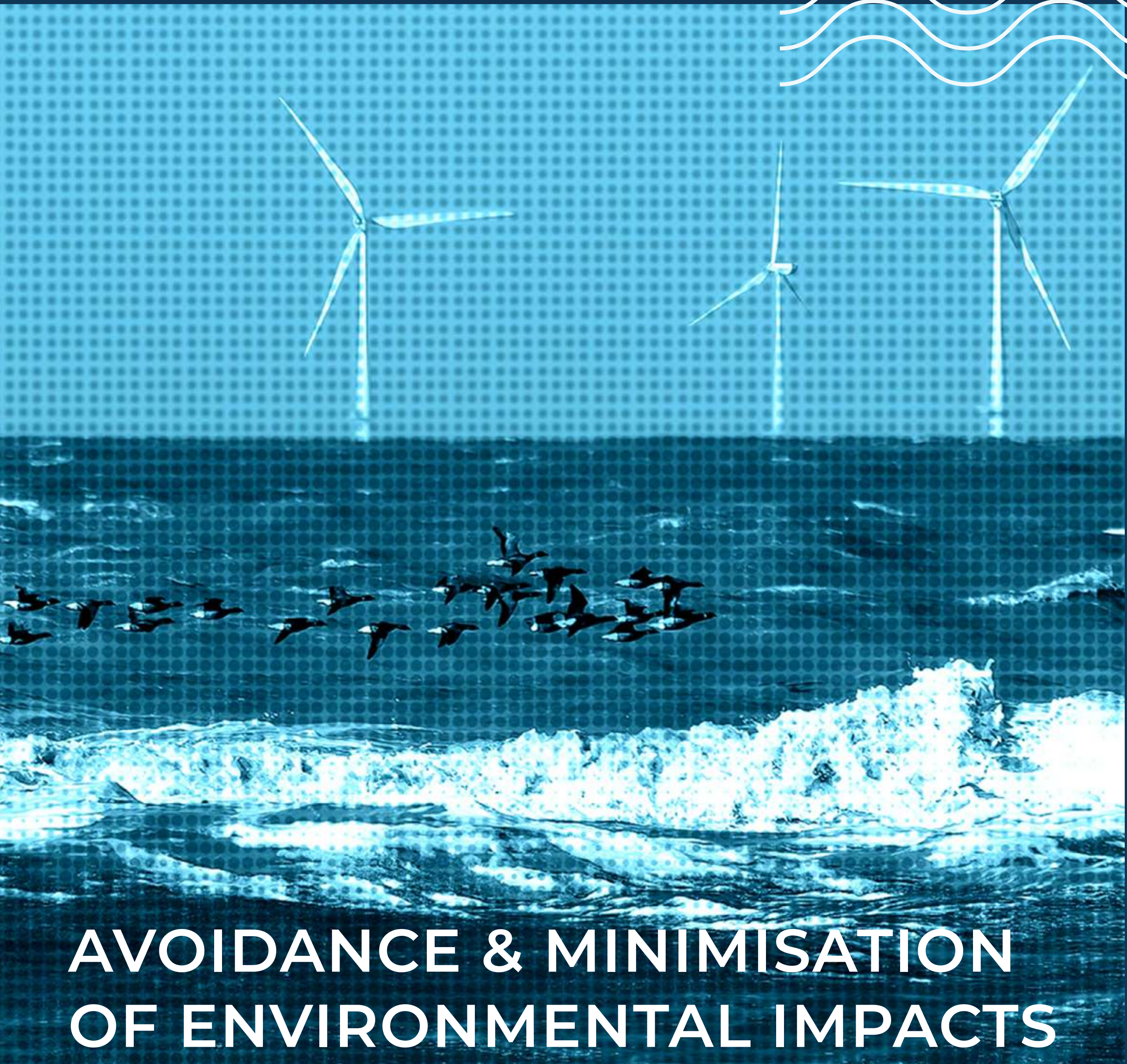


AVOIDANCE & MINIMISATION OF ENVIRONMENTAL IMPACTS FROM OFFSHORE WIND & GRID INFRASTRUCTURE

How to achieve a nature-friendly energy transition at sea

ocean
Offshore Coalition for Energy and Nature
NORTH & BALTIC SEAS

OCTOBER 2024

PREFACE

The Offshore Coalition for Energy and Nature (OCEaN) brings together non-governmental organisations (NGOs), transmission system operators (TSOs), and wind industry organisations from across Europe. Together we work towards a sustainable deployment of offshore energy and grid infrastructure while ensuring alignment with nature protection and healthy marine ecosystems. OCEaN focuses on nature-friendly offshore wind and grid deployment in the Baltic Sea and Northern Seas, including the Greater North Sea area and Celtic Seas.

OCEaN IS FUNDED, CONVENED, AND MODERATED BY THE RENEWABLES GRID INITIATIVE

MEMBERS OF OCEaN ARE

TSOs	50Hertz, Amprion, Elia, EirGrid, Energinet, National Grid Ventures, RTE, Statnett, TenneT
NGOs	BirdLife International - Europe & Central Asia, Climate Action Network Europe - CAN Europe, Germanwatch, Danish Society for Nature Conservation, Deutsche Umwelthilfe e.V. - DUH, Naturschutzbund - NABU, Natuur & Milieu, the North Sea Foundation - Stichting De Noordzee, the Royal Society for the Protection of Birds - RSPB, the Wildlife Trusts, the World Wide Fund for Nature - European Policy Office - WWF EPO
WIND INDUSTRY ORGANISATIONS	Energie Baden-Württemberg AG- EnBW, Iberdrola, Ørsted, Seawind Ocean Technology, Renewables Norway, RWE, Siemens Gamesa, Skyborn Renewables, SSE Renewables, Vattenfall, WindEurope, Wind Energy Ireland, the German Network for Wind Energy - WAB, the German Federal Association of Offshore Wind Farm Operators BWO
SUPPORTING ORGANISATIONS	The Ocean Institute and IUCN

This report was made as a part of the OCEaN workstream on mitigation measures, through which OCEaN Members dissect the potential environmental impacts of offshore wind and grid infrastructure deployment, identify ways to avoid and minimise them, and advocate for the further uptake of these measures. However, avoidance and minimisation of impacts on marine ecosystems is just one puzzle piece in achieving a nature-friendly energy transition at sea. Other proactive and innovative measures such as adopting nature-inclusive design, restoring nature on- and off-site, and finding synergies with other human activities at sea are equally important if the biodiversity and climate crises are to be addressed in a comprehensive way. While OCEaN also works on these topics, they fall outside the scope of this report.

TABLE OF CONTENTS

ABBREVIATIONS

EIA	Environmental Impact Assessment
EMF	Electromagnetic field
EU	European Union
HDD	Horizontal Directional Drilling
ICCP	Impressed Current Cathodic Protection
MMO	Marine Mammals Observer
MPA	Marine Protected Area
MSP	Maritime Spatial Planning
NGO	Non-governmental organisation
OCEaN	Offshore Coalition for Energy and Nature
OWF	Offshore wind farm
PAM	Passive acoustic monitoring
SEA	Strategic Environmental Assessment
TSO	Transmission System Operator
UXO	Unexploded ordnance

EXECUTIVE SUMMARY

The world faces two interconnected crises – climate change and biodiversity loss. There are known approaches to address these challenges, however, a solution for one can unintentionally intensify the other. For instance, to address the climate change, rapid decarbonisation of our energy systems is the top priority. Countries bordering the Northern and Baltic Seas are planning to achieve this through large-scale deployment of renewable energy, including offshore wind. This means additional human activities will take place in seas with already depleted and fragile ecosystems. However, if offshore wind farms (OWFs) and grids are planned in a responsible way, we can minimise the additional pressures placed on nature from these developments.

In order to support the deployment of offshore wind and grid in a nature-friendly manner, the Offshore Coalition for Energy and Nature (OCEaN) has identified 80 measures through which wind and grid developers can minimise potential environmental impacts on marine ecosystems. This work includes measures that reflect the first two steps of the mitigation hierarchy – avoidance and minimisation. This was done by combining the fragmented knowledge on available avoidance and minimisation measures for offshore wind and grid infrastructure, including the most recent, relevant, and available information, and finding common ground between the diverse stakeholders that make up OCEaN. Furthermore, 'best practice' measures were identified, which are implemented across multiple sites and are proven to effectively reduce negative environmental impacts.

The purpose of this report is to outline the methodology used by OCEaN, provide a summary of the identified measures, highlight knowledge gaps and areas where mitigation efforts are still lacking, and provide recommendations on how to improve the deployment of offshore wind and grid to achieve even better outcomes for nature.

Avoidance and minimisation measures can be applied throughout all life stages of offshore wind and grid infrastructure. A comprehensive design and planning of activities within an offshore wind farm and grid infrastructure is crucial to avoid environmental impacts. For example, during planning, (micro)siting is completed in combination with design of infrastructure and the choice of materials. These decisions can avoid and significantly minimise negative impacts such as collisions and displacement. Throughout construction, noise emissions are released both above and below water and can potentially cause injury and avoidance of seabirds, fish, and marine mammals. Therefore, effective noise minimisation tools should be applied.

When the infrastructure becomes operational, offshore wind and grid developers should not stop their effort to minimise their environmental impacts. Informed and science-based curtailment is one of the measures that could potentially reduce the negative impacts on biodiversity, but more testing is needed to understand its effectiveness offshore. Although only a few offshore wind farms have undergone decommissioning so far, the current trend suggests that full removal of infrastructure is still generally seen as the default option at the end of the lifecycle. However, this approach is increasingly being challenged by various stakeholders. To minimize additional pressures on biodiversity during this process, extending the operational lifetime of these structures should be prioritised, where appropriate.

While there are many existing avoidance and minimisation measures that have been tested and vary in effectiveness, certain knowledge gaps still remain. This is particularly true for more subtle pressures which could lead to significant impacts on a cumulative level. We need to better understand the risks OWFs can pose to bats, primary production and the effect on the higher trophic level in the food web, and the relationship between electro-magnetic fields (EMFs) and behaviours of EMF-sensitive animals. Nevertheless, existing research projects trying to address these knowledge gaps were identified and OCEaN will continue to follow their results.

Many policies and guidelines aiming to minimise the harm caused by the development of offshore wind and grid infrastructure already exist. However, there is still room for improvement. OCEaN identified areas where more adjustments, flexibility, or guidelines from regulatory bodies and wind and grid developers are needed to reach better biodiversity outcomes and accelerate deployment of offshore wind farms. Furthermore, to reach both climate and biodiversity targets, cooperation is crucial. Therefore, OCEaN invites all interested stakeholders to give their feedback to this report and join the endeavour of ensuring offshore wind and grid deployment goes hand-in-hand with nature protection.

I. INTRODUCTION

Europe's northern seas have been supporting human civilizations for centuries. Transport, fishing, energy production, tourism, aquaculture, and recreation are just some of the services provided by the marine ecosystems in these bodies of water. Unfortunately, the health of the Northern and Baltic Seas is in a dire condition. For instance, populations of seabirds are decreasing due to shortage of prey, overfishing led to the bad status of the majority of fish stocks, marine mammals are impacted by increasing underwater noise, benthic communities are disturbed by human activities such as bottom trawling, and entire ecosystems face cumulative impacts from various anthropogenic pressures (Helsinki Commission - HELCOM, 2023; OSPAR, 2023).

> Healthy and resilient marine ecosystems are needed to not only support human activities, but also to maintain the climate of our planet by acting as its largest carbon sink. Therefore, urgent action is necessary to protect and restore our seas.

In addition, pressures on the ecosystem are exacerbated by climate change (Weinert et al., 2021). To address the climate crisis, rapid decarbonisation of energy systems is a top priority. Countries bordering the Northern and Baltic Seas are planning to meet their climate objectives through large-scale deployment of renewable energy, including offshore wind energy. More concretely, the European Union has the goal of reaching installed capacity of at least 60 GW of offshore wind by 2030 and 300 GW by 2050 (European Commission, 2020). Consequently, this means additional human activities will take place in seas with already depleted and fragile ecosystems. Offshore wind farms and grids should therefore be planned in a responsible way to minimise the additional pressures placed on nature as much as possible. The offshore wind sector can become frontrunner in addressing the intertwined challenges of climate change and biodiversity loss, while also bringing economic and social benefits.

There is growing awareness that healthy ecosystems are essential to adequately accommodate the expansion of offshore renewable energy production. National policies are set in place to minimise pressures and tender processes for new wind sites are increasingly incorporating qualitative award criteria, including ecological considerations. To facilitate offshore wind development without compromising ecological integrity, adherence to the mitigation hierarchy is paramount. Avoidance of environmental impacts is a foundational principle to work towards a resilient marine ecosystem. Unavoidable impacts should be minimised throughout the whole lifecycle of an offshore wind farm. This can be achieved by implementing mitigation measures, with an increasing number of options available. However, an overview is lacking. Information is scattered and not up to date, complicating effective implementation of mitigation measures, especially on a sea basin scale.

To address this fragmented state of knowledge, OCEaN has undertaken the development of a comprehensive overview aimed at understanding the potential environmental impacts associated with offshore wind and grid developments in the Northern and Baltic Seas. This framework served as the basis for identifying specific avoidance and minimisation measures. The purpose of this report is to outline our methodology, provide a summary of the identified measures, highlight knowledge gaps and areas where mitigation efforts are still lacking, and provide recommendations on how to improve the deployment of offshore wind and grid to achieve even better outcomes for nature.

[1] For the purposes of this paper, Northern and Baltic Seas refers to the Greater North Sea region, Celtic Sea, and Baltic Sea.

II. OBJECTIVE AND SCOPE

Some overviews of mitigation measures for environmental impacts caused by the offshore wind and grid infrastructure currently exist (see for instance, Bennun et al. (2021), BildLife International - Europe and Central Asia (2023), or Crown Estate Scotland (2024)). However, they fail to include mitigation measures for grid infrastructure, are incomplete, have limited geographical scope, or are outdated.

OCEaN'S WORKSTREAM ON MITIGATION HAS THE OBJECTIVE OF

FACILITATING THE ACCELERATED SUSTAINABLE ENERGY TRANSITION IN THE NORTHERN AND BALTIC SEAS BY

a Combining the fragmented knowledge on mitigation measures for offshore wind (bottom-fixed) and grid infrastructure;

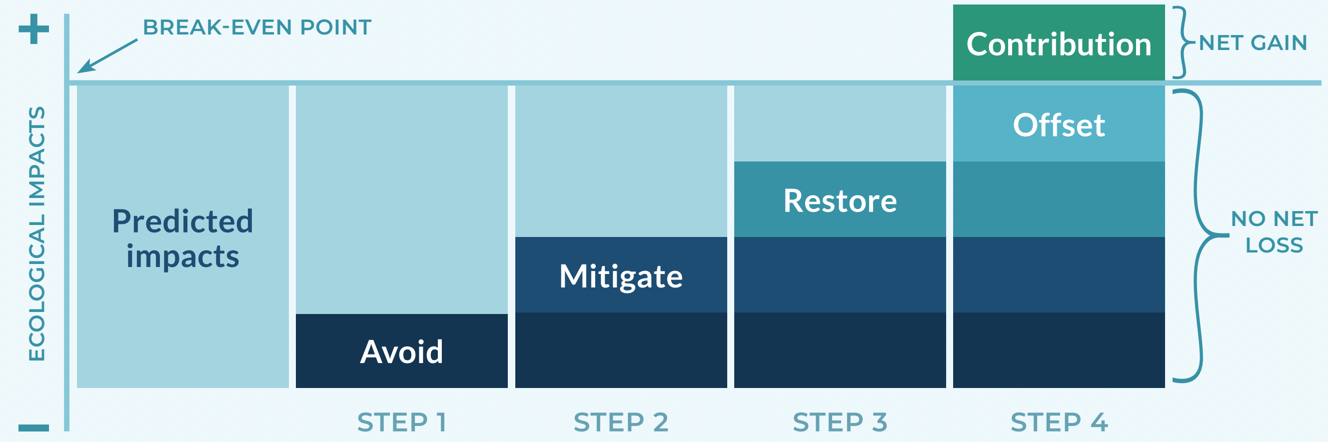
b Including the most recent, relevant, and available information;

c Finding common ground between the diverse stakeholders that make up OCEaN.

According to the 2014 EU Directive on Environmental Impact Assessment, all major development projects in the EU, offshore wind farms included, should first be assessed for their impacts on the environment before receiving a permit. Within this process, project developers are obliged to identify all potential negative impacts on human health, biodiversity, land, soil, water, air, climate, landscape, material assets, and cultural heritage. In the case of identified significant negative impacts, methods to address them should also be proposed. To guide this process, the mitigation hierarchy is used (Box 1). Though the application of avoidance and minimisation is mandatory by law, offshore wind and grid developers have a certain amount of freedom and flexibility in choosing the measures they will apply.

01

MITIGATION HIERARCHY



The implementation of a mitigation hierarchy is essential for effectively managing adverse ecological consequences. This hierarchy, as seen by OCEaN, includes avoidance, minimisation, restoration, and offsetting measures and provides a structured framework to guide mitigation efforts.

The graphic was adapted from the International Institute for Sustainable Development (IISD)

This report focuses on **the first two steps of the mitigation hierarchy – avoidance and minimisation** (Textbox 2). In this way we highlight the importance of avoiding the environmental impacts in the first place and, if this is not possible, we call for their proper minimisation. This approach is not only the best for the nature but is also economically beneficial for developers in the long run. OCEaN Members actively work on the other steps of the mitigation hierarchy (see for instance Energy & Nature Database), but these aspects are outside of the scope of this report.

02

DEFINITION OF AVOIDANCE AND MINIMISATION MEASURES

Firstly, **avoidance measures** prioritise the identification and selection of project sites, or locations within a site, with minimal ecological sensitivity, thereby reducing the likelihood of significant harm to marine habitats and species.

Subsequently, **minimisation measures** focus on reducing the intensity and extent of impacts through the adoption of best practices in project design, construction, operation, and decommissioning. This includes, for instance, employing advanced technologies to minimise noise and vibration during installation and implementing measures to mitigate seabed disturbance.

Our collection of avoidance and minimisation measures **is not categorised according to effectiveness**. It is important to highlight that the level of effectiveness for the included measures depends on specific environmental conditions unique to each site. Therefore, project developers always conduct individual assessments to determine the most suitable measures for their projects. There are frameworks being developed to help this assessment, such as the one developed by the Dutch consultancy Witteveen + Bos (Hermans et al., 2024). The Witteveen + Bos framework provides a systematic approach to evaluating and implementing nature conservation (avoidance and minimisation) and enhancement measures (e.g. nature-inclusive design) for offshore projects. The assessment criteria within this framework relates to expected ecological impact, technical feasibility, and costs. Their results are not meant to be interpreted as a definitive outcome, but offer a foundation for further discussions on implementation strategies. Optionally, it can be used to assess mitigation measures identified by OCEaN and facilitate informed discussions on suitable measures for a certain project, considering their unique environmental characteristics.

Lastly, OCEaN **identified 'best practice' avoidance and minimisation measures**, which are not only tested in the offshore context but are also implemented in multiple sites and are deemed effective at reducing negative environmental impacts, based on current evidence. These 'best practices' could be considered across all projects to maximise environmental protection. In addition to offering a comprehensive overview, this compilation of best practices has the potential to inspire advocacy efforts that promote the adoption of measures designed to minimize the environmental impacts of future offshore wind and grid infrastructure. Moreover, the process of compiling avoidance and minimisation measures has facilitated the identification of crucial gaps where further development or testing of mitigation strategies is required. This exercise thus serves to inform stakeholders and represents a significant advocacy tool which aims to enhance environmental stewardship in offshore wind projects across the Northern and Baltic Seas.

III. METHODS

The starting point of OCEaN's efforts to compile avoidance and minimisation measures was the development of a comprehensive framework which connects potential pressures caused by offshore wind and grid infrastructure with specific receptors observed across the lifecycle of this infrastructure. The framework developed by OCEaN draws inspiration from the widely used and broadly accepted DPSIR (driver, pressure, state, impact, response) framework. In this context, ***pressure*** is defined as any excessive amount of resource use, change in land use, or production of emissions that is a direct result of human activities (Kristensen, 2004), while ***receptor*** is any species or habitat under the influence of a certain pressure. The lifecycle of an offshore wind farm and accompanying grid infrastructure in this context includes the phase of planning, construction, operation, and decommissioning. The identified potential pressures and associated impacts can be seen in Table 1.

TABLE 1

OVERVIEW OF IDENTIFIED PRESSURES WITH ASSOCIATED IMPACTS

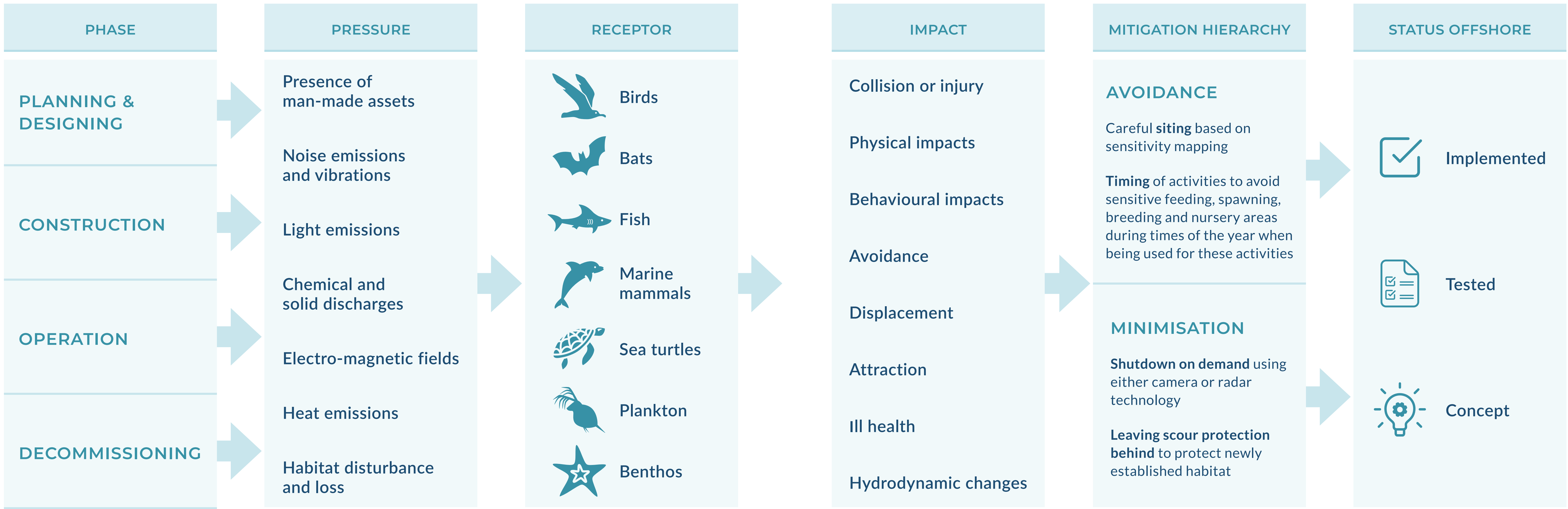
PRESSURES	IMPACT(S)
Presence of man-made assets (which include all anthropogenic structures and objects, including all types of vessels)	* Avoidance * Displacement * Injury * Collision * Hydrodynamic changes * Attraction of native and non-native species
Noise emissions and vibrations	* Avoidance * Displacement * Injury
Light emissions	* Attraction * Avoidance * Displacement
Chemical and solid (e.g. microplastics) discharges	* Ill health (including fitness degradation, injury, health hazards, contamination, toxication)
EMF and heat emissions	* Potential behavioural and physical impacts * Injury * Avoidance * Displacement * Attraction

PRESSURE	IMPACT(S)
Habitat disturbance and/or loss	* Avoidance * Displacement * Attraction of native and non-native species

For each of these pressures, biodiversity receptors were investigated and assessed for potential negative impact. To be as comprehensive as possible, receptors from both above water (namely bats and birds (migratory and local)) and underwater (fish (pelagic and demersal), marine mammals, plankton, sea turtles, and benthos) were looked at. Once the relationship between pressures and biodiversity receptors was established, avoidance and minimisation measures created to address these impacts were collected. These measures were then categorised according to the infrastructure they apply to (wind farm or grid), their position in the mitigation hierarchy (avoidance or minimisation), and their status of application offshore (concept, tested, or different levels of implementation).

This information was further supplemented with examples where these measures are being implemented and relevant sources. The work of identifying measures was undertaken through literature reviews, interviews with OCEaN Members, and discussions in a larger Task Force dedicated to this workstream. After a few rounds of collecting and discussing the measures, around 80 avoidance and minimisation measures were identified in the framework. **This collection is the result of collective knowledge based on experience of more than 25 years of offshore developments in the Northern and Baltic Sea**. A full collection of measures accompanied with examples where these measures have been implemented is available via the OCEaN website upon request. This report doesn't mention all measures available in the collection, but instead summarises the main findings. Furthermore, the process facilitated the identification of knowledge gaps. More research is needed on the relationship between certain pressures caused by offshore wind and grid infrastructure and biodiversity receptors, and areas where potential negative relationships could exist, but avoidance and minimisation measures are either missing or are still being tested and waiting to be validated (see more under Knowledge gaps). Lastly, discussions between OCEaN Members also led to consensus regarding needed adjustments in legislation and coordination with other maritime sectors to improve current approaches to nature-friendly offshore wind deployment (see more under Recommendations).

FIGURE 1
FRAMEWORK USED FOR IDENTIFYING MEASURES



IV. OVERVIEW OF COLLECTED AVOIDANCE AND MINIMISATION MEASURES

It is important to highlight that the development of nature-friendly offshore wind and grid infrastructure starts before the project planning phase. The first stage includes the government-led Maritime Spatial Planning (MSP) process coupled with a Strategic Environmental Assessment (SEA). During this process, it is crucial to identify sites for offshore wind and grid development which avoid biodiversity-rich and sensitive areas, by for instance using biodiversity sensitivity maps and risk screening. A government-led and SEA-informed MSP is essential to ensure siting takes biodiversity into account, but also to help level the playing field for developers. Therefore, policymakers and relevant authorities are invited to develop comprehensive SEA-informed MSPs. Furthermore, cross-border cooperation during MSP is vital for the successful development of offshore wind projects, as our oceans form a single, interconnected ecosystem that transcends national boundaries.

1 PROJECT PLANNING PHASE

Comprehensive planning of an offshore wind farm and its connected grid infrastructure is crucial to avoid many environmental impacts. This is also reflected in OCEaN's collection of measures, where almost half are implemented during the planning phase of OWFs and grids. During planning, decisions on (micro)siting, design, and timing of activities take place. To enable responsible planning decisions, detailed **surveying and mapping** of a site is a prerequisite. The actor responsible for surveying and mapping differs between countries. One type of conducted studies necessary for site characterisation is geophysical surveys. The conductor of the survey, either the state or the developer, is advised to consider using least-intrusive equipment and complete surveys outside of sensitive periods for threatened species at the site (Bennun et al., 2021). Additionally, seismic surveys can produce substantial noise, which calls for the application of noise minimisation measures. Furthermore, sometimes surveying, threat, and risk assessment for potential unexploded ordnance (UXOs) is required. If UXOs are identified, the site should ideally be located away from them. If this is not possible, low order deflagration and removal should take place (Robinson et al., 2020). Traditional detonation and removal could be coupled with noise mitigation measures such as a double bubble curtain, acoustic mitigation devices (AMDs), or acoustic deterrent devices (ADDs) to alert marine mammals in the area (Salomons et al., 2021).

In general, **siting** is the most powerful tool governments and offshore wind and grid developers can and are using to avoid negative environmental impacts such as bird collisions, displacement and injury of fish, marine mammals, and benthic habitat disturbance, and habitat loss. Siting is usually informed by Maritime Spatial Plans (MSP), as governments typically identify sites for offshore wind development during MSP development. However, not all MSPs are done properly and/or in time. Therefore, governments, wind and grid developers are recommended to:

* Avoid areas designated as Natura 2000 sites, Marine Protected Areas (MPAs), and areas designated under national protection schemes for nature and biodiversity conservation.
* Avoid migration flyways or areas used frequently by bats.
* Avoid valuable areas used by sensitive seabird species, such as breeding colonies, migration flyways for vulnerable species, and routes that seabirds use to travel between their colonies and foraging areas. This can be achieved by using standardised bird surveys and sensitivity mapping.
* Avoid spawning and nursery habitats for fish, species-rich habitats, and biogenic reefs. If information on where these are located is not available, a dedicated survey within an Environmental Impact Assessment should be conducted.
* Avoid marine mammal migratory routes, mating and nursery grounds, and haul out sites used by seals, especially during sensitive periods such as breeding seasons. Taking haul out sites in consideration is important as they could coincide with key locations for grid connections from sea to land.
* Depending on the site conditions and characteristics, avoid seasonally stratified waters to minimise changes in nutrient richness and primary production and therefore avoid negative ecosystem effects.
* If possible and relevant, avoid areas with sand waves present to reduce the need for dredging prior to installation.

A comprehensive assessment of baseline conditions within all offshore wind development sites is needed and careful **micro-siting** of infrastructure should be done. For instance, the layout design of turbines could consider migratory routes of seabirds by arranging turbines in clusters, depending on flight paths of migrating birds and their migratory routes (Gartman et al., 2016). Depending on bird species, they could exhibit either avoidance behaviour (and therefore use more energy to circumvent OWFs), no avoidance, or can even be attracted to the OWF, which could potentially lead to collisions. By using behaviour movement modelling, it is possible to inform the layout of turbines in an OWF and minimise both avoidance behaviour and collisions (Masden et al., 2012). Positioning of turbines in the development site should consider avoiding the placement of turbines within each other's atmospheric- and current wakes. This can potentially reduce the risk of (long term) ecosystem effects through the reduction of mixing of air and water (van Duren et al., 2021), though more research is needed to understand the importance and risk of this mechanism.

Furthermore, it is recommended to do micro-siting of turbines and cables in a way that avoids vulnerable habitats, such as dense aggregations of reef-building organisms, but also to avoid silty deposits and peat to limit turbidity (Department for Business Enterprise & Regulatory Reform, 2008).

Adjustments to the **design** of infrastructure elements can also potentially minimise the environmental impact. For instance, scour protection is typically applied around piles to prevent scouring and sediment re-suspension. The choice of turbine foundation type can also influence the size of the seabed footprint and, depending on the type, can produce less noise emissions during construction. Bird collisions can potentially be minimised if either lower or upper tip height is adjusted to local migratory flight patterns of bird and bat species or by applying achromatic patterns to the blades, painting them in contrasting colour, or with UV colours to enhance their detectability (Martin & Banks, 2023; May et al., 2020). However, these blade design adjustments are still in a conceptual phase for offshore wind turbines. While some measures work for onshore wind turbines, research in the offshore context has yet to prove their effectiveness in the marine environment. Nevertheless, research shows that maximising the height of the rotor zones is assumed to minimise collision risk for bats, as a higher proportion of migrating bats cross in heights below 30 meters (Seebens-Hoyer et al., 2024).

The design of lights used on turbines and platforms can potentially minimise the attraction or avoidance of bats, birds, and marine mammals. Avoiding non-mandatory lighting, reducing the level of illumination, adjusting the colour spectrum of lighting, or using deflectors are some of the potential light design adjustments that could take place (Bennun et al., 2021; BirdLife International - Europe and Central Asia, 2023; Deakin et al., 2022). It is crucial to adjust the design of lighting in consultation with relevant stakeholders, considering its significant role in ensuring aviation and navigational safety. Cable design and burial depth are also crucial to minimise the level of electro-magnetic field (EMF) at which the animals can be exposed to and heat emissions being produced (Hermans, 2022).

Lastly, the choice of **materials** used can be extremely important to minimise infrastructure's chemical emissions on the environment. To minimise the amount of metal pollution entering water and sediment, environmentally-friendly techniques for corrosion protection are encouraged (e.g. use of impressed current cathodic protection (ICCP) systems) (Federal Maritime and Hydrographic Agency & Helmholtz-Zentrum Hereon, 2022). Furthermore, anti-fouling paint containing biocides should ideally be avoided. When cable protection by covering is necessary, the use of inert materials which do not undergo any dangerous chemical modification is recommended.

If complete avoidance of the site, and therefore impacts, is not possible, timing and scheduling of activities becomes crucial. This is particularly important for the activities taking place during construction phase, which will be further elaborated on in the next chapter.

CONSTRUCTION PHASE

The *construction phase*, for the purposes of this report, encompasses the installation of offshore wind turbines and their foundations, laying and protection of submarine cables, and installation of marine electrical substations. All these activities require numerous vessel movements.

Before starting the construction, it is essential to prepare a detailed and comprehensive **construction protocol** which should aim to reduce the number of vessel trips to only necessary ones (Bennun et al., 2021). Besides reducing the number of trips, it is recommended for vessels to adjust their speed and routes to reduce noise emissions and minimise the chances of animal disturbances and injury (BildLife International - Europe and Central Asia, 2023; Department for Business Enterprise & Regulatory Reform, 2008). Furthermore, timing of all construction activities could be adjusted in a way to avoid important periods, such as migratory periods, over-wintering, or breeding periods for birds and nursery periods for marine mammals (according to the life stage and abundance of target species). To minimise the risk of injury to marine mammals, there is a possibility to hire a marine mammal observer (MMO) on the installation vessel. The MMO can then request adjustments of the activities if marine mammals are observed in the area and therefore minimise the disturbance of animals (Bennun et al., 2021; Department for Business Enterprise & Regulatory Reform, 2008).

Noise is one of the most severe pressures on the environment during construction, particularly during piling. Therefore, most of the identified mitigation measures for the construction phase are dedicated to noise emissions and have already been implemented in various sites. To manage noise emissions during construction, **mandatory noise threshold values** could be established (where supported by the necessary data), offering developers guidance on the noise levels that should not be exceeded during their activities. These values usually come from governments, are defined by law, and based on specific noise-sensitive species. For instance, to minimise the effects of noise emissions on harbour porpoises, compliance with a dual noise protection criterion is mandatory in Germany (Bundesministerum für Umwelt, Naturschutz und Reaktorsicherheit, 2022). When deciding on the methodology of installing piles, it is recommended to assess if pile drilling is an option instead of pile hammering since the former is less noise intensive than the latter (Bennun et al., 2021). There are many ways to minimise the noise emissions emitted in the environment from piling. **Bubble curtains and cofferdams** are some of the noise minimisation measures which are already implemented on a larger scale with good results (Bennun et al., 2021; Defingou et al., 2019).

New noise minimising piling methodologies are also being developed and tested constantly. For instance, instead of using conventional hydraulic hammering while piling, it is possible to use blue piling technology (Defingou et al., 2019). Another example is the use of **vibro-piling**, instead of conventional impact-piling, which causes a temporary reduction in the surrounding soil resistance that allows the pile to sink into the seabed (Verfuss et al., 2019). Exciting developments in lower-noise installation methods, which includes jetting technology lowering the resistance of the surrounding sandy soil, have recently been tested in a new German OWF Gode Wind 3 (Ørsted, 2024).

Timing of piling is also crucial. Like vessel movements, limiting the number of hours per day when piling takes place or limiting the total number of piling days will influence the amount of noise emitted in the environment on a cumulative level. The decision which approach to take will depend both on the national regulations and local ecosystems. It is also important to avoid sensitive feeding, spawning, breeding, and nursery areas during times of the year when they are being used for these activities. Additionally, piling preferably wouldn't take place during sensitive spawning times for substrate spawning species and seasonal migration of specific fish and shellfish species All of this should be included in the **installation protocol**.

Furthermore, developers are recommended to use a **soft start**, which means they adjust their piling energy in the beginning of the pile-driving-process in a way that increases the piling energy gradually so noise-sensitive animals have enough time to leave the area (Defingou et al., 2019). Another way to displace marine animals from the area is to use **acoustic deterrence devices (ADD)** such as seal scarers and pingers. However, deterrence devices introduce more noise to the environment on a cumulative level and sometimes produce a stronger deterrence effect than needed, which can consequently lead to a negative impact on biodiversity, including also sessile species in the surrounding area. Therefore, their usage should be undertaken carefully. Which device to use should be decided on a case-by-case basis, with the overall goal to use the deterrence device with the smallest environmental impact (McGarry et al., 2022; Voß et al., 2023). Furthermore, to ensure no marine mammals are within a specified area prior to the construction activities, it is possible to use **passive acoustic monitoring (PAM)** to monitor marine mammals at night and during poor visibility (JNCC, 2023).

Cable laying is another essential part of offshore wind farm and grid construction, and to ensure negative impacts on environment are minimised it is important to use the least intrusive technique available. Which technique to use depends on seabed conditions. In intertidal and landfall areas where habitats may be vulnerable (such as chalk cliffs and saltmarsh), using **horizontal directional drilling (HDD)** can avoid significant habitat disturbance (Department for Business Enterprise & Regulatory Reform, 2008). In soft seabed, using jet ploughing can help reduce benthic disturbance (Bennun et al., 2021). After the cable is laid and buried, it is recommended to back fill the trench with original excavated materials to promote the recovery of the seabed. In the case of hard substrate areas, if the same material cannot be used, use of sustainable nature-based materials to cover cables is preferred.

OPERATIONAL PHASE

Most of the avoidance and minimisation measures that can be implemented for offshore wind farm and grid infrastructure should take place during the planning and construction phases. During the operational phase it is either too late, extremely complicated, and/or too costly to adjust or remove infrastructure. This is particularly the case for pressures such as light emissions, chemical and solid emissions, electromagnetic fields (EMF), and heat emissions. However, even during the operational phase certain minimisation measures of environmental impacts can be used.

The biggest threat to the environment when an offshore wind farm becomes operational is the collision of birds and bats with the infrastructure, which can lead to injury and death. Bats can also experience barotrauma, a condition caused by a sudden drop in air pressure within the vortex of wind turbine blades, which, combined with their comparatively delicate lungs, can be harmful to them (The North Sea Foundation, 2022). A proposed solution for these problems is to implement **curtailment or shutdown on demand**, during which the speed of blade rotation is almost completely halted.

THIS SHUTDOWN ON DEMAND CAN BE IMPLEMENTED IN DIFFERENT WAYS

- During already determined times of the day/night (e.g. 1 hour after sunset) or ambient environmental factors (e.g. westerly wind and low temperatures) (Ahlén et al., 2009; Bach et al., 2022; Bennun et al., 2021; Brabant et al., 2021; Lagerveld et al., 2021; Rydell et al., 2014; Seebens-Hoyer et al., 2024).
- During specific pre-determined periods based on, for instance, the outputs of migration predictive models for birds and bats.
- Using either digital camera, radar, or acoustic technology to do post-construction monitoring and identify which turbines should have their rotation halted at what times (e.g. migratory periods or other periods of high activity).
- Preventing bird collisions through active control of wind turbines by making small adjustments to the rotor speed after detecting the presence of birds within a certain distance of the blades.

Even after an offshore wind farm is finally constructed, regular **vessel trips** are still needed for maintenance and occasional repairment services. It is recommended to minimise the number of trips as much as possible to reduce the disturbance of ecosystems. Furthermore, the speed of maintenance vessels could be adjusted to minimise the noise emissions being produced and minimise the risk of collision with fauna.

DECOMMISSIONING PHASE

OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations has been critical in defining offshore decommissioning obligations since its publication in 1998. While the dumping prohibition for oil and gas installations is clear, there is less clarity when it comes to offshore wind and grid infrastructure, which is mostly nationally regulated. These national regulations dictate whether the complete removal of infrastructure is mandated, or partial decommissioning is permissible. Nevertheless, the important measure to avoid, minimise or at least postpone the impacts of decommissioning activities on onsite biodiversity is to **extend the lifespan of the infrastructure, where appropriate**, such as by increasing the longevity of wind turbine foundations.

When full removal is compulsory, minimisation strategies closely resemble those employed during construction phase, particularly those for noise minimisation. Coordination of decommissioning activities by making regional decommissioning plans can aid in minimising cumulative disturbance as a result of consecutive activities. By grouping decommissioning activities together, the periods of disturbance can potentially be shortened. When partial decommissioning is allowed, the emphasis shifts towards safeguarding crucial species that have established ecosystems within these structures. It is important to already integrate decommissioning considerations in the design phase to ensure effective planning of decommissioning activities. Potential activities for **partial decommissioning** include cutting monopiles below the seabed or leaving scour protection in place. While such approaches aid in minimising habitat disturbance, questions arise regarding their alignment with circularity principles and future material needs. Despite regulations typically favouring full removal, the reality often diverges due to a lack of comprehensive regulatory frameworks and incomplete understanding of environmental impacts, posing challenges for developers and transmission system operators (TSOs). The decision regarding whether infrastructure is fully or only partially decommissioned **should be assessed on case-by-case basis**.

V. KNOWLEDGE GAPS

Offshore wind and grid infrastructure is necessary for a sustainable energy transition, and ongoing research on how to deploy it in an environmentally-friendly way is producing relevant and new knowledge every day. The offshore environment is a challenging one to operate in for many reasons, and this is compounded by knowledge gaps on how marine ecosystems function and uncertainties about how human activities are affecting them. Nevertheless, certain threats to the environment posed by offshore wind and grid infrastructure are proven. For these clear and direct impacts, targeted avoidance and minimisation measures have been developed and are to some extent being implemented. When the nature, size, and scale of the impact is clear, it is easier to develop avoidance and minimisation measures and consequently assess their efficacy to reduce the impact. Furthermore, efforts to reduce the impact should be proportional to the impact's size.

While doing this exercise, OCEaN Members were not only able to identify ways to deploy offshore wind and grid in a nature-friendly way, but also areas where more research is still needed to understand the relationship between deployment of offshore infrastructure and marine ecosystems. For certain aspects, there are already ongoing research projects trying to fill in these knowledge gaps while in other areas more attention is needed. There is a growing realisation that some more subtle environmental impacts have the potential to become more prominent on a cumulative level. Therefore, more research on the relationship between offshore wind and grid infrastructure and biodiversity is needed, coupled up with pilot projects testing new minimisation measures. For this, collaboration between academia, civil society and industry is crucial.

OCEaN invites relevant stakeholders to approach these collaborations pro-actively to address the topics mentioned below. This chapter provides an overview of identified knowledge gaps and existing research projects trying to address them.

A good understanding of suitable mitigation measures for impacts of offshore wind and grids on bats is lacking. Scientists have observed that migrating bats cross the North and Baltic Sea and are impacted by offshore wind farms (Rydell et al., 2010; Voigt et al., 2015). In some regions offshore bat migration has been investigated for several years, creating a sound knowledge base on activity patterns, phenology, and weather dependence of bat migration events (Bach et al., 2022; Brabant et al., 2021; Lagerveld, Geelhoed, et al., 2023; Lagerveld, Wilkes, et al., 2023). In contrast, knowledge on offshore bat migration is limited in several other regions (most of Scandinavia, the Baltics, and Great Britain). Detailed knowledge on population dynamics is lacking and hampers efforts to quantify the impact on overall bat populations (The North Sea Foundation, 2022).

To help fill these knowledge gaps, Vattenfall, Energinet, Danish Energy Agency and conslutants from WSP, Pennen & Swærdet and EnviroPlanning are conducting the research project Kattegat West Baltic Bats Project (KABAP) to investigate bat behaviour around offshore wind farms developments in the Kattegat - SW Baltic Sea region. More than 100 bat detectors were placed throughout the area to understand bat migrations, activity patterns, phenology, and responses to weather conditions. The results should inform impact assessments for future offshore wind farms and allow for the evaluation of appropriate mitigation measures. Similarly, Iberdrola's Saint-Brieuc offshore wind farm off the coast of Brittany is conducting a three-year bat monitoring study using acoustic recording devices placed on eight of the wind turbines. The objectives of this monitoring include providing information on the presence of migrating bats in the offshore wind farm and investigating whether bats are attracted to wind farm lights.

While onshore wind farms are minimising their bird collision impacts by applying different versions of **curtailment** (Birdlife International, 2015), its implementation in the offshore environment is still either in a conceptual or testing phase. For instance, radar technologies for shutdown on demand are being tested in a few offshore wind farms (Fryslan OWF, and Maasvlakte II OWF), however, their turbines are located very close to shore and the technology is only being implemented on a limited number of turbines (Cunningham, 2022). The Dutch Government is currently testing its Start/Stop program, which shuts down offshore wind turbines in wind farm zones parallel to the coast of Zeeland and Holland when bird migration is expected to reach a peak. To inform curtailment, it is necessary to understand the collision risk. The PrediCtOr project is trying to improve the accuracy of collision risk estimates and therefore contribute to the reduction of bird collisions in offshore wind farms.

While seabird collisions and curtailment are getting increasing attention, more understanding is needed on the impacts of **seabirds avoiding offshore wind farms** and how to properly address them. For instance, more information on migratory corridors allows developers to adjust the planned layout of offshore wind turbines to minimise negative impacts on seabirds. Layout adjustments might reduce displacement, however, the trade-off of reducing the level of displacement might be an increase in collision risk (Harwood & Perrow, 2019). Therefore, it is advised to already consider migratory routes during government led MSP and site allocation, rather than solely creating migratory corridors within an OWF. If migratory corridors within an OWF are created, they should be done in coordination with migratory corridors of other neighbouring offshore wind farms to ensure the flight path of birds is not interrupted.

Creation of the exact migratory corridors within an OWF would be then done by wind developers; however, regulatory bodies, particularly permitting authorities, should ensure these corridors are coordinated between developers and that they are based on real scientific knowledge, which is still missing. Therefore, more research and pilot projects are needed to understand the role migratory corridors can play in minimising both collisions and avoidance behaviour of birds and their effectiveness.

As already mentioned in the project planning phase, while some potential ideas for mitigation measures involving the **design of wind turbine** do exist, they are still in a conceptual phase. Some alterations, such as vision-based collision mitigation, are proving to be effective onshore for some species, but direct transfer of these measures to offshore environments should be assessed carefully (Martin & Banks, 2023; May et al., 2020). Currently, there is a trial underway testing the effectiveness of painting a turbine blade black on existing turbines in a nearshore wind farm in the Netherlands. The project is an initiative of RWE and Groningen Province in collaboration with other public authorities and private parties in the wind sector. Reducing Seabird Collisions Using Evidence (ReSCUE) project, led by Natural England, is striving to improve knowledge of seabird flight heights and collision risk with offshore wind turbines in UK waters. Additionally, Iberdrola's Saint-Brieuc offshore windfarm is currently testing a bird collision avoidance system on three of the wind turbines. The system is composed of a network of cameras, which detect the trajectories of different categories of birds, connected to a sound scaring system, which is activated once a bird enters a risk perimeter around the rotor of the wind turbine. While such systems have been in use onshore for several years now, applications offshore are only just catching up.

Research and modelling on the **impacts offshore wind can have on primary production, nutrient cycling, oxygen saturation and therefore entire ecosystems** is scarce and needs more attention. Primary production is essential for providing food and oxygen production in marine ecosystems and driving oceans' chemical cycles. Underwater structures, such as foundations and piles, may cause turbulent current wakes, which impact circulation, stratification, mixing, and sediment resuspension. This can affect the ability of plankton to perform primary production and change the intensity, timing, and distribution of primary production, which can impact higher trophic levels and therefore entire food web dynamics (Daewel et al., 2022; Dorrell et al., 2022; Slavik et al., 2019; The North Sea Foundation, 2022). Considering the potential cumulative impact of these combined changes, it is important to test if specific wind farm layouts or avoidance of stratified waters can help alleviate this problem. Monitoring and adaptive management frameworks should be established to address abiotic changes and their potential impacts on primary production, ensuring timely intervention to safeguard marine ecosystems.

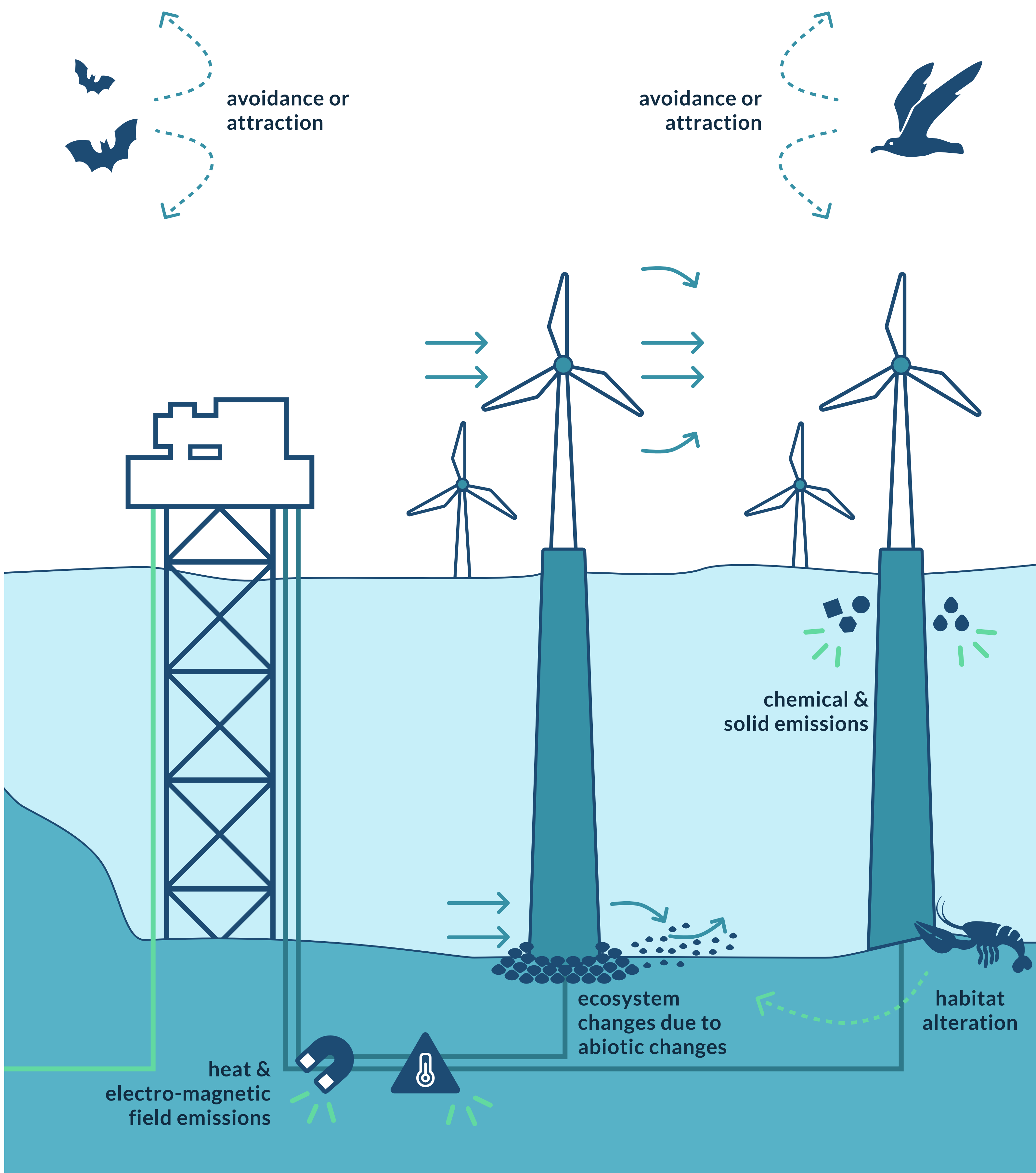
Research on **chemical pollution** caused by corrosion protection, microplastics or other potential chemical spills is still scarce and should be expanded (Federal Maritime and Hydrographic Agency & Helmholtz-Zentrum Hereon, 2022; The North Sea Foundation, 2022). There are several ongoing research projects in this field, such as ANEMOI, ECOCAP and PREMISE. ANEMOI studies the chemical emissions from offshore wind farms and their impact on ecosystems and aquaculture, while ECOCAP analyses if cathodic protection materials used to prevent corrosion of infrastructure (such as galvanic anode and impressed current) have negative impacts on marine ecosystems and their food webs. Furthermore, although research on **microplastics pollution** in offshore wind farms is so far quite limited, existing results show negligible amounts of microplastics from infrastructure are being released into the surrounding environment (Piarulli et al., 2023). More monitoring could be conducted so the scale and potential impact of chemical pollution can be understood better. PREMISE project aims to address this gap by evaluating the size and volume of microplastics erosion and assessing environmental risk and toxicological effects.

Existing research on the impact of **EMF on marine ecosystems** is limited, and the studies that do exist often yield mixed results. This inconsistency makes it difficult to draw clear conclusions about the overall impact of EMF on marine ecosystems (Hermans, 2022; The North Sea Foundation, 2022). To address this knowledge gap, the FlatEMF study is trying to uncover the impacts EMF might have on commercially important flatfish species and how to mitigate them. This topic is particularly important for discussions with other maritime sectors, such as the fishing industry. Furthermore, ElasmoPower project focuses on the potential impacts of EMF on benthic elasmobranch. Similarly, **heat emissions** produced by offshore wind farm and grid infrastructure needs more research to understand what possible impacts might be, especially on a cumulative level. Some limited research is showing that the temperature changes resulting from power cables are within the range of natural temperature variations (SEER, 2022b).

As already mentioned, habitat alteration caused by offshore wind farm and grid infrastructure can cause habitat disturbance and loss for many species. An additional risk connected to habitat alteration is the attraction of other non-native species. While most habitat alteration is localised to the area closest to the infrastructure (The North Sea Foundation, 2022), the impact could become more significant on the long-term and cumulative level (Rezaei et al., 2023). More understanding regarding how introduced hard substrate on the seabed and in the water column can alter habitats and attract non-native or invasive species is needed (The North Sea Foundation, 2022). To enhance our scientific knowledge, monitoring of changes to benthic communities and habitats should be done. Some research on this topic already exist, such as the research project FISHOWF on monitoring strategies to identify impacts on fish communities from OWFs and their export cables and DRACCAR-MMERMAID, which looks at monitoring marine megafauna around OWFs.

GRAPHIC SUMMARY

KNOWLEDGE GAPS CONNECTED TO THE PRESSURES CAUSED BY OFFSHORE WIND AND GRID INFRASTRUCTURE



VI. RECOMMENDATIONS

FOR POLICY MAKERS AND PERMITTING AUTHORITIES

While there are already some policies and guidelines in place which are ensuring that the harm caused by the development of offshore wind and grid infrastructure is minimised, there is still opportunities for advancement. Throughout discussions between its Members, OCEaN identified areas where further adjustments, flexibility, or guidelines from **regulatory bodies** are recommended to reach both better biodiversity outcomes and accelerated deployment of offshore wind farms.

LIGHT DESIGN & TURBINE BLADE COLOUR

While **light design and turbine blade colour** could reduce negative impacts on biodiversity, at least if proven effective, developers are often limited by the guidelines and restrictions given by national regulations, especially with connection to aviation and safety standards. Therefore, wind developers don't have a lot of freedom to choose their light design and blade colours, which could have negative impacts on various biodiversity receptors. Therefore, more flexibility is needed from the national regulators to address this pressure. This can be done by allowing different light designs and turbine colours when requested by the OWF developer.

NOISE EMISSIONS

Thresholds for **noise emissions** should be based on best available science. Currently the type of noise mitigations applied in each country depends on national regulations. For instance, Sweden has no national guidelines and leaves local municipalities to decide on a case-by-case basis.

NOISE EMISSIONS

(continued)

Danish guidelines consider accumulated levels of noise, while in Germany and the Netherlands mitigations are only applied once a set maximum level of noise is reached. Therefore, **coordination between nation states within a sea basin is needed to agree on how to approach noise minimisation** and should be based on the presence of noise-sensitive species. Potential fora where these conversations can take place are regional organisations such as OSPAR and HELCOM.

CHOICE OF MATERIALS

As previously mentioned, the choice of materials used for infrastructure can minimise chemical emissions on the environment (e.g. using environmentally-friendly corrosion protection and avoidance of anti-fouling paint with biocides). However, there should be a consistent, standardised requirement from permitting authorities to use these less damaging chemicals.

DECOMMISSIONING

Decommissioning practices largely depend on what is mandatory or allowed by law. Currently, all infrastructure needs to be removed, including subsea cables. If this continues to be the standard, coordination of decommissioning activities on a regional level could be done in order to potentially group activities and therefore shorten the period of cumulative disturbance. However, complete decommissioning might not always be the best solution for biodiversity and therefore there is a need to **reconsider decommissioning obligations**.

DECOMMISSIONING

(continued)

Importantly, the decision on whether to pursue a partial or full decommissioning should be completed on case-by-case basis to find the best decision for species at the site. In the of case of partial decommissioning, it is advised to focus on protecting key species that might have developed stable populations within the footprint of offshore wind and grid infrastructure.

VII. BEST PRACTICES

INSPIRATION FOR OFFSHORE WIND AND GRID DEVELOPERS

The collection of avoidance and minimisation measures provided by OCEaN aims to give an overview of measures that can be implemented in offshore wind farms and grid infrastructure. However, the effectiveness of each measure is context- and site-dependant. OCEaN therefore encourages offshore wind and grid developers to use the collection as a first step to get acquainted with existing measures (full collection of measures is available via OCEaN website upon request). Nevertheless, avoidance and minimisation measures that have been implemented in various environmental, geographical, and geophysical settings and have proven to be effective in these settings were also identified. These 'best practices' measures are listed below.

- During geophysical surveys necessary for site characterisation, consider using least-intrusive equipment and doing surveys outside of sensitive periods for threatened species present at the site.
- Aim at siting away from areas designated as MPAs and avoiding spawning and nursery habitats and species-rich habitats. Micro-site in a way which avoids habitats valuable for threatened species (e.g. spawning, nursery and feeding grounds) and reefs.
- Apply careful (micro)siting based on sensitivity mapping and standardised bird and bat surveys, avoiding valuable areas for sensitive seabird species (e.g. functionally linked areas), migration flyways for vulnerable species of birds and bats, and routes that seabirds use to travel between their colonies and foraging areas.
- Avoid haul out sites in general, but especially during sensitive periods such as breeding seasons.
- Site offshore substations in a way which minimises the number and length of inter-array cabling.
- Avoid the use of anti-fouling paint containing biocides.
- When cable protection by covering is necessary, use inert materials that do not undergo any dangerous chemical modification.
- Shield and bury cables to reduce the amount of seabed under EMF.
- Prepare detailed and comprehensive construction protocols that include all vessel movements and activities. The aim should be to reduce the number of trips to only necessary ones.
- Avoid construction during sensitive periods for species present at the site (e.g. migratory periods, over-wintering periods, breeding periods).
- While scour protection is originally placed to ensure stability around the monopile, scour protection in soft sediment areas can also help avoid sediment resuspension which can affect benthic communities (and subsequently plankton).
- Adjust piling energy (soft start) in the beginning of the pile-driving-process and gradually increase the piling energy so that noise-sensitive animals can leave the area.
- Deploy noise abatement systems such as Hydro Sound Dampers (HSD) and cofferdams to reduce noise during installation of monopiles and jacket foundation for turbines and offshore platforms.
- Use the Horizontal Directional Drilling method when laying underground cables to reduce damage in intertidal and landfall areas where habitats may be more sensitive (e.g. chalk cliffs, saltmarsh).
- Reduce the number of maintenance vessel trips as much as possible to reduce the disturbance of ecosystems. Adjust the speed of maintenance vessels to reduce the noise emissions.

VIII. CONCLUSION

While offshore wind and grid infrastructure are an essential part of the endeavour to mitigate the climate crisis, it is important to highlight that there is an ongoing biodiversity crisis as well. Therefore, all future offshore wind and grid infrastructure should be deployed with a comprehensive and careful application of measures which avoid and minimise potential negative environmental impacts. The overview provided by OCEaN, which this report tried to summarise, contains around 80 of these measures spanning across different stages of an offshore wind farm's lifecycle. The overview can act as a first step by identifying existing measures. All measures should be then assessed for their effectiveness on a case-by-case basis.

What is apparent from this joint work is that many environmental impacts can be minimised, or even avoided, if they are considered early on during Maritime Spatial Planning and in the project planning process. However, even better results could be achieved if MSP is done on a sea basin level and if more offshore wind farm auctions include non-price ecological criteria. MSP should, therefore, integrate ecosystem-based approach, ensuring that future offshore wind projects are implemented in a way that is both environmentally responsible and aligned with nature-friendly practices. Furthermore, while most pressures occur during infrastructure construction, there are plenty of avoidance and minimisation measures that are and should continue to be applied due to their proven effectiveness in reducing environmental impacts. These, along with many others, were identified in the 'best practice' list, and OCEaN advocates for their continued adoption.

The goal of this collection was to be as comprehensive as possible, however, there are still areas which should be explored further. Besides identified knowledge gaps regarding more subtle pressures which may operate at larger geographical or long-term scales, there is also uncertainty if identified measures can be directly transferred to other sea basins with the same effectiveness. Another clear gap is that this collection only covers bottom-fixed technology. Considering developments in floating technology and especially its relevance for the Mediterranean basin, it would be useful to identify which measures already implemented for bottom-fixed technology are of relevance for floating technology, and which environmental pressures caused by floating technology need specialised avoidance and minimisation measures.

The complete collection of avoidance and minimisation measures, their status of implementation offshore, and examples of deployment is available to everyone upon request via OCEaN website. This collection was developed as part of OCEaN's commitment to supporting the nature-friendly deployment of offshore wind and grids and demonstrating that this goal is achievable. Furthermore, OCEaN will continue the work on avoidance and minimisation to ensure the collection is still relevant and useful. Innovation and new developments in the offshore wind and grid sector are constantly emerging and therefore adjustments to the database are anticipated. To support this process, all stakeholders are invited to give their feedback and join OCEaN in ensuring offshore wind and grid deployment goes hand-in-hand with nature protection.

GLOSSARY

ACOUSTIC DETERRENT DEVICES (ADDS)

A variety of different devices which emit sounds to deter/alert animals form a specific hazard/ area, sometimes also called Acoustic Mitigation Devices (AMDs) and Acoustic Harassment Devices (AHDs) (McGarry et al., 2022).

BENTHOS

An encompassing term used to classify organisms found on, in, or in close contact with the bottom region of bodies of water and seabed (Walag, 2022).

BUBBLE CURTAIN

The air-bubble curtain is one potential noise minimisation measure, which consists of rising air bubbles that encircle the pile, forming a closed curtain which minimises the amount of noise being emitted in the surrounding environment (Tsouvalas & Metrikine, 2016).

COFFERDAM

A type of temporary structure designed to keep water and/or soil from the execution of construction at a site, so that the permanent structure/facility can be constructed in water (Qian et al., 2018).

CUMULATIVE IMPACTS

Total impacts resulting from the successive, incremental, and/or combined effects of a project when added to other existing, planned, and/or reasonably anticipated future projects, as well as background pressures (Stephenson, 2022).

DISPLACEMENT

Limiting the normal use of an area within or adjacent to a wind farm. Occurs when species alter their normal use of the habitat (SEER, 2022a).

ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

EIA is a systematic process that examines the environmental consequences of development actions in during planning process (Glasson et al., 2005).

HABITAT DISTURBANCE

A change in conditions which interferes with the normal functioning of a biological system. A disturbed habitat indicates a temporary change in environmental conditions, which causes a pronounced change in the ecosystem (Capucchio et al., 2019).

HORIZONTAL DIRECTIONAL DRILLING (HDD)

HDD is a construction technique whereby a tunnel is drilled under a waterway or other designated area, and a pipeline or other utility is pulled through the drilled underground tunnel (Enbridge, 2023).

IMPACT

Changes in the state of ecosystems may have environmental consequences on their functioning, their life-supporting abilities, and ultimately on human health and on the economic and social performance of society (Kristensen, 2004).

MARITIME SPATIAL PLANNING (MSP)

Maritime Spatial Planning manages the distribution of human activities in space and time to achieve ecological, economic, and social objectives and outcomes (Zaucha & Gee, 2019).

MITIGATION HIERARCHY

The mitigation hierarchy is a framework developed to guide activities toward limiting negative impacts on biodiversity. It includes four categories of actions that are designed to be implemented sequentially: avoid, minimise, restore/remediate, and offset (Arlidge et al., 2018).

NATURA 2000

Natura 2000 is a network of protected areas covering Europe's most valuable and threatened species and habitats. The sites within Natura 2000 are designated under the EU Birds and the Habitats Directive (European Environment Agency, 2023.

NATURE-INCLUSIVE DESIGN

In the context of offshore wind and grid development, nature-inclusive designs refer to nature-inclusive construction, in which the design and construction of wind farms include the potential to enhance biodiversity and natural resources (Stephenson, 2022).

PASSIVE ACOUSTIC MONITORING (PAM)

PAM entails using fixed autonomous acoustic recording devices which are placed at the development site before the activities with potential negative impacts on marine flora take place. With the help of PAM, developers can understand if animals are available at the site and therefore time their activities accordingly (JNCC, 2023).

PRESSURE

A product of excessive amount of resource use, change in land use, or emissions as a result of human activities (Kristensen, 2004).

RECEPTOR

Receptor is any element of biodiversity that is affected by the release of pressures in the environment (Kristensen, 2004).

STRATEGIC ENVIRONMENTAL ASSESSMENT (SEA)

SEA is a process which facilitates a proactive approach to ensuring that environmental and sustainability considerations are considered during early stages of strategic decision-making process. It evaluates environmental impacts of policies, programs and plans (Fundingsland Tetlow & Hanusch, 2012).

UNEXPLODED ORDNANCE (UXO)

UXOs are explosive mines and amunition that did not explode when they were employed and still pose a risk of detonation (Office for Coastal Management, 2024).

REFERENCES

Ahlén, I., Baagøe, H. J., & Bach, L. (2009). Behavior of Scandinavian Bats during Migration and Foraging at Sea. *Journal of Mammalogy*, 90(6), 1318–1323. https://doi.org/10.1644/09-MAMM-S-223R.1

Arlidge, W. N. S., Bull, J. W., Addison, P. F. E., Burgass, M. J., Gianuca, D., Gorham, T. M., Jacob, C., Shumway, N., Sinclair, S. P., Watson, J. E. M., Wilcox, C., & Milner-Gulland, E. J. (2018). A Global Mitigation Hierarchy for Nature Conservation. *BioScience*, 68(5), 336–347. https://doi.org/10.1093/biosci/biy029

Bach, P., Voigt, C. C., Göttsche, M., Bach, L., Brust, V., Hill, R., Hüppop, O., Lagerveld, S., Schmaljohann, H., & Seebens-Hoyer, A. (2022). Offshore and coastline migration of radio-tagged Nathusius' pipistrelles. *Conservation Science and Practice*, 4(10), e12783. https://doi.org/10.1111/csp2.12783

Bennun, L., Van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., & Carbone, G. (2021). *Mitigating biodiversity impacts associated with solar and wind energy development: Guidelines for project developers*. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2021.04.en

BildLife International - Europe and Central Asia. (2023). *Overview of the ecological impacts of offshore wind on the marine environment*

Birdlife International. (2015). Review and guidance on use of *"shutdown-on-demand" for wind turbines to conserve migrating soaring birds in the Rift Valley/Red Sea Flyway*

Brabant, R., Laurent, Y., Jonge Poerink, B., & Degraer, S. (2021). The Relation between Migratory Activity of Pipistrellus Bats at Sea and Weather Conditions Offers Possibilities to Reduce Offshore Wind Farm Effects. *Animals*, 11(12), Article 12. https://doi.org/10.3390/ani11123457

Bundesministerum für Umwelt, Naturschutz und Reaktorsicherheit. (2022). *Konzept für den Schutz der Schweinswale vor Schallbelastungen bei der Errichtung von Offshore-Windparks in der deutschen Nordsee*. https://www.bsh.de/DE/THEMEN/Offshore/Meeresfachplanung/Flaechenentwicklungsplan/_Anlagen/Downloads/FEP_2022_2/Schallschutzkonzept_BMU.pdf;jsessionid=5452D39D6B7F6EF9633341DE567ED1E7.live11311?__blob=publicationFile&v=2

Capucchio, M. T., Colombino, E., Tarantola, M., Biagini, D., Alborali, L. G., Maisano, A. M., Scali, F., Raspa, F., Valle, E., Biasato, I., Schiavone, A., Salogni, C., Bar, V., Gili, C., Guarda, F., Capucchio, M. T., Colombino, E., Tarantola, M., Biagini, D., … Guarda, F. (2019). The Disturbed Habitat and Its Effects on the Animal Population. *In Habitats of the World—Biodiversity and Threats*. IntechOpen. https://doi.org/10.5772/intechopen.84872

Crown Estate Scotland. (2024). *Collaboration for Environmental Mitigation & Nature Inclusive Design (CEMNID)*. https://www.offshorewindscotland.org.uk/media/kcghvske/collaboration-for-environmental-mitigation-nature-inclusive-design-full-report.pdf

Cunningham, C. (2022). Mitigation and management across wind energy and other sectors

Daewel, U., Akhtar, N., Christiansen, N., & Schrum, C. (2022). Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea. *Communications Earth & Environment*, 3(1), 292. https://doi.org/10.1038/s43247-022-00625-0

Deakin, Z., Cook, A., Daunt, F., McCluskie, A., Morley, N., Witcutt, E., Wright, L., & Bolton, M. (2022). *A review to inform the assessment of the risk of collision and displacement in petrels and shearwaters from offshore wind developments in Scotland*

Defingou, M., Bils, F., Horchler, B., Liesenjohann, T., & Nehls, G. (2019). PHAROS4MPAs: *A Review of Solutions to Avoid and Mitigate Environmental Impacts of Offshore Windfarms*

Department for Business Enterprise & Regulatory Reform. (2008). *Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry*

Dorrell, R. M., Lloyd, C. J., Lincoln, B. J., Rippeth, T. P., Taylor, J. R., Caulfield, C. P., Sharples, J., Polton, J. A., Scannell, B. D., Greaves, D. M., Hall, R. A., & Simpson, J. H. (2022). Anthropogenic Mixing in Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure. *Frontiers in Marine Science*, 9, 830927. https://doi.org/10.3389/fmars.2022.830927

Enbridge. (2023). *Horizontal Directional Drilling—Specialized construction for large waterways and sensitive areas.* https://www.enbridge.com/~/media/Enb/Documents/Factsheets/FS_Horizontal_Directional_Drilling.pdf

European Commission. (2020). *An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future.* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0741

European Environment Agency. (2023). *The Natura 2000 protected areas network.* https://www.eea.europa.eu/themes/biodiversity/natura-2000/the-natura-2000-protected-areas-network/

Federal Maritime and Hydrographic Agency & Helmholtz-Zentrum Hereon. (2022). *Chemical Emissions from Offshore Wind Farms—Summary of the Project "OffChEm."* https://www.bsh.de/EN/TOPICS/Research_and_development/Current_projects/OffChEm/_Anlagen/Downloads/Zusammenfassung-des-Projekts-OffChEm.pdf?__blob=publicationFile&v=2

Fundingsland Tetlow, M., & Hanusch, M. (2012). Strategic environmental assessment: The state of the art. *Impact Assessment and Project Appraisal, 30(1)*, 15–24. https://doi.org/10.1080/14615517.2012.666400

Gartman, V., Bulling, L., Dahmen, M., Geißler, G., & Köppel, J. (2016). Mitigation Measures for Wildlife in Wind Energy Development, Consolidating the State of Knowledge — Part 1: Planning and Siting, Construction. *Journal of Environmental Assessment Policy and Management, 18(03)*, 1650013. https://doi.org/10.1142/S1464333216500137

Glasson, J., Therivel, R., & Chadwick, A. (2005). *Introduction to Environmental Impact Assessment: Principles and Procedures, Process, Practice and Prospects* (2nd ed.). Taylor & Francis

Harwood, A. J. P., & Perrow, M. R. (2019). Mitigation for birds with implications for bats. *In Wildlife and Wind Farms, Conflicts and Solutions.* Pelagic Publishing

Helsinki Commission - HELCOM. (2023). State of the Baltic Sea 2023—*Third HELCOM holistic assessment 2016-2021.* https://helcom.fi/wp-content/uploads/2023/10/State-of-the-Baltic-Sea-2023.pdf

Hermans, A. (2022). *Current state of knowledge on Electromagnetic fields.* Rijkswaterstaat

Hermans, A., Schilt, B., van der Endt, J. J., & Smit, M. (2024). *Onderzoek naar natuurbeschermende en natuurversterkende maatregelen voor energie infrastructuur op de Noordzee.* https://www.noordzeeloket.nl/nieuws/nieuws/2024/noordzeeoverleg-publiceert-afwegingskader/

JNCC. (2023). *JNCC guidance for the use of Passive Acoustic Monitoring in UK waters for minimising the risk of injury to marine mammals from offshore activities*

Kristensen, P. (2004). *The DPSIR Framework.* bhttps://greenresistance.wordpress.com/wp-content/uploads/2008/10/dpsir-1.pdf

Lagerveld, S., Geelhoed, S. C. V., Wilkes, T., Noort, B., van Puijenbroek, M., Van Der Wal, J. T., Verdaat, H., Keur, M., & Steenbergen, J. (2023). *Spatiotemporal occurrence of bats at the southern North Sea 2017-2020.* Wageningen Marine Research. https://doi.org/10.18174/571525

Lagerveld, S., Jonge Poerink, B., & Geelhoed, S. C. V. (2021). Offshore Occurrence of a Migratory Bat, Pipistrellus nathusii, Depends on Seasonality and Weather Conditions. *Animals: An Open Access Journal from MDPI*, 11(12), 3442. https://doi.org/10.3390/ani11123442

Lagerveld, S., Wilkes, T., Van Puijenbroek, M. E. B., Noort, B. C. A., & Geelhoed, S. C. V. (2023). Acoustic monitoring reveals spatiotemporal occurrence of Nathusius' pipistrelle at the southern North Sea during autumn migration. *Environmental Monitoring and Assessment*, 195(9), 1016. https://doi.org/10.1007/s10661-023-11590-2

Martin, G. R., & Banks, A. N. (2023). Marine birds: Vision-based wind turbine collision mitigation. *Global Ecology and Conservation*, 42, e02386. https://doi.org/10.1016/j.gecco.2023.e02386

Masden, E. A., Reeve, R., Desholm, M., Fox, A. D., Furness, R. W., & Haydon, D. T. (2012). Assessing the impact of marine wind farms on birds through movement modelling. *Journal of the Royal Society Interface*, 9(74), 2120–2130. https://doi.org/10.1098/rsif.2012.0121

May, R., Nygård, T., Falkdalen, U., Åström, J., Hamre, Ø., & Stokke, B. G. (2020). Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. *Ecology and Evolution*, 10(16), 8927–8935. https://doi.org/10.1002/ece3.6592

McGarry, T., De Silva, R., Canning, S., Mendes, S., Prior, A., Stephenson, S., & Wilson, J. (2022). *Evidence base for application of Acoustic Deterrent Devices (ADDs) as marine mammal mitigation (Version 4)*

Office for Coastal Management. (2024). *Unexploded Ordnance Areas.* https://www.fisheries.noaa.gov/inport/item/66206

Ørsted. (2024). *Ørsted successfully pilots new technology that further optimises offshore wind monopile installation.* https://orsted.com/en/media/news/2024/07/orsted-successfully-pilots-new-technology-that-fur-13959650

OSPAR. (2023). *Quality Status Report 2023*

Piarulli, S., Sørensen, L., Kubowicz, S., & Booth, A. M. (2023). *Analysis of microplastics in sediments from the Hywind Scotland wind farm [Final Report].* SINTEF. https://cdn.equinor.com/files/h61q9gi9/global/583ed3220187ca6839a7c625e4fcb38459261d2e.pdf?analysis-of-microplastics-in-sediments-from-hywind-scotland-sintef-ocean-report.pdf

Qian, Q., Eslamian, S., Ostad-Ali-Askari, K., Marani-Barzani, M., Rafat, F., & Hasantabar-Amiri, A. (2018). Cofferdam. In P. T. Bobrowsky & B. Marker (Eds.), *Encyclopedia of Engineering Geology* (pp. 159–161). Springer International Publishing. https://doi.org/10.1007/978-3-319-73568-9_59

Rezaei, F., Contestabile, P., Vicinanza, D., & Azzellino, A. (2023). Towards understanding environmental and cumulative impacts of floating wind farms: Lessons learned from the fixed-bottom offshore wind farms. *Ocean & Coastal Management*, 243, 106772. https://doi.org/10.1016/j.ocecoaman.2023.106772

Robinson, S. P., Wang, L., Cheong, S.-H., Lepper, P. A., Marubini, F., & Hartley, J. P. (2020). Underwater acoustic characterisation of unexploded ordnance disposal using deflagration. *Marine Pollution Bulletin*, 160, 111646. https://doi.org/10.1016/j.marpolbul.2020.111646

Rydell, J., Bach, L., Bach, P., Diaz, L. G., Furmankiewicz, J., Hagner-Wahlsten, N., Kyheröinen, E.-M., Lilley, T., Masing, M., Meyer, M. M., Petersons, G., Suba, J., Vasko, V., Vintulis, V., & Hedenström, A. (2014). Phenology of migratory bat activity across the Baltic Sea and the south-eastern North Sea. *Acta Chiropterologica*, 16(1), 139–147. https://doi.org/10.3161/150811014X683354

Rydell, J., Bach, L., Dubourg-Savage, M.-J., Green, M., Rodrigues, L., & Hedenström, A. (2010). Bat Mortality at Wind Turbines in Northwestern Europe. *Acta Chiropterologica*, 12(2), 261–274. https://doi.org/10.3161/150811010X537846

Salomons, E. M., Binnerts, B., Betke, K., & Von Benda-Beckmann, A. M. (2021). Noise of underwater explosions in the North Sea. A comparison of experimental data and model predictions. *The Journal of the Acoustical Society of America*, 149(3), 1878–1888. https://doi.org/10.1121/10.0003754

Seebens-Hoyer, A., Bach, L., Bach, P., Pommeranz, H., Göttsche, M., Voigt, C., Hill, R., Vardeh, M., & Matthes, H. (2024). *Fledermausmigration über der Nord- und Ostsee. Abschlussbericht „Untersuchung zur Konnektivität und zum Verhalten von über dem Meer wandernden Fledermäusen zur genaueren Abschätzung der Auswirkungen von Offshore-Windenergieanlagen"*

SEER. (2022a). *Bat and Bird Interactions with Offshore Wind Farms*. https://tethys.pnnl.gov/sites/default/files/summaries/SEER-Educational-Research-Brief-Bat-Bird-Interactions.pdf

SEER. (2022b). *Benthic Disturbance from Offshore Wind Foundations, Anchors, and Cables*

Slavik, K., Lemmen, C., Zhang, W., Kerimoglu, O., Klingbeil, K., & Wirtz, K. W. (2019). The large-scale impact of offshore wind farm structures on pelagic primary productivity in the southern North Sea. *Hydrobiologia*, 845(1), 35–53. https://doi.org/10.1007/s10750-018-3653-5

Stephenson, P. (2022). *Essential Environmental Concepts for the Offshore Wind Energy Sector in Europe*. Renewables Grid Initiative

The North Sea Foundation. (2022). *Roll out wind at sea with respect for nature—An analysis of potential risks to North Sea nature posed by the offshore wind energy transition*. https://noordzee.s3.eu-west-1.amazonaws.com/app/uploads/2022/03/15134930/202203-SDN-Ecological-risks-Wind-at-Sea.pdf

Tsouvalas, A., & Metrikine, A. V. (2016). Noise reduction by the application of an air-bubble curtain in offshore pile driving. *Journal of Sound and Vibration*, 371, 150–170. https://doi.org/10.1016/j.jsv.2016.02.025

Van Duren, L. A., Zijl, F., van Kessel, T., Vilmin, L. M., van der Meer, J., Aarts, G. M., van der Molen, J., Soetaert, K., & Minns, A. W. (2021). *Ecosystem effects of large upscaling of offshore wind on the North Sea—Synthesis report*. Rijkswaterstaat Water, Verkeer en Leefomgeving

Verfuss, U. K., Sinclair, R. R., & Sparling, C. E. (2019). A review of noise abatement systems for offshore wind farm construction noise, and the potential for their application in Scottish waters. *Scottish Natural Heritage Research Report No. 1070*

Voigt, C. C., Lehnert, L. S., Petersons, G., Adorf, F., & Bach, L. (2015). Wildlife and renewable energy: German politics cross migratory bats. *European Journal of Wildlife Research*, 61(2), 213–219. https://doi.org/10.1007/s10344-015-0903-y

Voß, J., Rose, A., Kosarev, V., Vílela, R., Van Opzeeland, I. C., & Diederichs, A. (2023). Response of harbor porpoises (Phocoena phocoena) to different types of acoustic harassment devices and subsequent piling during the construction of offshore wind farms. *Frontiers in Marine Science*, 10, 1128322. https://doi.org/10.3389/fmars.2023.1128322

Walag, A. M. P. (2022). Chapter 1 - Understanding the World of benthos: An introduction to benthology. In P. S. Godson, S. G. T. Vincent, & S. Krishnakumar (Eds.), *Ecology and Biodiversity of Benthos* (pp. 1–19). Elsevier. https://doi.org/10.1016/B978-0-12-821161-8.00002-7

Weinert, M., Mathis, M., Kröncke, I., Pohlmann, T., & Reiss, H. (2021). Climate change effects on marine protected areas: Projected decline of benthic species in the North Sea. *Marine Environmental Research*, 163, 105230. https://doi.org/10.1016/j.marenvres.2020.105230

Zaucha, J., & Gee, K. (Eds.). (2019). *Maritime Spatial Planning: Past, present, future. Springer International Publishing*. https://doi.org/10.1007/978-3-319-98696-8

RENEWABLES GRID INITIATIVE E.V.

Manfred-von-Richthofen Strasse 4
12101 Berlin, Germany

+49 30 2332 11000
www.renewables-grid.eu

THE NORTH SEA FOUNDATION

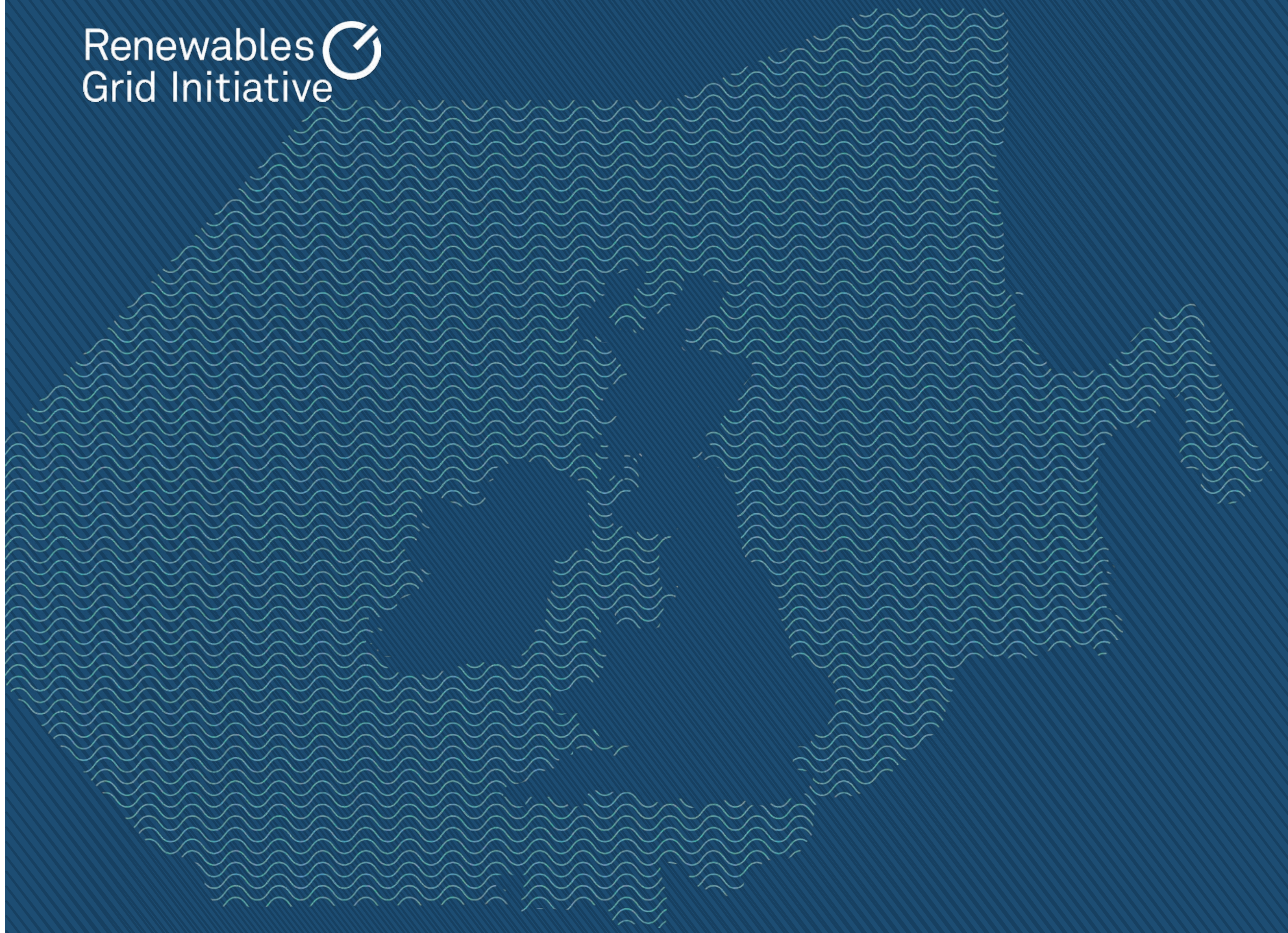
Arthur van Schendelstraat 600
3511 MJ Utrecht, Netherlands

+31 30 2340 016
www.noordzee.nl

CONTACTS

Team lead, Cristina Simioli
cristina@renewables-grid.eu

Editor, Ana Miljanović Rusan
ana@renewables-grid.eu



The Offshore Coalition for Energy and Nature (OCEaN) brings together NGOs, TSOs and wind industry organisations from across Europe. Together we work towards a sustainable deployment of offshore energy and grid infrastructure, while ensuring alignment with nature protection and healthy marine ecosystems.

Co-funded by the European Union

VELUX FOUNDATION

We thankfully acknowledge financial support from the VELUX FOUNDATIONS and the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union, CINEA or the VELUX FOUNDATIONS. The European Union, CINEA, and the VELUX FOUNDATIONS are not responsible for any use that may be made of the information it contains.