Herkül
Estonian Marine Institute, University of Tartu, Estonia

Abstract

Wind energy is considered to be one of the most promising sources of renewable energy in the future. Planning and construction of offshore wind parks is very active in the Northern Europe and Baltic Sea area. Currently, numbers of large-scale projects are under development in the Baltic Sea area and, in most cases, the information on proper environmental impact assessment (EIA) of this activity is missing. There are a number of environmental concerns that are well documented from terrestrial environment (e.g. effects on bird migration) but the marine environment creates some additional possible impacts and threats. Some of them are already well studied, but many aspects remain unclear. The Baltic Sea, being a unique ecosystem, is considered to be vulnerable to many pressures which can be caused by large construction activities. These harmful effects can be destruction and modification of habitat characteristics during the construction phase, noise pollution during construction and low frequency vibration during operation, modification of migration routes, formation of artificial substrate and favourable conditions for alien species invasion etc. Besides harmful impacts, also some positive effects on local biodiversity are usually mentioned, such as the so-called “reef effect”.

In the current paper we analyse existing information on the known effects of the construction of offshore wind parks in the Baltic Sea area and illustrate the negative and positive effects of the construction activities on local biodiversity based on a study performed in the framework of EIA of offshore wind park development project in the north-eastern Baltic Sea (Neugrund bank, Gulf of Finland). Results are generalized for the whole Baltic Sea area and recommendations are drawn for EIA studies of future development projects.

Keywords: Baltic Sea, North Sea, offshore wind park, marine biota, marine ecosystem, reef effect, renewable energy.

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1 Introduction

Currently and in the nearest future wind energy is going to be one of the key renewable energy sources. This is important resource, exploitation of which is increasing fast because of the general concern about global warming and limited oil resources in the world [1]. It is proved to be a reliable, natural and renewable source of electrical power supply [1, 2]. This technology has potential to significantly reduce the emission of carbon dioxide and the use of fossil fuels and their negative impact on the environment. Emission of carbon dioxide takes place only during the construction, maintenance and decommissioning phases of operation of offshore wind parks while energy generation, at the operation phase, is carbon dioxide neutral [2].

Offshore marine environment, that is characterized by extensive resources of frees space and strong winds, provides an enormous supply of wind energy [1, 3]. Large area allows to install large wind parks and higher wind speed permits installation of more efficient wind turbines. Installing the wind farm far from shore enables different designs of wind turbines and ensures more effective use of wind [1].

In the Baltic Sea and North Sea, there are currently number of operating (as shown in table 1), under construction and planned offshore wind farms. The majority of wind farms in the North Sea belong to United Kingdom and Denmark. In the Baltic Sea the largest wind farm, Nysted II, is installed in Danish coastal waters. There are also a number of single and test wind turbines in the area [4].

In the near future, there are plans for much larger number of offshore wind park construction projects. Large-scale wind farms are currently advancing in the United Kingdom, Denmark, Germany and Estonian marine areas [4].

2 The Baltic Sea as a unique marine ecosystem

The Baltic Sea is a unique marine ecosystem featured by presence of large variety of environmental gradients. Among those, most remarkable are North–South and East–West salinity gradient, North–South climate related gradients of water temperature and ice conditions and East–West gradient of coastal habitats (changing from Scandinavian archipelago or skerry type coasts to exposed sandy beaches and limestone cliff coasts). All this contributes to several gradients in habitats and biodiversity as a whole. In addition to that there exist many different large-scale and local gradients in human impact by human introduced nutrient enrichment leading to eutrophication, pollution by toxic substances and oil products as well as mechanical disturbance by coastal defence and other construction.

On the whole Baltic Sea scale the biodiversity is most vulnerable in the central part – around the basin called Baltic Proper. According to checklist of macroscopic species published by HELCOM the lowest number of macroscopic species in the Baltic could be observed in basins around the central part (Baltic Proper, Gulf of Riga, Archipelago Sea) [5]. This corresponds to the sea area

Table 1: Operating offshore wind farms in the Baltic and North Seas [4].

Wind farm	Country	Operation time	Location	Turbines	Capacity, (MW)
Greater Gabbard	United Kingdom	2012	North Sea	140	504
Sheringham Shoal	United Kingdom	2012	North Sea	88	316.8
Baltic I	Germany	2011	Baltic Sea	21	48.3
Nysted II	Denmark	2010	Baltic Sea	90	207
Gunfleet Sands I + II	United Kingdom	2010	North Sea	48	172.8
Thanet	United Kingdom	2010	North Sea	100	300
Alpha Ventrus	Germany	2010	North Sea	6	60
Belwind Phase I	Belgium	2010	North Sea	55	165
Horns Rev II	Denmark	2009	North Sea	91	209
Lynn	United Kingdom	2009	North Sea	27	97.2
Inner Dawsing	United Kingdom	2009	North Sea	27	97.2
Thorontobank	Belgium	2009	North Sea	6	30
Sprogø	Denmark	2009	Baltic Sea	7	21
Princess Amalia	Netherlands	2008	North Sea	60	120
Egmond an Zee	Netherlands	2008	North Sea	36	108
Lillgrund	Sweden	2008	Baltic Sea	48	110
Kemi Ajos I + II	Finland	2008	Baltic Sea	10	30
Irene Worrink	Netherlands	2006	North Sea	28	16.8
Kentish Flats	United Kingdom	2005	North Sea	30	90
Scroby Sands	United Kingdom	2004	North Sea	30	60
Nysted I	Denmark	2003	Baltic Sea	72	165.6
Samsø	Denmark	2003	Baltic Sea	10	23
Rønland	Denmark	2003	North Sea	8	17.2
Horns Rev I	Denmark	2002	North Sea	80	160
Yttre Stengrund	Sweden	2001	Baltic Sea	5	10
Middlegrund	Denmark	2000	Baltic Sea	20	40
Utgrunden I	Sweden	2000	Baltic Sea	7	11
Bockstigen	Sweden	1998	Baltic Sea	5	2.75
Tuno Knob	Denmark	1995	Baltic Sea	10	5
Vincleby	Denmark	1991	Baltic Sea	11	4.95

where the salinity gradient is most unfavourable both for marine and brackish water species. At the same time this area is most favourable for development of wind parks having the best properties of wind climate. Analyses made on the data obtained from habitat modelling performed by EU funded BALANCE project show that the depth interval suitable for wind park development overlaps with most of the habitat diversity and existing nature conservation activities in the area. Almost 75% of existing nature conservation areas cover the sea depth of 20 m or less. Of 40 habitat classification units identified by BALANCE project 25 have their majority in the depth zone of 20 m or less. Same depth zone has 87% of all Baltic Sea photic zone. Table 2 shows quantitative characterization of distribution of benthic habitats and existing nature protection areas in relation to the depth zone potentially affected by offshore wind energy development.

Table 2: Distribution of benthic marine habitats (defined by EU BALANCE project as marine landscapes) and other features in the Baltic Sea area (excluding Kattegat).

Feature/habitat*	Total area	Depth 20 m or less, km^2	Depth 20 m or less, percent from total
111	176.4	162.1	91.9
112	2782.1	2507.8	90.1
113	167.2	157.7	94.3
114	1.8	1.8	99.7
121	104.0	61.7	59.4
122	4121.1	2053.8	49.8
123	940.7	84.4	9.0
124	2.3	2.2	97.9
211	4269.1	4054.9	95.0
212	6533.8	6312.6	96.6
213	1034.2	1015.7	98.2
214	524.0	484.7	92.5
221	10365.9	4532.3	43.7
222	25903.7	8235.4	31.8
223	5501.4	860.4	31.8
224	689.8	157.8	15.6
311	2265.0	2216.4	22.9
312	5449.0	5381.2	97.9
313	3295.7	3263.1	98.8
314	497.0	491.8	99.0
321	5880.7	2810.8	47.8
322	26585.5	7715.7	29.0
323	24237.5	7370.0	30.4
324	2809.9	1621.7	57.7
411	405.3	380.2	93.8
412	2612.3	2491.1	95.4
413	103.5	101.9	98.4
414	9.6	9.6	100.0
421	4798.1	695.5	14.5
422	47174.4	4851.0	10.3
423	30560.3	199.6	0.7
424	2906.2	93.71	3.2
511	1200.0	1153.5	96.1
512	4202.1	3873.3	92.2
513	452.9	447.3	98.7
514	36.4	23.0	63.1
521	14312.0	1999.2	14.0
522	47910.2	4860.2	10.1
523	58723.0	423.5	0.7
524	16088.0	117.2	0.7
Nature protection areas	36585.9	27111.1	74.1
Non-photic seafloor	306355.1	30291.2	9.9
Photic bottom seafloor	62944.2	54880.2	87.2

*Habitat names are coded according to the following key – in three digit code first digit represents bottom substrate: 1= bedrock, 2=hard bottom, 3=sand, 4=hard clay, 5=mud; second digit photic zone: 1=photic, 2=aphotic; third digit salinity: 1=0–5 psu, 2=5–7.5 psu, 3=7.5–11 psu, 4=11–18 psu, 5=18–30 psu, 6= <30 psu.

Habitat distribution data is based on marine landscape maps produced by EU funded project BALANCE, the data on protected areas of the Baltic Sea originates from the HELCOM map portal [6]. The light availability data used in the analysis has been produced within the EUSeaMap project. Map layer used was downloaded from HELCOM map portal [6].

The result of analysis indicate potential conflict and threat from interest of development of wind parks and location of nature values as large proportion of unique and rare habitats are located in the same area where the potential interest for development of wind parks would be located (depth zone less than 20 m [7]).

3 Environmental impact to the marine ecosystem

Offshore wind farms, while in operation, cover a large area of the sea and thereby include considerable part of marine habitat. Generally, the impacts of wind farms to the marine ecosystem have been estimated to be positive on a global scale but negative on a local scale [8]. Some impacts are specific to the offshore wind parks, but there are also a number of impacts that differ significantly between the construction and operational phases (fig. 1).

One of the largest impacts on the marine environment originating from offshore wind parks so far documented is the so called "reef effect" [10],

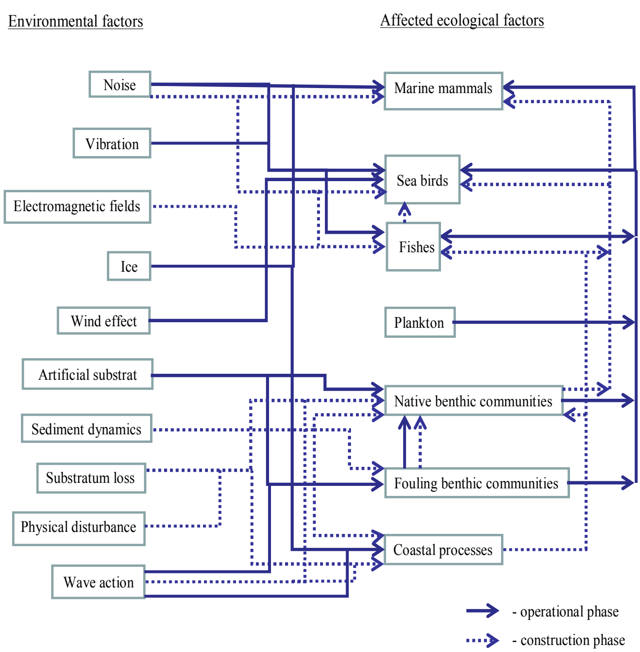

Figure 1: Diagram illustrating possible impact of different stressors related to the operation and construction of offshore wind park to different components of marine ecosystem [9].

primarily caused by solid manmade structures founded on the seafloor [2, 11]. Offshore wind park turbines are functioning as artificial reefs, affecting local ecosystem [12]. Artificial structures may favour the settlement, reproduction, growth and change in biomass of native and fouling benthic species, which could influence the small and large scale processes in coastal and offshore systems [12].

Blue mussels (*Mytilus trossulus*) and barnacles (*Amphibalanus improvisus*) dominate hard bottom and also possible artificial substrate [9, 11–14] in the most part of the Baltic Sea. Both species are superior competitors in benthic communities due to a massive recruitment and rapid growth [11, 15, 16]. Introduction of hard substrate by construction of wind parks enables the colonisation of the aforementioned species which may significantly change the local dynamics of ecosystem. The phenomenon of artificial reefs is favourable for marine birds by improving feeding conditions and for fishes by providing better feeding conditions and shelter against predators [8, 9, 17, 18]. Artificial reefs can potentially be beneficial also for marine mammals [19]. Monopile as an effect of artificial reef attract species that would not have been wind park areas before [20].

It has been shown that among primary producers the artificial structures in the Baltic Sea are dominated by annual filamentous green algae in the sections close to sea surface [21]. The remaining part of the wind turbine is usually dominated by brown and red algae (*Pilayella/Ectocarpus*, some species of *Ceramium* family) [21, 22]. They have adaption of poor light conditions in the cold and nutrient rich water [23]. So far relatively few macroalgal species have been identified to inhabit wind park installations, mainly because of poor light conditions [17]. It has been also noted that occurrence of green algae is rare in those habitats [22].

Occurrence of reef effect in connection with installation of new hard substrate has high importance for the soft bottom communities. The construction of wind parks adds hard substrate on soft bottom and it changes completely existing seabed habitats. Native benthic communities are partly or completely replaced by fouling benthic communities associated with hard bottom structures [9].

Study on possible effect of disturbance on hard bottom habitat by construction of gravitational foundations of offshore wind park was carried out in the Neugrund Bank, NE Baltic Sea. It was concluded that in certain depth intervals the amount of disturbed seafloor causes significant, long term changes in benthic communities. In shallower depths the disturbed communities recovered within one vegetation season while in deeper and intermediate depths the effect of disturbance was observed over several vegetation periods causing change in community structure and also favouring occurrence of new species previously not recorded in the native communities.

Physical disturbance, like installation of turbine and cable, affects sediment dynamics, causes removal of sediments (substratum loss) [17, 21–24], and influences currents and waves [18, 21]. These changes affect benthic communities, fishes, sea birds and marine mammals [18, 24, 26]. Habitat loss and change in hydrodynamic regime depends on the diameter, size and shape of turbine and the foundation type [17, 22]. Higher turbine capacity requires larger monopiles [22], that consequently cause more extensive loss of substrate and changes in the water currents.

Installation of cables could cause electromagnetic fields and heat emissions, which influence marine organisms [22], especially fish. It may influence the behaviour and migration of the fish fauna [17, 22, 27], because they use the Earth's magnetic fields for navigation. The cable could act as a barrier to the migration of fish [17, 27] and also have scaring effect [27]. Heat emission can change physicochemical conditions of sedimentary substrates leading to positive impact on reproduction of certain species, especially those adapted to warmer water [22]. Currently there are no studies reporting impacts of electric or magnetic fields on marine invertebrates [22].

Underwater noise and vibration have not been reported to affect marine invertebrates and attached fauna [22], but noise and vibration may have effects on fish and marine mammals. Pile driving and servicing vessels activities are the main problems in the wind park areas [28, 29]. Shallow areas are important calving and nursing areas for harbour porpoises and they are reported to partly or completely avoid the wind park areas [19, 21, 27–29]. Turbine installation and servicing boats make loud noise that may cause injuries and deafness [8, 19, 27, 28]. It has been observed that seals have returned to the construction sites after construction was completed.

Some offshore areas are rich in large bird species and these areas are breeding, roosting and feeding habitats. Offshore wind parks influence marine birds in several ways. Risk of collision is related to species, abundance and behaviour of birds and number of wind turbines [30]. Collision risk is higher at sea than on land, because turbines are taller and rotor blades are longer [31, 32]. Most collisions take place at night, especially on moonless night or in unfavourable weather condition like fog and rain [32]. Offshore wind farms are considered to be artificial barriers on migration routes [30, 32]. During the construction phase, short-term loss of breeding, feeding and roosting habitats may appear [31, 32].

Offshore wind parks increase collision risk for bats and also cause destruction of habitats, commuting corridors, roosts and feeding areas [33]. Bats forage over the sea in areas with an abundance of insects in the air and crustaceans in the surface water [34]. Installation of wind turbines will probably have negative impacts on bat populations.

In general it could be concluded that offshore wind farm has a potential to be a new habitat for marine biota and causes significant changes in the environment and habitat quality in closest vicinity and possibly a cumulative effect over large areas.

4 Conclusions

The Baltic Sea has a number of unique features and properties that should be taken into account while planning and executing large-scale technical installation projects including erection of offshore wind energy parks. Effects on the ecosystem can differ in the different parts of the Sea depending on several local features and large scale gradients. While most of the environmental effects could be treated as reversible and insignificant, low species diversity, specific physical features, such as ice conditions and extremely low water transparency, should be treated as additional risk factors having magnification effect for any possible impact. Addition of hard substrate to the soft bottom environment, so called "reef effect", has potentially very significant impact to local benthic habitat quality. Similar effect can be expected also for disturbance of hard substrate – speed of recovery and degree of impact can differ in different parts of the Baltic Sea area and should be carefully considered in each separate case.

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