

Retrospective and Outlook for an Environmentally Sound Development of Offshore Wind Energy

DR. JENS LÜDEKE
Beuth University of Applied Science
Luxemburger Str. 10, 13353 Berlin
GERMANY
Jens.luedeke@beuth-hochschule.de

Abstract: - This article shows the state of knowledge regarding ecological impacts of offshore wind farms. It developed proposals for reforms and incorporated international developments into the research. These proposals are derived from the experiences of the first OWF projects in Germany and their obstacles in the approval procedures. Therefore consistent and international standards for environmental impact assessments, a focus on specific subjects of protection (i.e. some birds or harbor porpoises) are proposed. Further recommendations include applying research findings to spatial planning and technical mitigation measures and regulating resting impacts with marine compensation measures.

Key-Words: - Wind Energy at Sea, Marine Spatial Planning, Marine Environmental Impacts, Marine Mitigation Measures, Marine Compensation Measures

1 Retrospective on the State of Knowledge on Environmental Impacts and Environmental Planning of Offshore Wind Energy

In this article proposals for environmentally friendly development of offshore wind energy are made, as demanded in the federal offshore strategy of the year 2002. The German energy transition aims to fundamentally restructure the energy supply. Offshore wind will play an important role. The 2013 plans drawn up by the Federal Government envisage 6,500 MW of offshore wind energy by 2020 and 15,000 MW by 2030. The approval procedure as well as the environmental assessment and ecological accompanying research in Germany are carried out in accordance with the Offshore Installation Ordinance (SeeAnIV). The Federal Maritime and Hydrographic Agency (BSH) authorized 33 OWFs in the German Exclusive Economic Zone (EEZ) - 30 in the North Sea and three in the Baltic Sea. In 2017, about 20 OWFs are online (see Fig. 1). The installed offshore capacity in 2018 is more than 5,000 MW.

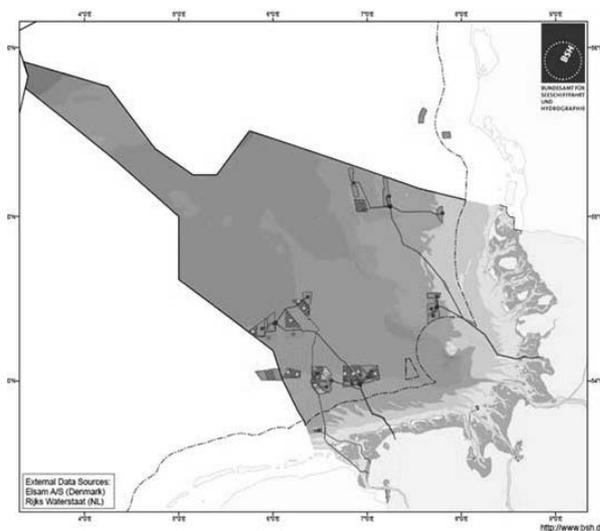


Fig. 1. In use and planned offshore wind farms in German North Sea [0]

The methodology of the investigation mainly based on a literature search and a review of ongoing research and monitoring, the methodology drew on a case study analysis of already approved offshore wind farms, an international comparison of research results and expert interviews.

The investigation made tried to answer six main research questions and the working hypothesis. The working hypothesis was that the application of spatial planning instruments, the use of technical avoidance measures, and the compensation for unavoidable impacts would enable an environmentally sound development of offshore wind energy in Germany, as it has already been required for the development of offshore wind

energy by the Federal government in 2002 [1]. The individual research questions are dealt with both retrospectively and in outlook. In summary, proposals for the reform of good practice in the development of offshore wind farms (OWFs) are presented.

Research Topics:

- (1) State of knowledge on environmental impacts of the development of offshore wind energy
- (2) Status of environmental planning and assessment of the development of offshore wind energy
- (3) Status of environmental planning and assessment of the grid connection for offshore wind energy
- (4) State of knowledge on technical avoidance measures for the relevant environmental impacts of offshore wind energy (especially against underwater noise)
- (5) Compensation measures for the relevant environmental impacts of offshore wind energy
- (6) Possible future environmental strategies for an environmentally sound development of offshore wind energy

1.1 State of Knowledge on the Environmental Impact of Offshore Wind Energy Development

According to the 2002 Federal Government strategy on the use of wind energy at sea [1], the development of offshore wind energy should take place in a way that is compatible with nature and the environment. OWFs cause especially visual and auditory impairments or impacts, temporary or permanent loss of habitats during the construction phase. In the operating phase, visual and auditory impacts, shadows cast by the rotor blades, vibrations, electric and magnetic fields, the sealing of the seabed, the changes in sediment distribution and dynamics, changes in existing ocean current conditions, collisions with wind turbines (bird strikes), barrier effects for fauna (e.g. barrier effects on birds' migratory flight to the south and back, or fragmentation of the connections between different resting and feeding areas), displacement effect (resulting e.g. in birds' long-term loss of resting and feeding areas), as well as disturbances by maintenance measures and emission of pollutants, are referred to as negative effects of OWFs. In addition, there may also be further impacts in the decommissioning phase [2].

A summary of the relevant effects of OWFs on benthos, fish, resting and migratory birds and mammals is presented on the basis of data published over the last ten years was published in 2015 [3].

The results collected in Germany were generated mainly within the framework of the StUKplus project funded by the Federal Ministry of Environment at the Alpha Ventus wind farm [4]. Data was also generated by the environmental impact assessments (EIAs) of the first OWFs actually built in Germany. The effects observed at Alpha Ventus were subsequently validated by means of a literature review on Google Scholar and Science Direct, in particular by comparison with international studies.

Only parts of the environmental impacts on the EIAs' subjects of protection appear to be relevant for the decision making in the approval process. Based on the data from the StUKplus project and from the monitoring data of the OWFs in Germany, which were examined according to the standards for environmental investigation (StUK) [2] and validated by comparison with international research, it was estimated that the negative effects of OWFs, at least for benthos and fish, are less relevant. With benthos and fish, the biodiversity of species found on hard substrate even increases after construction. But an increase in biodiversity is not necessary good in conservation terms, as the ideal (especially according to the nature protection law) is to maintain the biodiversity of each site. Special attention should therefore be paid to non-indigenous species which introduction can be facilitated by these infrastructures used as stepping-stones. Changes in species composition already have been detected. Submarine cables do not seem to have any effects on fish [5] and the turbines serve as artificial reefs ([3], [6]). The effect of the fishing ban seems to be positive for the biodiversity of fish and benthos after several years [7]. But it has also to be stated that the potential for impacts on fish in the longer term is still largely unknown and in terms of biodiversity maintenance, thus an increase is not an unreserved positive outcome. On the other hand, found that the benthos was dominated by a few species after a few years, and also invasive species were found [8]. The scientific and published studies on the effects of OWFs on benthos summarize, that in particular, the hypothesis that the number of species of benthos and fish is increased by the construction of OWFs (albeit partially by species that did not previously occur in, for example, sandy areas) was confirmed. But the positive effects of the ban of the fishery inside the OWFs on the other side have socio-economically negative impacts for the fishermen communities.

Significant effects on migratory birds, especially on their population level, have not yet been proved. Migratory birds show clear macro-, meso- and

micro-avoidance behavior in relation to OWFs, especially during the day, and thus rarely reach the danger zone of rotating rotors at least [9]. However, collision studies in the offshore sector - especially at night and in bad weather conditions - have been difficult to achieve for technical reasons. In the process, at least during the day, it was possible to substantiate the thesis of a species-specific evasion above the original forecasts and thus a reduced risk of collision by migratory birds [10]. But the impact on migratory birds is one area where there is still a lot of uncertainty. And there is some evidence that lighting may make species which migrate at night particularly vulnerable to collisions [11]. Another author describes the spatial scales at which avoidance behavior may take place, but it does not present detailed information about the proportion of birds reaching the rotor [9]. One challenge for OWFs is that it is far from clear what proportion of migrants do or do not avoid wind farms especially in night times.

For harbor porpoises, it can be shown that they can be affected by impact noise during construction, especially when no sound-reducing measures are applied. Due to the measured sound pressure and the knowledge about the porpoises' biology, it is beyond question that pile-driving of OWFs can, in the immediate vicinity of the OWFs, have a negative impact on harbor porpoises, e.g. due to injury to the animals by permanent threshold changes (so-called PTS) [12]. For this reason, technical mitigation measures have been seen as a requirement for approval, mainly in Germany [13] but more recently also in other countries. The need for mitigation measures for harbor porpoises e.g. in the UK has been widely discussed since before 2012. Injuries or potential disturbances due to the displacement effect on harbor porpoises, which can have an impact on their population, can thereby be avoided as much as possible. A comprehensive study published on behalf of the Offshore Wind Energy Forum in 2016, which examined over several years all OWFs installed in the German North Sea (over 400 foundations) for their effects on harbor porpoises, found that the population of harbor porpoises in the German North Sea remained constant and even increased in some areas [12]. No impact on harbor porpoises due to the operating noise of the OWFs has been demonstrated in the numerous studies conducted in recent years. Essentially, it was possible to verify the thesis that porpoises leave (temporarily) the danger area around the pile-driving in order to avoid injuries. Upon completion of the pile-driving, no reduction in the abundance of porpoises was detected [12]. But no sign of a

reduction in the number of harbor porpoises in the North Sea does not necessarily mean that there is no effect e.g. on their distribution.

The effects of OWFs on bats have also been increasingly included in EIAs. Bats are primarily land animals. There are only a few species that forage offshore or migrate across the sea. In 2009 first migratory behavior of bats up to 14 km offshore was described [14]. It has been reported that these not only migrate but also forage over the sea. Most bats migrate less than 10 meters above the surface of the water [14], which is below the rotor-swept area. But bats partly fly around the turbines because of an accumulation of insects even at higher altitudes. The presence of bats more than 40 km off the coast and at relatively high altitudes, more than 100 m and even more than 200 m above sea level were also reported [15]. Migration also took place in daylight. Bat activity reached its peak in September during strong tailwinds [15]. Other authors reported that bats have been recorded with a mean distance of about 8 km to 22 km off the coast [16]. In two Dutch OWFs, bats were detected in autumn nights and at low wind speeds [17]. Next it was concluded that the risk of collision during offshore migration is likely to be low. During foraging, the risk to the bats increases especially near the coast and under weather conditions that attract insects [14]. In contrast to this conclusion, it was estimated that OWFs could cause similar collision rates to those seen on onshore wind farms [16]. Since 2014, bats have been included in the Environmental Impact Assessment [2] in the German Baltic Sea [18].

In addition to these results, it was also confirmed a large number of the German findings on the impacts of OWFs in their international review [6]. After up to two decades of work done on the impacts on Offshore Wind Farms in the UK, Denmark, the Netherlands and Belgium, the international research results also have to be taken into account. But for a comprehensive and generalized evaluation of the effects of offshore wind energy, it must be acknowledged that the current state of knowledge in Germany was generated mainly from data in the first years of operation of a single OWF with only twelve turbines. What is therefore largely lacking are trusted insights into the cumulative effects and, closely linked, the long-term effects of offshore wind energy. There is still a wide field here for internationally networked research.

1.2 Status of environmental planning and environmental assessment in the development of offshore wind energy

In 2010 it was shown to what extent future spatial planning and its Strategic Environmental Assessment (SEA) and effective nature conservation in the EEZ must ensure that important breeding and resting areas of species (in particular for resting birds such as loons, (*Gavia stellata* and *Gavia arctica*) or for harbor porpoises (*Phocoena phocoena*) have to be kept free from disturbance [19]. This requirement has already been implemented in Germany, with the definition of a main rest area for the loon or a main concentration area for harbor porpoises [20, 21]. This is intended to protect the habitats of particularly endangered fauna and important migratory bird corridors, even outside protected areas, from uses that may affect these habitats or their functions. This could also be done in the framework of spatial planning in the EEZ, for example by designation as a priority area for nature conservation or at least as a reserve area. The delimitation of main concentration areas for certain animal species as exclusion areas for offshore wind power for future spatial planning is therefore consistent with an environmentally sustainable development. When unacceptable impacts on the natural environment cannot be avoided, these have to be compensated for (see also § 56 BNatSchG). For example, fishing exclusion zones (e.g. in Natura2000 areas) could be declared, which would also have to compensate, for example, for impacts on resting birds. On the other hand, in such exclusion zones, of course, fishing grounds are also lost. These socio-economic aspects must not be forgotten in such proposals. A financial compensation of fishermen therefore has to be discussed.

The environmental impacts of OWFs have been widely explored. However, this knowledge has not yet been satisfactorily applied in practice during environmental assessment and approval procedures. An important step would be the use of harmonized forecasting models and thresholds. Above all, however, an effective location of OWF using marine spatial planning (and the associated exclusion of OWFs outside such priority areas) would create a necessary precondition for the environmentally sound management of offshore wind energy.

The environmental impact assessment of OWFs has evolved since the first OWF in Germany, Alpha Ventus, was built in 2005. In addition to RAVE (Research at Alpha Ventus) investigations, extensive environmental impact assessment studies

based on the standard investigative concept for the 33 OWFs now approved have achieved significant advances in knowledge. The development of technology has also progressed. Today, a large number of efficient noise mitigation techniques and monitoring methods are offered, digital recordings of resting birds and marine mammals are taking place, and new radar equipment is being used to determine bird migration. These developments were reflected in the revisions of the standard examination concept (StUK1 2001, StUK2 2003, StUK3 2007, StUK4 2013). The most recent revision (StUK4) included in particular requirements for underwater sound measurements, the digital recording of resting birds, the standardization of examinations in connection with the use of databases for the collection of results, an investigative concept for the benthos in submarine cable projects, the use of fish echoes, the detection of bats (in the Baltic Sea) as well as a standard for the investigation of landscape scenery have been newly established. Furthermore, if the period between the end of the basic investigation and the start of construction is more than 5 years, new environmental investigations have to be carried out. The opportunity for joint environmental investigations of several OWFs in clusters is granted. Some of the amendments made to the environmental assessment already have been implemented in the new StUK4 [2]. Other aspects, such as the lack of stringency in spatial planning (excluding OWFs outside priority areas), still need reform from an environmental perspective.

1.3 Status of environmental planning and environmental assessment in the development of offshore wind energy

In 2012 it was faulted, that the comprehensive analysis of the environmental status of the relevant species and habitats in connection with the German offshore net plan (ONP), which is used for the electrical connection of the OFWs to the shore, is rated generally as positive in the Strategic Environmental Impact Assessment (SEA) of the ONP [22]. A main criticism of the environmental report on the ONP is the lack of consideration of the alternatives (at least in the first environmental report from 2012) and the related legal uncertainty regarding the underlying SEA Directive. One of the main tasks of a SEA can therefore be assessed as not fulfilled. The lack of consideration of alternatives is the result of a previous erroneous procedure [22]. It would make sense to have the offshore grid connection already taken into account when drawing

up the spatial planning plans for the EEZ. At that time, for example, in the definition of priority areas for offshore wind energy generation, a strategic discussion of the alternatives of the accompanying cable connection could have taken place. The previous rather uncoordinated approach without overall planning has led to uncertainty and delays. For example, in the coordination of offshore wind energy with the necessary grid connection continues to be an unresolved problem that originally arose during spatial planning [19]. Furthermore, it would be useful, and requested by the EIA Directive, to investigate the cumulative effects of all network planning together with the planning of OWFs and other offshore activities, such as extraction of raw materials, military uses or shipping. It would also make sense to include the relevant plans of neighboring states. Determining the cumulative impact would be particularly difficult in Germany, because of the widely differing valuation approaches in neighboring countries, but also in the twelve nautical mile zone. The development of cumulative impact methods, models and limits is now in progress [23]. Finally, the ONP also lacks satisfactory assessment procedures: While data collection from offshore is very extensive, there is a lack of using them in the decision making. The topic of § 30 biotopes in the sea, which are protected according to the Federal Nature Conservation Act (BNatSchG), as well as the possibilities for compensation offshore are still unresolved in connection with the grid. Up to 2018 13 network connections for OWFs in the North Sea have been approved, the cable routes and the locations of converter platforms are shown in the figure below (Fig.2).

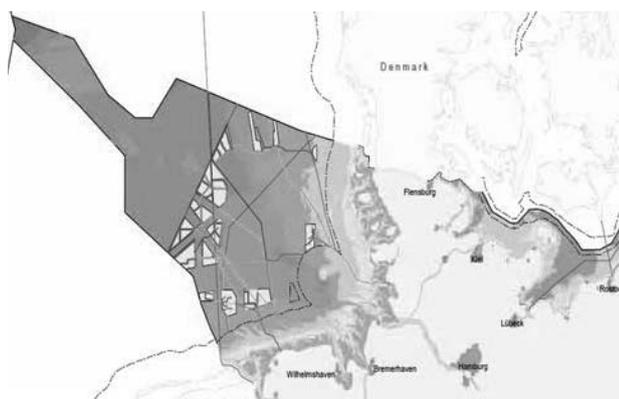


Fig. 2 *Offshore Grid Plan* [24]

In the meantime licensing of submarine cables has been developed further on. Nowadays, grid connection has been included in the standard

investigative concept StUK 4 [2] Monitoring standards for the monitoring of benthos, biotope types and biotope structure for the laying of submarine cables have been included [2]. Environmental requirements are regularly made for the construction of converters and submarine cables: For converters, similar to OWFs themselves, the sound threshold during pile-driving, for example, is regulated. The compensation according to § 15 Abs. 2 BNatSchG for the platform SylWin, for example, was the demolition of 105 km of submarine cables [62].

In the past, permits in the territorial sea were issued by the federal and state authorities with their own application procedures; now, only the Federal Network Agency (BNetzA) plans and approves the grid connections in the territorial sea and in the EEZ. The transmission system operators are obliged to draw up an offshore network development plan (ONEP). For this purpose, a SEA with participation options in accordance with the EIA Directive is carried out. The previously uncoordinated individual planning of wind farms and grid connections, with their partly unrelated environmental and nature conservation standards, was replaced by a standardization of the planning principles for grid connection. However, a major criticism of ONP has remained: Due to the temporal parallelism of the procedures of SEA and ONP, a real site alternative assessment in the sense of environmental precaution according to the EIA Directive cannot fully take place [22].

2 Outlook for the Environmentally Sound Development of Offshore Wind Energy

In order to enable a more environmentally friendly development of offshore wind energy beyond the status quo, in accordance with the objectives of the Federal Government, proposals for reforming current practice in Germany are presented and discussed in this chapter. Proposals for good practice in planning, mitigation, EIA and compensation for OWF impacts are made. The BNatSchG requires, where adverse effects on the natural environment occur, that these effects must be avoided above all (§ 14ff BNatSchG). If this is not possible, they are to be reduced or minimized, and only where this is not possible can they be compensated for as the last resort. Only if genuine compensation is not possible can a substitute payment be granted. This intervention model has so

SEA. This first spatial plan identified suitable areas for offshore wind energy. However, the offshore plans are not as stringent as the onshore plans because they do not exclude areas from development. However, in addition to effective strategic environmental assessment, this is imperative for effective OWF management [27, 28, 29].

In 2011, the BSH was commissioned to develop an offshore network plan (ONP), based on a change in the German Energy Industry Act, and to update it regularly. This should be closely linked with maritime spatial planning. Its aim is to achieve the coordinated and coherent spatial planning of network infrastructure, in particular for OWFs in the German EEZ [30]. Future spatial planning should represent alternative locations and cumulative effects of OWFs [22].

The plan recommended that strict measures be taken to minimize the impact of OWFs (e.g. noise control and eco-friendly lighting). The SEA for the ONP was carried out by the BSH and showed that no significant impact on the marine environment is to be expected. It should be borne in mind that this assessment had to be based on inadequate models that have since been developed further and need to be further developed in the future. In addition, the SEA for spatial planning and grid connection showed that no significant negative effects on species protected by legislation due to converter platforms and underwater cable trays are to be expected [22, 30]. However, the impact on strictly protected habitats and species, especially with regard to the potential cumulative impact of bird migration, could not be adequately assessed due to the lack of scientific evidence and standard assessment procedures. As a result, strategic environmental assessments have to be further developed regularly in network plans [22, 30].

Monitoring measures (primarily the monitoring of individual OWFs) form another pillar of the SEA. In addition, monitoring provided by the SEA serves to close knowledge gaps and verify uncertain forecasts. The monitoring results are taken into account when updating the plan. The SEA, however, reached its limits in terms of maritime spatial planning and grid connection, as the cumulative effects of the large number of OWFs could not be assessed stringently, because the prognoses for these effects are still unknown. Possible basic location or technical alternatives have not yet been investigated in the previous SEAs [22].

With regard to the main results of German ecological research in the offshore area, future spatial planning and network planning should focus

on the relevant impacts of OWFs: loss of habitat of seabirds by the presence of turbines and loss of habitat of harbor porpoises due to construction noise and the potential collision risk of migratory birds, if scientifically proven. Future OWFs should therefore be planned outside of major habitats of seabirds (e.g. loons) in order to avoid habitat losses above the relevant thresholds [22]. Furthermore, for precautionary reasons, corridors between the habitats of seabirds should be left free from wind farms so that birds can safely switch between sites. Because of the limited empirical data, research on this topic will have to continue in the future. In spatial planning, corridors should be kept clear between the wind farms [31].

The most important migratory bird routes should also be included in spatial planning and aligned with the objectives of offshore wind energy. However, it seems that there is a broad front line of bird movements over the North Sea. On the other hand, there is a particularly outstanding migration area between "Fehmarn - Lolland" and "Rügen - Schonen", which could have a special significance in nature conservation (see Fig. 4). The latter, in particular, is considered to be one of the most important main migratory routes of cranes and numerous species of songbirds in Europe. Unless already designated as an FFH or bird sanctuary, future spatial planning should take account of such important areas of bird migration in the future when selecting priority areas for offshore wind energy. For the assessment of the sensitivity of marine areas, basic data such as the contribution to nature conservation planning by the Federal Agency for Nature Conservation could be incorporated, which, however, now requires a comprehensive overhaul after more than 10 years [31]. Findings could also result from the ongoing research project BIRDMOVE of the Research and Technology Center West Coast Kiel.



Fig.4. Areas of particular importance for bird migration (Baltic Sea) [31]

For the loons, it was decided in Germany to exclude future OWFs from their particularly important main area of occupation [21].

In addition, the BMU created the "concept against underwater noise" [20], which aims to keep high-density porpoise habitats free of more OWFs in the future. The highest population of harbor porpoises in Germany was found in the early summer months west of the Sylt outcrop [32].

Due to the soundproofing concept, this area enjoys special protection status and further planning (especially for the sensitive times of the year) is particularly important. Future spatial planning should therefore take into account factors such as the importance of an area for harbor porpoises (e.g. their main concentration zones and sensitive breeding areas) [20].

In summary, the impact of OWFs on marine life can be avoided or at least minimized through careful site selection and through the temporal and spatial coordination of the construction of OWFs.

2.3 Reduction: Technical Avoidance Strategies for the Relevant Environmental Impacts of Offshore Wind Energy

The habitat loss for resting birds and the collision risk for migratory birds and the risk of damage to the hearing of marine mammals were described as particularly relevant [33]. Technical measures can be used to reduce the risk of collision and to prevent damage to the harbor porpoise.

2.3.1 Reduction of collision risk

To reduce the risk of collision of migratory birds, fewer luminaires or lower light intensities or other types of light are suitable [11]. In order to protect migratory birds when planning OWFs, it is

advisable to provide lighting for offshore wind turbines only when needed (when ships or aircraft approach). In nights during mass migrations, where in addition weather and visibility are bad, the licensing authority reserves the right to temporarily shut down the facilities. However, an "early warning system" for shutting down the turbines in these nights does not yet exist. Further research on collision risk and lighting is needed [11]. However, it seems that deactivating the lamps could be a more effective collision mitigation measure than deactivating the turbines. But it has to be taken into account, that the turning off of the turbine lights as a mitigation option still is a difficult matter, as these lights are a legal requirement due to international aviation regulations. In addition, there is a continuing discussion as to whether turning off the wind turbines really reduces the risk of collision, as there are indications that the birds seem to have a higher evasion response with moving rotors [11]. But there is yet no clear evidence that stationary blades pose a higher collision risk to birds than moving blades.

2.3.2 Reduction of underwater noise by pile-driving

Most offshore wind turbines have so far been anchored into the ground by pile driving, which causes severe underwater noise that can damage marine mammals and especially porpoises. To keep porpoises out of the danger zone, pingers or seal-scarers are used. These work well and displace the porpoises from the potential hazard zone. In addition to the defined limit of 160 dB (re 1 Pa²s) at a distance of 750 meters from the pile, approval notices in Germany generally require the use of the state of the art in the construction of OWFs. Noise reduction techniques, such as bubble curtains, are a sound-absorbing obstacle around the ram. The detailed description of the individual sound reduction techniques can be found in Table 1, it shows that they all reach to reduce the injuring noise from the pile-driving.

The best way to completely avoid damaging noise in offshore ramming is to find an alternative method for anchoring offshore wind parks. In the case of the gravitational foundations and the floating devices, after a number of attempts, one is now well on the way to developing a relevant level of technology.

Table 1. Technical measures to avoid underwater noise due to offshore ramming [34, 35]

Reduction technique	Noise reduction Δ SEL [dB]
Big Bubble-Curtain (BBC): Ring of perforated pipes positioned on the sea floor around the foundation to be piled.	Single 10 - 15 Double 14 - 18
Small Bubble-Curtain (SBC): Not positioned at the sea floor, but surround the pile in a close fit.	Up to 14
Casings/Pile Sleeve: Use of various combinations of different materials, like water, steel, air.	Up to 15
Hydro Sound Damper (HSD): Small gas filled elastic balloons and robust PE-foam elements fixed to nets or frames are placed around the pile	Up to 13
Cofferdam: Rigid steel tubes surrounding the pile from seabed to surface, the interspace between pile and cofferdam is completely dewatered.	Up to 20

Next to the above mentioned reduction techniques, also alternative foundation methods, which do not emit harmful noise at all, also nearly have reached the state of technique, as there are: offshore foundation drilling, gravity foundation, suction bucket or floating devices [26].

2.4 Application Process: Reform of the Environmental Impact Assessment

In addition to measures to prevent and compensate for impacts, the expert survey made also identified the possibilities for improving environmental planning and testing as important [33]. In addition to concentrating on the decision-relevant impacts, especially on porpoises and birds, the establishment of threshold values (such as the 160dB value for porpoise sound attenuation) is required.

Furthermore, a reform of spatial planning is considered important.

2.4.1 Focusing the EIA on the Relevant Impacts in a Standardized Form

About 80% of the 25 experts support the proposal, that standards for EIAs are important [33]. The interviewed experts were representative from the different sectors of offshore research (industry, regulator, NGOs). Particularly in the early years of offshore wind energy development, offshore companies often complained that EIAs were taking excessive time and money or lacked clear standards, which could be an obstacle to achieving the objectives of offshore wind energy. Various approaches to the EIA of OWFs have been discussed in the literature. In a project by the TU Berlin [36], it is proposed to apply semi-quantitative assessment models for the decision-relevant topics in the EIA (e.g. for the displacement of resting birds and harbor porpoises). Other authors propose a number of parameters that should cover an EIA and address environmental stressors (e.g. acoustic emissions), receptors (e.g. marine mammals), effects (e.g. multiple or short-term), impairments (e.g. biotic process of displacement) and cumulative effects (e.g. spatial, temporal and other consequential effects of human activities) [37]. In 2010 the inconvenient fact was stated that causal relationships between wind farms and impacts on populations are still largely unknown [38], so that the essential foundations for a relevant judgment are missing. It was also tried to develop a potential biological removal model that reflects the correlation between habitat displacement and mortality [39]. For the assessment of whether the impacts are relevant, the absolute number of displaced animals is always an important parameter. For this prognosis, in addition to the affected area (from which the animals are displaced), the abundance of the individual species and the sensitivity to OWFs must be included in the calculation. For the numerical calculation of the effect of displacement, it is possible to proceed in such a way that only an identification of the area of disturbance around the OWF (A), measured on the structural properties of the wind farm (e.g. lighting, intensity of the maintenance traffic, turbine type or piling method) is carried out. Subsequently, the species density must be examined under different weather conditions in different seasons (D). Finally, the species-specific recommendation (SI) should be included. The impact prediction and assessment of the number of potentially displaced animals can

then be calculated by multiplying the above factors ($A \times D \times SI$) [36]. The importance of habitat loss for the population must be assessed on the one hand in terms of the value of the previous habitat and, on the other hand, in terms of alternative habitats. If no alternative habitats are available, total loss of the animals (complete displacement) is possible. To assess the population size reduction, an avoidance capacity factor can be included in the calculation model. Specific indexes of indication (SSIs) already exist in large numbers [40, 41, 42, 43 or 44]. The above-mentioned conceptual model should be able to assess and standardize the environmental impact of OWFs in an objective and comparable way [36]. In order to facilitate the cumulative effects of OWFs from other countries, these methods should also be made internationally comparable. However, it remains unclear to what extent a displacement of animals could also have an impact on their population development (disturbance in terms of species protection law). The model of Busch and Garthe is a first attempt to set a threshold above which any additional mortality will be unsustainable. It relates different levels of mortality arising as a result of displacement to this threshold [39]. However, a comprehensible and clear statistical correlation between e.g. displacement and mortality has yet to be demonstrated. Nevertheless, a forecast of the displacement effect for the environmental assessment of the impact of OWFs should certainly remain a very important factor in the licensing process.

2.4.2 Thresholds for the relevant impact in the approval process

The data obtained by the standardized models should be used for comparison with (mostly politically) predetermined objectives and limits. Whether the impact of a new OWF can be tolerated or rated as "endangering the marine environment" is a difficult question. The decision depends on the one hand on the conservation status and on the other hand on the appreciation of the species (e.g. with regard to the EU Habitat Directive). The higher the societal value of the affected subpopulation and the more endangered the population, the smaller the tolerance of significant negative changes.

To help with the approval decision, first of all the most important relevant effects of the OWF limit values should be presented (effects on resting and migratory birds and effects of construction noise on mammals [3]). In Germany, frontier or precautionary values have already been developed. Because scientific evidence for population-altering

disturbances or values for a significantly higher probability of killing is not yet available, these thresholds have so far been developed politically according to the state of knowledge following the precautionary principle.

In summary, regulatory authorities require transparent and comparable decision-making models which are consistently focused on the relevant effects and based on a systematic analysis of the research results from the EIAs of the first OWFs. Next, the introduction of thresholds for their impacts is required. As long as scientific evidence is lacking, uniform thresholds will have to be predominantly politically determined. So far, this could not be achieved using the different approaches of EIA and EIS and lacks thresholds, especially between the different countries. The methods differ significantly [37, 38] but the standard investigation concept in Germany [2] is an important step towards a standardized model, at least with regard to the monitoring requirements. However, it would still require an international equivalent to the StUK4 model.

2.5 Compensation Measures for Relevant Ecological Impacts of Offshore Wind Energy

Possible approaches to "marine compensation" were examined in 2014 [25]. It shows that marine mitigation measures are a prerequisite for environmentally sound offshore development of renewable energy.

2.5.1 The Need for Marine Compensation Measures

Even if all the strategies and measures for avoidance and reduction mentioned above are used, there is nevertheless the risk of a lasting impact, in particular of the relevant protected birds and mammals. The BNatSchG already mentions compensatory measures according to § 59 for an impact on the marine environment in Germany. But until 2017, no compensation was required for offshore wind power. However, from 2018 on, according to § 56a BNatSchG, marine compensation measures will also be provided for OWFs, but this requirement still has to be filled with content. Here further research is required. Only 7% of the proposed measures in French EIAs have so far been intended to compensate for the predicted biodiversity benefits [45]. In Germany, empirical studies of OWF marine compensatory measures can only be developed from the twelve nautical miles zone or from the already obligatory compensatory

measures for the cable connection. The guidelines of the BSH on compensation measures have so far mainly been concerned with avoiding negative effects through OWFs and grid connections. Internationally, however, numerous studies have been carried out on the possibilities for marine compensatory measures. Several international agreements (e.g. HELCOM, OSPAR and the Habitats Directive) and spatial planning in the EEZ call for such measures. In fact, there is still a lack of official guidelines or references for the EEZ as to what a marine compensation might look like. In principle, compensatory measures could also be used to avoid prohibited offenses under European species protection legislation (for example in the sense of CEF (Continuous Ecological Functionality)) measures.

2.5.2 Real Marine Compensation Measures

Many studies on the possibilities for the practical implementation of compensatory measures have been carried out nationally and internationally [25]. In an international context, there are numerous studies on the creation of marine habitats, such as seagrass or artificial reefs, some of which have been very effective [46, 47, 48, 49]. Artificial reefs can be created by adding stones to the sea. The turbines of the OWF itself can serve as an artificial reef, so that the OWF represents, so to speak, an in situ compensation. However, many experts argue that the introduction of non-site-specific species by the artificial reefs cannot have a positive effect on biodiversity. On the other hand, it was even emphasized in this context that OWFs can have similar positive effects for habitats, benthos, fish and mammals as marine protected areas [50]. Real marine compensation measures have so far been made mainly in offshore waters. In deeper waters, there is still a lack of usable experience [49]. Since the loss of habitat through the construction of OWFs is particularly important for seabirds and harbor porpoises, compensatory measures are of greater interest, especially for these species. This compensation could be attained, for example, by improving the habitats for birds and porpoises by improving food availability, such as benthos or fish. Marine compensatory measures for certain marine biotopes and species already exist and should be integrated into the licensing procedure.

2.5.3 Minimizing other Marine Impacts as a Form of Marine Compensation

Another potential approach to marine compensation

for OWF degradation is to reduce the intensity of marine impacts. This could e.g. mean that fishing and shipping companies should in the future no longer be allowed to use certain sensitive areas (such as Natura 2000 sites). In this context, the Federal Environment Ministry is already working on a concept for the exclusion of fisheries from protected areas in the context of FFH area management. However, since the European Union is responsible for its technical application and shipping is the responsibility of the International Maritime Organization (IMO) in particular, creative solutions must be found both for legal restrictions and for compensatory payments. Another way to compensate for adverse effects, such as on seabirds or harbor porpoises, could be to further reduce pollution of the oceans as a major cause of death for birds and mammals. Reducing the risk of accidental bycatch of porpoises could also be envisaged as a compensatory measure. Research into marine compensatory measures to reduce marine uses has been driven forward in recent years. It proposes general fishery prohibition zones, more careful fishing, the purchase of existing mining concessions, the reduction of marine littering, as well as risks and restrictions [51].

2.5.4 Compensation of Offshore Damage Onshore

Another approach would be to compensate for OWF impacts on land as well. Onshore offsetting measures could particularly support the conservation status of affected species, for example by establishing compensatory measures in the breeding grounds of OWF-affected bird species. Another option for onshore measures would be to reduce species-specific risks such as collision with power grids or reduce hunting risks. Furthermore, the food supply in the (onshore) breeding grounds could be improved [25]. However, onshore compensation measures for offshore impacts do not take place in the same natural area, as required by the BNatSchG [25]. In order to ensure this requirement for compensation in the same natural region is met (in accordance with § 15 para. 2 BNatSchG), the compensation and replacement would have to be in accordance with the intervention in the natural habitat main unit D 70 (German Bight) or D 71 (Dogger Bank with adjacent central North Sea), or in the Baltic Sea in D 72 (West Baltic Sea) or D73 (East Baltic Sea). The possibilities of such onshore offsetting compensation are discussed [51]: e.g. summer dyke openings, dike relocation, the installation of polders

in the dike without relocation of the main dyke, the revitalization of estuarine side gutters with or without rear sighting, the extension of agricultural use, the purchase of hunting rights and measures for nature-friendly tourism in terms of visitor guidance or proposed shut-off areas.

2.5.5 Compensatory Payments as a Form of Marine Compensation

As a last solution, marine compensatory measures could also be possible in the form of monetary payments. Especially in cases where real compensation causes a disproportionately high level of expenditure, these compensatory payments could replace compensatory measures [25]. However, in order to be able to guarantee ecological benefit, these must be used in a purposeful manner within the meaning of § 15 para. 6 BNatSchG. It was also described how to successfully create an ecological "net profit" through compensation arrangements from the OWF developer to the Marine Reserve Manager [52].

However, procedures for the monetary valuation of marine interventions have so far been insufficiently developed. Approaches to the calculation of compensation payments within the framework of the approval of OWFs in Germany, for example in the 12-nm zone, were analyzed [25]. In the German Bundesland Lower Saxony a compensatory payment of 3.50 euros per square meter of the seabed has been calculated. These have only been applied in a few cases in German approval procedures. Measures for using replacement funds for marine impacts may be e.g. reef construction, the dismantling of cables, the reintroduction of individual species, the restoration of natural water exchange (coastal sea) [51].

A proper valuation of offshore impacts requires a monetary valuation model. As a marine compensation model, it was quantified the impact of loss of ecosystem services [46]. Other authors propose that the size of the sea compensation (for example, for the impact on fish through the creation of new reefs) is calculated by means of "Visual Habitat Equivalency Analysis" [53]. On the other hand, other authors describe a system of "Habitat Equivalency Analysis", which has been used to rehabilitate marshland as a marine compensation for marine nitrate pollution [54].

In addition others discuss the topic of marine compensation options for the British Crown Estate [55]. The possibility of applying the basic principles of biodiversity balancing to the marine environment was examined in two case studies, after which the

results were discussed in a multi-stakeholder workshop at the Royal Society.

It was found that marine biodiversity information from freely available sources is essential in order to create a marine intervention balance. There are still considerable data gaps. The use of indicators for biodiversity assessment in marine balancing is therefore proposed. The implementation of such a marine compensation in legal regulations and subordinate regulations is proposed by the authors. In addition, opportunities for marine balancing are identified, including the creation of habitats, the restoration of habitats and measures to conserve and prevent risks to biodiversity. The current lack of knowledge about and impact on some marine ecosystems is leading to an increased need for marine research activities. Because marine ecosystems are highly dynamic, it will not always be realistic or desirable to implement environmental improvements at fixed sites. For these sites, the compensation should be designed with regard to the desired state of a system and not in the form of biotope features at a specific location. For example, compensation for marine degradation could be achieved by reducing other adverse effects elsewhere.

Based on the case studies of an OWF and a tidal power plant, the compensation principles were subjected to a practical test. In both case studies, a number of marine compensation options were identified. For example, habitats similar to those that are affected and that are not part of protected areas should be given special protection, as provided for in the Habitats Directive. Sub-tidal marine habitats represent a specific challenge in the design of biodiversity compensation measures. In addition to the area and the quality of the habitat, criteria include the type of impact. Compensation may be e.g. by improving the quality of disturbed areas.

In the end, it has to be recorded, that compensatory payments can only be considered as a compensation measure, if their costs are supported by wind farm developers. Otherwise, compensatory payments only serve as a transfer of responsibilities.

2.5.6 Summary for the Possibilities for Marine Compensation

The results of the research on marine compensatory measures clearly show the need for a consistent, internationally agreed approach to marine offshore wind compensation. Furthermore, it can be stated that marine compensatory measures already exist for certain marine biotopes and marine onshore replacement measures. The investigations for the

Crowne Estate [55] show the limits for marine compensation. In the future, compensation measures should be integrated into the approval requirements. The possibility of marine compensatory measures has been created in Germany in the new § 56a BNatSchG in 2017. Only if real compensatory measures are completely disproportionate could compensation be set alternatively [25]. In particular, since the loss of habitat for seabirds and porpoises is of particular importance, compensatory measures have high priority, especially for these species. A compensation for these species could be generated by improving habitats for birds and porpoises by increasing the availability of feed such as benthos or fish.

2.6 Possibility of an Exception Procedure of Legal Species Protection for the Construction of OWFs

Even if the above-mentioned avoidance, reduction and compensation measures are used, offenses according to European species protection may possibly take place. It must not come to a deliberate "planning in" into prohibited statutes. According to the case law of the Federal Constitutional Court (BVerwG), an exemption presupposes a non-foreseen and therefore atypical, singular case (BVerwG, Decision of 26.3.1998 - 4 A 7.97). The examination of species protection legality must take place according to the "state of knowledge". The BSH has developed a standard investigation concept [2] for environmental assessment. Guidance on the assessment of species protection can be found, for example, in the paper on loons [21] or the sound abatement concept of the Federal Ministry of Environment [20]. However, there remain uncertainties that could be resolved by setting clearer standards for establishing precise limits.

Following § 45 (7) BNatSchG an exception may be granted for the construction of OWFs within the scope of the planning approval procedure according to the Offshore Installations Ordinance (Seeanlagenverordnung). This would have to be examined by the licensing authority, i.e. the BSH as planning approval authority in cooperation with the nature conservation authority in charge of the EEZ, the Federal Agency for Nature Conservation (BfN). So far in only two cases (in the Baltic Sea) have OWFs not been approved because of nature conservation concerns, otherwise the occurrence of prohibition of species protection (by avoidance and abatement measures) could be regularly excluded within the approval procedure. However, the issue was particularly pertinent in areas of particular

importance to the porpoise or loon, often controversially. An exception procedure according to European protection of species has not yet been carried out in the offshore area in the German approval practice

The procedure for a species protection exemption has already been extensively described in the field of onshore wind energy and assessed by courts [57]. Now it is important to transfer this practice of possible exemptions to the offshore sector as well. In the case of offshore wind energy, an overriding public interest could in principle be assumed on the basis of clear political and legal stipulations. The fact that the expansion of renewable energies is of particular importance is based solely on § 1 (3) sentence 4 of the BNatSchG ("the establishment of a sustainable energy supply, in particular through the increasing use of renewable energies").

With the objectives of the offshore strategy of the Federal Government, this special importance is underlined even further. However, according to the settled case-law of the European Court of Justice, exemptions from species protection must be interpreted and implemented restrictively (see ECJ, Decision of 07.03.1996, C-118/94, paragraph 21). The Federal Government's goals for offshore wind energy in connection with climate protection do not give it any automatic priority over the issues of species protection [58]. It must be demonstrated that the importance of the overriding public interest in offshore wind energy is given priority over the importance of protecting species. In a case-by-case consideration, the significance of the predicted impacts on species protection (in particular, for example, for the porpoise as a species in accordance with Annex IV FFH Directive or the loon as a species in Annex I of the Birds Directive) have to be compared with other public interests (here, for example, the goals of Germany for climate protection and the related objectives for the development of offshore wind energy) [59].

Furthermore, according to § 45 (7) sentence 2 BNatSchG, it must be stated in the exceptional nature protection procedure that "reasonable" alternative locations do not exist. "Alternative" means the real possibility of achieving a planning objective pursued by the project in another way [59]. In addition to alternative locations, alternatives might include alternative techniques. In the offshore sector, for example, this could mean the application of a different pile-driving procedure with less impact on the harbor porpoise. Consideration of alternatives should also include "reasonableness". This criterion respects the principle of proportionality. The individual case should be

analyzed, taking into account the respective interests concerned [60]. If unreasonable deviations from the planning objective become necessary, then it is really no longer an alternative, but another project (BVerwG, Decision of 01.04.2009, 4 B 62.08, RN 45; BVerwG, Decision of 13.12.2007, 4 C 9.06, RN 67). The so-called "zero variant", which means the complete abandonment of the OWFs, should not be considered as an alternative. The construction of other renewable energy generation facilities (e.g. onshore wind energy) should also be a "different project". Even the theoretical possibility of being able to implement the project elsewhere has, according to jurisdiction in the field of wind energy onshore, not been considered a "reasonable alternative", but a non-realization of the project (Administrative Court Saarlouis, Decision of 2007, 5 K 58/06). Even technically feasible alternatives may be rejected as unreasonable if they are outside of any reasonable ratio to the achievable profit for nature and the environment (BVerwG, Judgement of 17.05.2002, 4 A 28.01). An alternative may also be rejected as a disproportionate means for reasons external to nature protection (BVerwG, Decision of 09.05.2010, 9 A 20.08;). Whether the costs or other burdens and disadvantages of the alternative are disproportionate is to be measured by the weight of the affected species protection concerns. In the area of offshore wind energy, locations could be further removed from the coast or, at a certain point, with alternative foundation methods, may prove economically unacceptable.

Alternatives are also unreasonable if they are themselves affected by the prohibitions of § 44 para. 1 BNatSchG. If there is an alternative which, while less significant in terms of species protection, seriously compromises the conservation objectives of one or more Natura 2000 sites, it is not preferable, according to the regular case-law. A project promoter therefore does not need to be referred to an alternative solution if the protection regulations of an Natura2000 area sanctuary at the alternative location prove to be equally effective in blocking approval (BVerwG, Decision of 12.03.2010, 9 A 3/06 and [59]. Finally, an exception may only be allowed if the conservation status of the populations of a species does not deteriorate (§ 45 (7) sentence 3 BNatSchG). For this, the conservation status of populations of a species in their natural range must be determined (according to the national report in Germany, for example, this would be for the porpoise in the Atlantic region the ecological status: unfavorable - insufficient, and in the continental

region: unfavorable - bad), and examining the effects of the planned exemption on the population concerned [61].

If an exception for species conservation is approved, it must be ensured that the species' good conservation status continues to be ensured or can be achieved, *inter alia* by targeted measures to safeguard the state of preservation, so-called FCS measures. These measures should serve to compensate for the impact on populations. Therefore, from the point of view of the European species protection, we should urgently deal with possible avoidance and compensatory measures. The FCS measures must also be put into effect before the negative effect occurs, for example, through the construction of the OWF. FCS measures can be used for species protected by Annex IV of the Habitat Directive, but also for birds that are protected by the Birds Directive. In order to prove the effectiveness of population-supporting measures, as a rule an accompanying monitoring, including risk management with possibility for correction, is required. The overall result of a derogation should always be neutral or positive for a species (ECJ, Decision of 14.06.2007, C-342/05, paragraph 29). However, standards for assessing the effectiveness of FCS measures in the EEZ have yet to be worked out. All in all, it should be noted that a derogation under species protection law can really only be approved in exceptional cases; regular planning of exemptions will not be possible.

2.7 Delphi Study Evaluating Proposed Reforms for the Sustainable Development of Offshore Wind Energy

In order to gain an impression of which improvements should be expected in the future development of offshore wind energy (research question 6), experts were interviewed by means of Delphi analysis using a questionnaire. It essentially concerned the evaluation of the reform proposals [33]. An analysis of the 25 responses provided by the 44 surveyed experts showed in principle a broad agreement for all proposed reforms. In order to validate an assessment of the relevance of the different protected items in the EIA, in 2011 the author carried out a further survey using a questionnaire among nearly 50 experts from the various branches of the offshore wind energy sector (universities, administration, offshore wind farms companies, environmental NGOs). As a result of the survey, it can be stated that from the point of view of the experts, all mitigation, minimization and compensation measures discussed are meaningful and should be applied, but a particularly urgent need

is for the use and further development of technical avoidance measures (for example against underwater noise) and the introduction and application of real marine compensation measures (see Fig. 5).

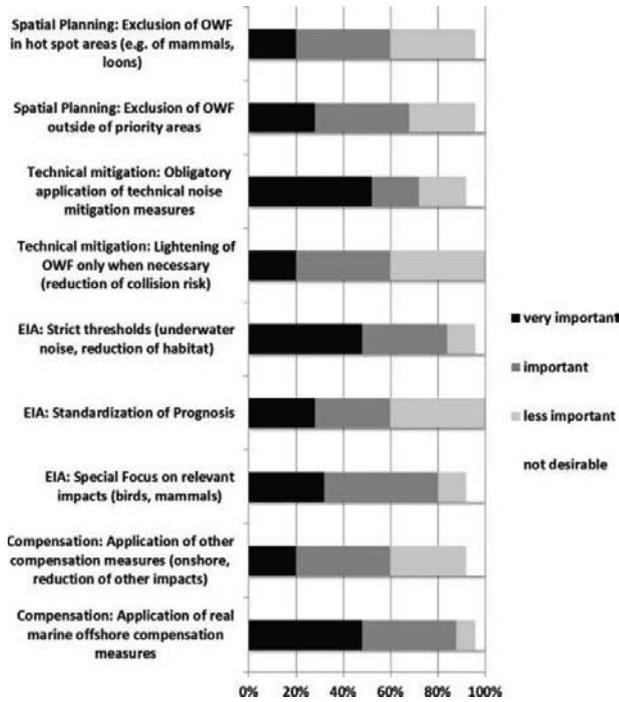


Fig. 5. Approval for proposals for an environmentally sound development of OWFs. Expert interviews via questionnaire and Delphi method. Answers from experts in % [33]

3 Conclusions: An Environmentally Sound Development of Offshore Wind Energy is Possible

Knowledge of the environmental impact of OWFs on the marine environment has progressed significantly through the data generated in Germany over the past decade. Sufficient knowledge was gained to evaluate some impacts, such as the change in living space for benthic organisms and fish near OWFs. Furthermore, the impacts on birds and on harbor porpoises are very well known. Although the research is not yet complete, it is time to draw first conclusions in an interim assessment: Relevant effects mainly concern resting birds and possibly migratory birds (not yet conclusively scientifically proven) as well as porpoises during pile driving. The challenge is to take into account these findings as well as the problems of the current development of offshore wind energy in future planning

processes, approval procedures and the construction of OWFs, and to exchange this knowledge internationally. For this purpose, proposals for reform based on the hierarchy of intervention regulations were made. First of all, impacts should be avoided as much as possible (reform of spatial planning in the EEZ), after which they should be reduced by technical means (especially technical noise abatement measures). Approval processes should be improved by a reform of the EIA as the basis of assessment and finally unavoidable impacts should be compensated for by means of marine compensatory measures.

Spatial planning in the EEZ shows a need for reform at some points. Future OWFs should also be excluded by spatial planning in areas with a high abundance of loons or harbor porpoises, as has already been done in the main resting area for loons and in the main concentration zone of porpoises in Germany. Furthermore, the construction of OWFs outside of the suitable areas identified by spatial planning should not occur. Naturally, the suitable areas need to be expanded to achieve the Federal Government's target of 15,000 MW of offshore wind energy by 2030 in Germany.

Technical protection measures can already often keep the noise below the thresholds of 160 dB. But no technology can fully guarantee compliance with the 160 dB limit at a distance of 750 m yet. Although hitherto no injuries or killing of porpoises by the impact of OWFs was detected on the international level, at the current state of knowledge, the technical reduction measures such as bubble curtains, for example, will continue to be integrated into the construction process, as is currently common practice in Germany.

At the project level, the EIA approval procedures would have to be adapted to newer findings. The evaluation and relevance of the rich data in these documents for OWFs is often rather vague. For this reason, standardized methods and thresholds must best be established throughout Europe and internationally. Only then can the effects be assessed and compared cumulatively.

Because not all of the impacts of OWFs can be avoided or completely prevented by spatial planning or technical mitigation measures, the resting impact of the maritime environment must be compensated for by offshore and onshore compensation measures.

In view of the results of the impact research of the past ten years in Germany and internationally, and provided that the further measures proposed above are implemented, there is strong evidence that an environmentally compatible development of

offshore wind energy is possible. Even synergies between offshore wind energy and nature conservation, such as the cessation of fishing within the OWFs or the creation of artificial reefs, can be achieved. In particular, the assessment of the environmental impact of offshore wind energy should consider whether alternatives to offshore wind energy exist. Properly weighed, this certainly represents one of the most ecologically sound types of power generation. Offshore wind energy has almost base load capacity. It will be a major pillar of the energy transition towards a nuclear-free world with minimum CO₂ emissions. It is our belief that the development of offshore wind energy can also be environmentally friendly thanks to the proposed reforms.

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