European Commission

Overview of the effects of offshore wind farms on fisheries and aquaculture

EASME/EMFF/2018/011 Lot 1:
Specific Contract No. 03

Final Report

Lead partner Wageningen Marine Research (including Wageningen Economic Research) in consortium with: MRAG Limited Europe; MRAG Limited; Centre for Environment, Fisheries and Aquaculture Science (Cefas); Research Institute for Agriculture, Fisheries and Food (ILVO); Johann Heinrich von Thünen-Institute: Federal Research Institute of Rural Areas, Forestry and Fisheries (TI), Technical University of Denmark (DTU); National Marine Fisheries Research Institute (NMFRI); Swedish University of Agricultural Sciences (SLU) and Institute of Food Safety, Animal Health and Environment (BIOR);
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Term	Description
BPNS	Belgian Part of the North Sea
BE	Belgium
DFPO	Danish Fishermen Producer Organization
DK	Denmark
EASME	Executive Agency for Small and Medium-sized Enterprises
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMFF	European Maritime and Fisheries Fund
FLOWW	Fishing Liaison with Offshore Wind and Wet Renewables
GW	Gigawatt
MSP	Maritime Spatial Planning
MW	Megawatt
NFFO	National Federation of Fishermen's Organisations
NL	The Netherlands
NSA	North Sea Agreement
ORJIP	Offshore Renewables Joint Industry Programme
OWFs	Offshore wind farms
RAC	Regional Advisory Council
SPL	scour protection layer
SIA	stable isotope analyses
UK	United Kingdom
VMS	Vessel Monitoring System

EXECUTIVE SUMMARY

The global shift to renewable energy, including large-scale development of offshore wind farms (OWFs), is well underway. This expansion will in certain places lead to increased coexistence and the potential for multiple uses of the space available for fishing and aquaculture activities, or to potential conflicts and restrictions for some fishing activities. Therefore, the overall objective of this study is to provide an overview of the state of knowledge on the existing and potential future effects of offshore wind farms (OWFs) on fisheries and aquaculture. A literature **review** on **several aspects** (ecology, management, legislation, socio-economics, stakeholders and governance) is executed, and complemented by **stakeholder interviews** (p 36-50) and **two case studies** (Belgian OWF [p51-57]; Danish Kriegers Flak area [p57-64]). This executive summary highlights the main outcomes, but also remaining challenges. A more elaborate overview can be found in the full summary (p 65-70) and gaps & recommendation section (p 73-78).

Ecology

Findings show that the installation and presence of offshore wind structures may lead to **a diverse set of changes on** the seafloor ecosystem (p 9-10). The type of effects is also related to the implementation stage of the OWF (construction, operation or decommissioning). Effects rank from low to medium or mixed (see table 1).

During **construction**, the marine ecosystem is temporally negatively disturbed through sediment displacement (altering the biodiversity) and high impulsive sounds from piling.

During the **operational** phase, introduced structures and/or turbine foundations **change the local habitat characteristics**, leading to mixed effects. Some can be considered as positive, as they provide a surface for colonization by fouling species and by attracting various fish (pelagic and demersal) and crustacean species (e.g. crabs, lobster) (artificial reef effect) (p 12). This changed the trophic interactions between species (p 11), with species profiting from the increased food availability or organic enrichment, also due to changes in hydrodynamics within OWFs (p 12). This **altered biodiversity** and **species occurrence** can lead to changes in ecosystem functions and processes (p 13-14), which are not yet well studied and are typically not addressed by environmental impact assessments (EIAs). Other effects are perceived more negatively, as the stepping stone effect for alien species, the effects caused by electromagnetic fields and operational sound. Most OWFs are **'*de facto*' closed areas for fisheries** (p 13). As such, an OWF area can be seen as a passive refuge and recovery area for long-living benthic species and fish, potentially resulting in higher densities and larger animals. Nevertheless, in practice, the effect seems currently modest in the short run. Therefore, in relation to fisheries, it is unknown what the observed changes (e.g. 'spill over' effect) mean at population level or wider regional scale for fish stocks.

The effects of **decommissioning** the OWF structures on ecology (e.g. some ecological benefits shall change), engineering possibilities (e.g. not increasing the OWF foot print in an area) and socio-economic aspects (e.g. OWF area back as fishing ground?) need to be collected.

Recommendation:

- The ecological research needs to be further oriented towards **ecosystem-based** approaches to better put into context if OWFs are **benefiting ecosystems** for fisheries and aquaculture.
- The ecological effects are documented, but the **degree** to which OWF development leads to **changes in biodiversity**, **species composition**, **spill-over effects** and **habitat characteristics** in the short, medium and long term have **to be defined** on wider scale (i.e. marine resource management scale).

Management

There is no general approach on **management strategies** for fishery and aquaculture in OWFs (p 15-21), as it is regulated case-by-case. The OWF development process is part of the obligatory **maritime spatial planning** (MSP) process for EU member states. The literature review and interviews conducted here show that the concerns of the fishery sector are often not fully considered in designing the OWFs areas. Some OWFs have set up compensation mechanisms for displaced fisheries; others have not. There are several hurdles that make co-location with fisheries difficult, such as safety risks (collision, cable damage) or the distance between turbines (to be larger to allow fishing operations). Therefore, the **MSP management process** needs to take into account these challenges to ensure co-existence between fisheries and OWFs. Consultation (from early stage and on continuous basis) can be regarded as a mitigation strategy to achieve this. For **offshore aquaculture**, which has a **clear co-location potential**, too few experimental studies testing its technical and economic feasibility are conducted and proving that there are many hurdles. Besides, the lack of clear licensing procedures and regulations are slowing down the development of offshore aquaculture in OWFs.

Recommendation:

- Describe **good practices of management** with respect to coexistence, co-location and cooperation of aquaculture and fisheries and describe the **net benefit** for both sectors for good management practices on the business model, livelihoods, social well-being.
- Analyze the short and medium term **losses in monetary units** for the fishing sector due to OWF development, while **considering the resilience of the sector** in the short and medium term by taking into account their potential to relocate effort or change occupation. This should give insights in possible compensation.
- Clarify the **management** and **legal framework** for **offshore aquaculture** activities by analyzing the different ways the multi-use process can be **stimulated** (e.g. incentives) and be better e**mbedded** in the member states **legislations and procedures** (e.g. licence process).

Legal

The right of Member States to regulate fisheries and aquaculture activities in and around OWFs derives from the **United Nations Convention on the Law of the Sea** (UNCLOS) (p 22-26), which confers upon them a right to claim a 12 nautical mile (nm) territorial sea (**full sovereignty**) and a 200 nm Exclusive Economic Zone (**sovereign rights**). Consequently, each Member State is free to adopt its own specific legislation on safety zones around OWFs. There is no **common approach to legislation on safety** around OWFs. In some Member States, the legislation provides for the creation of 500 m safety zones around OWFs in which all navigation is prohibited. Elsewhere the legislation permits navigation through OWFs but prohibits fishing either altogether or using active gear. In some Member States, safety zones are applied only during construction, maintenance and removal (overview table per member state at p 25-26).

Recommendation:

- Create an overview of national **legislations** determining the **operability** (possibilities and restrictions) of fishing and aquaculture in and around OWFs, and identify the possible modifications to these legislations for fishery and aquaculture stakeholders to operate within OWFs.

Socio-economic

The major **socio-economic effects** for **fisheries** (p 27-29) are the **loss of fishing grounds** (economic value, but also emotional value), leading to effects **on catch volume**, **gear conflicts** (e.g. bottom trawl gears cannot operated within OWFs, restrictions in anchoring passive fishing equipment [Pots, nets] within OWFs) and **changes in travel time** from harbor to fishing grounds. Fishermen tend to compensate for these through fisheries displacement (moving to other areas or fishing around the OWF edge) and switching to other gear types (e.g. mobile gear to crab or lobster potting). Nevertheless, this is associated with several issues, e.g. increased competition, safety implications (e.g. collision, cable damage), reduced flexibility and economic viability. It should be noted that there is no study that has provided complete quantitative data on the economic effects, especially those covering the full value chain (fishing, processing, transport, marketing). Therefore, positive or negative claims about the eventual socio-economic effects were not validated in this study.

Similarly, **socio-economic effects** on **offshore aquaculture** (29-31) were not identified, mainly because aquaculture in OWFs is still in its infancy and there were no real business cases or spatial conflicts that could be identified. Nevertheless, aquaculture within OWFs is identified in literature as the major co-use concept, offering possibly several advantages (creation of jobs directly and indirectly, new skilled labour, specialized suppliers, education programs, innovation jobs) and therefore enhancing and transforming local communities.

Recommendation:

- Develop the **socio-economic balance** for the fishery and offshore aquaculture sector in relation to restrictions and/or opportunities caused by OWFs to have a better view on possible **compensation** needs for **fisheries** and **wins** for offshore **aquaculture**.

Stakeholders

Stakeholders provided **different views** (often polarized by sector and areas) on the issues under study (p 36-50). These were largely dependent on the background of the stakeholder and their direct interactions with OWFs and collaborative opportunities with other stakeholders. Best practices in stakeholder governance were identified as early engagement in discussions and planning of OWFs, alongside support for active enforcement of multi-use in future marine spatial planning.

Recommendation:

- **Early engagement** in discussions and planning, on a **continuous basis** and by **taking into account** the fishery and aquaculture **needs** from the start of the OWF design is essential **to create beneficial conditions** for future multi-use and co-location of fishery and offshore aquaculture activities with OWFs.

RÉSUMÉ EXÉCUTIF (FRANÇAIS)

La transition vers les énergies renouvelables, incluant le développement à large échelle de parcs éoliens off-shore (PEO), est maintenant largement entamée. Ce développement va engendrer une multiplication des activités humaines sur les espaces maritimes qu'utilisent la pêche et l'aquaculture pour leurs activités, et pourra potentiellement engendrer des restrictions pour les activités de certaines pêcheries, voir des conflits d'usage. L'objectif général de cette étude est de présenter l'état des connaissances disponibles concernant les implications actuelles et à venir du développement des parcs éoliens sur les activités de pêche et d'aquaculture. Une **revue de la littérature** couvrant **différents points** (écologie, gestion, législation, socio-économie, décision et gouvernance) a été réalisée, et est complétée par des **enquêtes menées auprès des parties prenantes** du secteur (p 36-50) et par l'analyse détaillée de **deux cas d'étude** (PEO en Belgique, p65-70 et zone du Kriegers Flak au Danemark, p73-78).

Ce résumé exécutif reprend les principaux résultats, ainsi que les défis à relever. Pour plus de détails, le lecteur pourra se rapporter au résumé complet (p. 65-70) et à la section concernant les lacunes et recommandations (p 73-78).

Ecologie

L'installation et la présence d'éoliennes off-shore pourrait engendrer des divers **changements** des fonds marins et de l'écosystème dans son entier (p 9-10). Les effets potentiels varient selon le stade de développement de l'activité éolienne off-shore (construction, exploitation, démantèlement) et sont considérés faibles, modérés ou mixtes (voir table 1).

La phase de **construction** perturbe de façon temporaire l'écosystème marin du fait du brassage des sédiments (ce qui affecte la biodiversité) et des bruits et vibrations liés à la construction.

Pendant la phase **d'exploitation**, la présence des fondations des turbines et l'introduction de structures immergées changent les **caractéristiques locales de l'habitat,** ce qui a des effets multiples. Certains peuvent être considérés comme bénéfiques, car ces structures jouent un rôle de récifs artificiels, fournissant un substrat qui est colonisé par des organismes sessiles, qui à leurs tours attirent différentes espèces de poissons (pélagiques et démersales) et de crustacés (crabes et homards, p 12). Ceci altère les relations interspécifiques (p 11), certaines espèces profitant de la disponibilité accrue en nourriture ou de l'enrichissement en matières organiques causé par la modification de l'hydrodynamisme au sein des PEO (p 12). Ces changements de la **composition spécifique** et la **biodiversité** peuvent entrainer des modifications des processus et des fonctions de l'écosystème (p 13-14), qui ont à ce jour fait l'objet de peu d'études, et ne sont généralement pas prises en comptes dans les études d'impact environnemental (EIE). D'autres effets peuvent être considérés comme négatifs, tels que l'effet « porte d'entrée » pour les espèces allochtones ou les effets causés par les champs électromagnétiques et les perturbations sonores. La plupart des PEO sont **de fait des zones ou la pêche est interdite** (p 13). Une zone de PEO peut être considérée comme un refuge passif et une zone propice à la restauration des populations d'espèces benthiques à longue durée de vie, conduisant à l'augmentation à la fois densités de populations et du nombre d'individus de grande taille. On n'observe cependant en pratique que des effets modérés pour le moment. De ce fait, en ce qui concerne la pêche, on ignore quels effets de ces changement locaux peuvent avoir à l'échelle des stocks halieutiques, généralement distribués à plus large échelle.

Les conséquences du démantèlement des PEO en matière d'écologie (p. ex. réversibilité des effets bénéfiques), d'engineering (p. ex. ne pas augmenter l'empreinte d'un PEO dans une zone) et du point de vue socio-économique (p.ex. possible restitution des zones de PEO aux activités de pêche) n'ont pas encore été identifiées.

Recommandation:

- la recherche dans le domaine de l'écologie doit d'avantage s'orienter la compréhension des **aspects écosystémiques** afin de savoir si l'activité éolienne off-shore est **bénéfique aux écosystèmes** et à leur utilisation pour la pêche et l'aquaculture

- les effets écologiques sont documentés, mais il nécessaire de définir dans quelle mesure le développement des PEO conduit à des changement à plus large échelle (i.e. à l'échelle où s'effectue la gestion des ressources marines) en terme de biodiversité, composition spécifique, effets d'épanchement hors des zones des PEO , et caractéristiques des habitats.

Gestion

Il n'y a pas de cadre général pour la **régulation des activités** de pêche et d'aquaculture dans les zones couvertes par les PEO (p 15-21), celle-ci est définie au cas par cas. Le développement des PEO se fait dans le cadre de la **planification spatiale maritime** (PSM), processus obligatoire pour les états membre de l'UE. La revue de la littérature et les enquêtes menées lors de cette étude ont montré que les préoccupations des pécheurs ne sont en général pas prises en compte dans l'aménagement des zones de PEO. Pour certains PEO, des mécanismes de compensation ont été mis en place pour les pêcheries dont les zones de pêches ont dû être déplacées, mais cela n'est pas le cas partout. L'activité de pêche, dans ou autours des zones occupées par les PEO se heurte à un certain nombre de facteurs limitants, tels que des risques pour la sécurité (collision, dégâts sur les câbles) ou la distance séparant les éoliennes (qui devrait être plus grande pour permettre l'activité de pêche). Ces contraintes doivent être prises en compte lors de la PSM afin d'assurer la coexistence des activités éoliennes off-shore et la pêche. Ceci peut être facilité par la mise en place de stratégie de consultation entre les différents acteurs (dès le début du projet et de façon continue).

L'aquaculture en pleine mer, en revanche, pourrait **potentiellement mieux cohabiter** avec les activités éoliennes off-shore, mais trop peu d'études expérimentales testant leur faisabilité technique et économique ont été menées, et celles-ci montrent qu'il y a de nombreux obstacles. De plus, l'absence de règles d'attribution de licences et de régulations freinent pour l'instant de développement de cette activité.

Recommandation:

- quelles sont les bonnes pratiques (en termes de coexistence, co-location ou coopération) pour les activités de pêche et d'aquaculture et en quoi leur application bénéficierait elle au modèle économique, moyens de subsistance et bien-être social pour ces deux secteurs ?

- analyse des pertes en unités monétaires à court et moyen terme liées au développement des PEO pour le secteur de la pêche, tout en considérant la résilience du secteur à court et moyen terme en prenant en compte son potentiel à délocaliser son effort ou changer d'activité. Ceci devrait permettre d'appréhender les compensations possibles.

- clarifier les **règles de gestion et le cadre légal** pour les activités d'aquaculture dans les PEO en analysant par quels moyens (incitations) un usage multiple pour être encouragé et s'intégrer dans la législation des états membres (e.g. octrois de licences).

Législation

Le droit des Etat Membre à réguler les activités de pêche et d'aquaculture dans et autour des PEO est définit par **la Convention des Nations Unies sur le droit de la mer** (CNUDM, p 22-26), qui leur confère une **souveraineté totale** sur les eaux territoriales (distance de 12 miles nautiques de la cote) ainsi qu'un **droit souverain** sur la zone économique exclusive (200 miles nautiques de la cote). Les états membres sont par conséquents libres de définir leur propre législation concernant les zones de sécurité autour des PEO. Il n'y a pas **d'approche commune pour cette législation** au sein de l'UE. Certains états membres ont établi des zones de sécurité à une distance de 500m autour des PEO, dans laquelle la navigation est interdite. Ailleurs, la navigation au sein des PEO est autorisée, mais les activités de pêche, soit dans leur ensemble, soit lorsqu'elles utilisent des engins de pêche actifs, y sont interdites. Dans certains états membres l'accès aux zones de sécurité est interdit uniquement lors des opérations de construction, maintenance et démantèlement des éoliennes (tableau récapitulatif par état membre, p25-26).

Recommandation:

- faire l'inventaire des législations nationales sur concernant les possibilités et restrictions pour la pêche et l'aquaculture à l'intérieur et autour des PEO et identifier les nécessaires modifications de ces législations qui permettraient aux parties prenantes pour la pêche et l'aquaculture d'initier un développement au sein des PEO.

Aspects socio-économiques

Les principales **conséquences socio-économiques** pour la pêche (p 27-29) sont en premier lieu la **perte de zones de pêche** (impact économique mais aussi émotionnel) qui affecte le **volume des captures**, des **restrictions pour l'utilisation les engins de pêche** (par exemple le chalut de fond ne peut pas être mis en œuvre dans un PEO, l'encrage d'engions passifs – filet maillants, casiers – est soumis à restrictions) et **l'augmentation du temps de route** entre le port et les zones de pêche. Les pêcheurs doivent modifier leurs pratiques en déplaçant leur activité de pêche (vers d'autres zone, ou vers la périphérie des PEO). Cela a néanmoins certaines conséquences, notamment une compétition accrue, des risques en termes de sécurité (collision, dégâts sur les câbles), une moindre flexibilité et une viabilité économique diminuée. Aucune étude quantitative n'est encore disponible sur les effets économiques tout au long de la chaine de valeur (pêche, transformation, transport, vente). Cette étude ne peut par conséquence pas confirmer l'existence d'effets socio-économiques positifs ou négatifs.

De la même façon, les **effets socio-économiques** sur **l'aquaculture en pleine mer** (p 29-31) n'ont pas pu être identifiés. Cette activité commence tout juste à se développer au sein de PEO et qu'aucun exemple concret n'a pu être analysé durant cette étude et les conflits spatiaux n'ont pas pu être identifiés. L'analyse de la bibliographie indique que l'aquaculture au sein des PEO représente une des meilleures voies de co-utilisation de l'espace maritime, offrant de nombreux avantages (création d'emploi direct et indirect, d'une activité hautement qualifiée, d'une chaine d'approvisionnement, de programmes d'éducation) et a donc le potentiel pour faire évoluer et transformer les communautés locales basées principalement sur la pêche.

Recommandation:

- dresser un **bilan socio-économique** des effets des restrictions et/ou opportunités liées aux PEO pour les activités de pêche et d'aquaculture, afin de mieux définir les besoins de **compensation** pour le **secteur de la pêche** et les **gains** liés au développement potentiel de **l'aquaculture en pleine mer**.

Parties prenantes

Différents points de vue (souvent opposés en fonction des secteurs d'activité et des zones géographiques) ont été relevés chez les **parties prenantes** à propos de la problématique des PEO (p 36-50). La perception des enjeux variait en fonction du profil de la partie prenante, la nature de ses interactions directes avec les PEO et les opportunités de collaborations avec d'autres parties prenantes. Des règles de bonne pratique ont été identifiées pour la gouvernance en lien avec les parties prenantes, par exemple la nécessite de les impliquer dès le début des discussions et de la planification de PEO et d'encourager le développement des usages multiples de ces zone lors du processus de planification spatiale maritime.

Recommandation:

- un engagement précoce et continu des parties prenantes dans les discussions et la planification ainsi que la prise en considération des préoccupations du secteur de la pêche et de l'aquaculture dès le début de la conception des PEO sera nécessaire pour créer des conditions propices à une cohabitation sur un même espace des activités de pêche et d'aquaculture au sein des PEO.

1. INTRODUCTION

The global shift to renewable energy, including large-scale development of offshore wind farms (OWFs), is well underway. There are already about 5,000 wind turbines operating along European coasts, with an installed capacity of around 20,000 Megawatt (MW). Wind energy provides an essential contribution to meeting the goals of the Paris climate agreement[1] and the European Commission's decarbonization strategy[2]. Offshore wind represents a marginal source of energy for the EU today. However, it has a strong potential for development, as technology is mature and costs have dramatically decreased. According to the EU Offshore Renewable Energy Strategy[3], the aim is to increase the capacity of European OWFs from 12 GW today to 300 GW in 2050. Therefore, European offshore wind power will need to grow 3- to 4-fold by 2030 and 20-fold by 2050.

The long-term impacts of wind turbines on marine life are still under study, as several key knowledge gaps remain. Their interaction with regional marine ecosystems needs to be monitored closely. Besides the effects on the marine ecosystems (which may have positive as well as negative aspects), the increase in OWFs could affect or provide beneficial aspects to the operations of other industries, including the fishing and aquaculture sectors. The expansion of marine renewable energy will therefore inevitably lead to increased coexistence and the potential for multiple uses of the space available for fishing and aquaculture activities, or to the restriction and potential conflict for some fishing activities.

With this rapid rise in OWF development, it is important to be aware of the evidence that has already been gathered through research projects, studies and assessments of the effects of OWFs on fishing and/or aquaculture activities. This includes findings concerning circumstances where there may be positive consequences for fishing activities through, for example, an increase of stock species recruitment, and negative ones, where fishing activities experience economic losses and negative social consequences through, for example, loss of fishing grounds. As the effects are likely to vary considerably by area, among other factors, it is important to improve our knowledge. While results from many studies are available, their disparate and local focus make it difficult to obtain a consolidated overview at meaningful scales (i.e. regional or ecosystem wide) of the effects that have been observed on various aspects of fisheries and/or aquaculture activity.

[1] FCCC/CP/2015/10/Add.1

[2] COM/2019/640 final

[3] COM/2020/741 final

In this context, the overall objective of this study is to provide an overview of the state of knowledge on the existing and potential future effects of OWFs on fisheries and aquaculture. Therefore, this report delivers a critical, state-of-the-art overview of the effects of wind farms on fisheries and aquaculture, covering the North and Baltic Seas. Different types of effects are reviewed (chapter 3), with a focus on ecology, management, legal, socio-economic and governance aspects. The review of these aspects is based on a core set of scientific publications, project reports, expert views and experiences, with a view to identifying the major effects of wind farms on fishing and aquaculture activities now and in the future. This desk-based research is complemented with key stakeholder interviews (chapter 4) and case studies (chapter 5). The main results of the study are summarized in chapter 6. This is used to identify research gaps and recommendations for future studies (chapter 7).

Findings from this study can feed into discussions and decision-making on the Common Fisheries Policy (CFP)[4], analysis of maritime spatial planning, the sustainable blue economy strategy[5], and the implementation of the EU offshore renewable energy strategy announced as part of the European Green Deal[2].

What to expect?

The sections on the studied aspects (ecology, management, legal, socio-economics and stakeholders & governance) outline what can be learned from the literature review, based on peer-reviewed publications, reports, experiences from the research consortium and practices in certain EU Member States. The overview of each aspect is not exhaustive but sets the scene for what the main effects of OWFs on fishery and aquaculture activities are.

Perceptions from the fisheries and aquaculture sectors, wind farm developers, governments and NGOs were gathered through interviews. These provide an insight into stakeholders' experiences and knowledge of the studied aspects. These insights are outlined in detail in the report.

Two case studies are used to illustrate the issues under study. The Belgian OWF case study provides 'real-life' context on all aspects, based on insights from an operational OWF area with a long history of scientific research. It illustrates the importance of a two-tiered monitoring approach (combining basic and targeted monitoring) to increasing our knowledge base. The Danish Kriegers Flak case study provides a typical example of the environmental impact assessment (EIA) process required ahead of an OWF implementation, and illustrates how the knowledge gaps on anticipated OWFs effects are currently tackled in such EIAs.

The summary section integrates the main findings of the studied aspects, directly complementing the stakeholders' views (from Belgium, Denmark, the Netherlands and UK[6]) with 'real-life' examples from the case studies.

The recommendations are tabulated based on the gaps identified.

[4] Regulation (EU) No 1380/2013

[5] Will be published in Spring 2021

[6] UK, as non EU-member, is included in this study as it is one of the leading countries in offshore wind energy.

2. EFFECTS OF OWFs ON FISHERY AND AQUACULTURE

2.1. Ecology

2.1.1. Literature selection

This section presents a review of the ecological effects resulting from the presence of OWFs and their potential effects on marine fauna (primarily invertebrates and fish). A search of relevant available literature was undertaken in Web of Science and Google Scholar search engines. The searches used terms related to offshore wind including fisheries, effects and impacts and ecological receptors covering **fish** and **benthos**. A long list of the relevant documents was compiled and was later reduced to a short list of the most relevant and recent literature. These included the use of review scientific literature that had collated and interpreted evidence from earlier studies worldwide, e.g. Dannheim *et al.* 2020.

The compiled literature consisted of scientific and grey literature that had documented the suite of known and potential effects resulting from OWFs and comprised a total of 22 papers published between 2006 and 2020. It is worth noting that the most recent literature tends to cite previous studies or builds on work from 2005 and earlier. This literature was then used to compile and analyse the direct observed changes resulting from the different stages of an OWF, including construction, operation and decommissioning phases (Table 1). The effects were categorized according to the three main OWF structures of relevance to the ecology: turbines, scour protection and cables. An indirect (consequent) effect of OWFs, fishery exclusion was categorized separately. The analysis includes an expert judgement on whether there are positive, negative, mixed effects or no effect, and confidence in the effect scored as low, medium or high.

2.1.2. Summary of main observed ecological effects

Table 1. Summary of the main observed effects linked to three major structures (turbines, scour protection and cables) in the different wind farm phases. One reference is cited as an example for each effect statement. Text denoted in bold indicates ongoing challenges associated with the ecological effect assessment. The likely type of effect based on current knowledge is indicated as either *positive, negative, mixed or no effect*. Confidence in the effect category is indicated by (*low/medium/high*). The full short list of reference short list is published in the Appendices.

	Effects related to wind farms itself			Consequent effects
Phase	Turbine	Scour protection	Cables	Fishery exclusion
Construction	Habitat modification leading to altered biodiversity (Coates *et al.* 2014) - mixed (medium)			
	Increased sediment resuspension (Dannheim *et al.* 2020) - negative (medium)			
	High impulsive sound, effects on mobile species behaviour (Thomsen *et al.* 2006; De Backer *et al.* 2017b) - negative (medium)		Sediment displacement, impoverishment of sea floor ecosystem (Dannheim *et al.* 2020) - negative (low)	

Operational	Artificial reef effect: e.g. fouling community and attraction of mobile, pelagic fish (feeding) (Dannheim *et al.* 2020, Reubens *et al. 2013a & b*) - positive (medium)	Artificial reef effect: e.g. shelter and food for demersal fish between stones (Dannheim *et al.* 2020, Mavraki 2020) - positive (medium)	Artificial reef effect depends on cable protection matrix (e.g. stones = scour effects) (Sheehan *et al.* 2020) - positive (medium)	Refugium and recovery area for long-living benthic species and fish e.g. higher densities and larger size classes (Bergman *et al.* 2015, De Backer *et al.* 2020) - positive (medium)
	Altered biodiversity **and changes in ecosystem functions and *processes*** (Dannheim *et al.* 2020) - mixed (low)			
	Stepping-stone effect, increasing population connectivity (e.g. invasive species, red list species) (De Mesel *et al.* 2015) - negative (low)		**Electromagnetic field effects** (Hutchison *et al.* 2020) - negative (low)	
	Changes in hydrodynamics resulting in increased suspended material and local organic enrichment (Dannheim *et al.* 2020) - mixed (low)			
	Changes in trophic interactions (Mavraki 2020) - mixed (low)			
	Operational sound may disturb species behaviour in the long term and permanently (Dannheim *et al.* 2020, De Busschere *et al.* 2016) - negative (low)			
	Chemical pollution from corrosion protection system (Kirchgeorg *et al.* 2018) - negative (low)			
Decommissioning	**Effects are still poorly understood.** The current Danish Horns Rev offshore windfarm is one of the first examples in Europe in which to assess the effects of decommissioning. There are still many gaps to consider in terms of ecology, engineering and social aspects of removing a structure. Some lessons could be considered from oil and gas industry and wrecks work - negative (low)			

2.1.3. Effects on ecological components and the wider ecosystem

The presence of OWFs adds to local anthropogenic pressures on the seafloor and, with the scale of offshore wind development in the future, pressures may be greater at the ecosystem level. Therefore, an understanding of the effects on key ecological components is required to provide further ecological insights into the effects and their potential consequences. To date, research efforts have documented the current and expected ecological effects resulting from the initial and long-term installation stages at the scale of turbines and, in some cases, wind farms (e.g. Reubens *et al.* 2011; Krone *et al.* 2013; Coates *et al.* 2014; Stenberg *et al.* 2015; Lindeboom *et al.* 2015). Several reviews (see Boehlert and Gill 2010; Gill *et al.* 2018; and Dannheim *et al.* 2019 & 2020) have described the effects of OWFs, helping to illustrate the effects on **single ecological receptors** (e.g. benthos, mammals and fish). In general, there is still limited knowledge available on the interactions between and within ecological receptors. An understanding of the **ecosystem level effects** resulting from these OWFs is needed to determine how the effects translate to ecologically relevant impacts (see Boehlert and Gill 2010; Willsteed *et al.* 2017).

The introduction of structures into the marine environment results in a **locally altered biodiversity** due to habitat modifications (Wilding *et al.* 2017). Depending on the type of project, construction could last from several months to several years (Gill *et al.* 2018). Besides construction, there is an array of sub-sea cables and connectors to substations (offshore and onshore) that widen the area affected (e.g. intertidal and/or coastal areas). The benthic changes related to OWFs occur particularly at small spatial scales (turbine scale and close vicinity, e.g. Whitehouse *et al.* 2011). However, if these effects occur with each turbine then they could have implications for broader spatial scales and ecological interactions. These interactions are predicted to be related to trophic linkages and energy flows (Gill *et al.* 2018). However, to date, only a limited number of studies have tried to address these trophic linkages and ecological processes to elucidate the effect of OWFs on marine ecosystems at large.

An ecosystem model approach has been used to link different ecological receptors (from phytoplankton to mammals) to demonstrate **total ecosystem activity**, where the overall proportion of generalist feeders and recycling would increase in the presence of an OWF (Raoux *et al.* 2017). This ecosystem model approach showed that higher trophic levels, such as piscivorous fish, responded positively to the increased biomass on turbines and the scour protection layer (SPL) (Raoux *et al.* 2017). **Fish attraction** induced by OWFs has been observed in some studies (e.g. Reubens *et al.* 2011; Stenberg *et al.* 2015). Whether the presence of these fish may also result in increased production warrants further investigation. Nevertheless, some preliminary work (see section 4.1.2) on this exists in connection with the attraction–production hypothesis with respect to OWFs, showing that this is pivotal for efficient management for the associated fisheries (Reubens *et al.*2014; Mavraki 2020).

Mavraki (2020) has recently studied the local **food-web ecology** of OWFs using stable isotopes as tracers and showed that structural community differences are reflected in the food-web structure of communities occurring at different depth zones along the turbine. Furthermore, SPLs play a key role as feeding grounds for both vertebrate and invertebrate species (Mavraki 2020). Mavraki (2020) also suggested that trophic generalists will be over-represented and trophic specialists under-represented in the North Sea in the future because of new structures. Finally, it has been shown that the introduction of jacket foundations causes the highest increase in carbon assimilation compared to other types of foundations, significantly reducing the carbon content of the water column (Mavraki 2020). This implies that foundations with SPLs, such as **gravity-based and monopile foundations**, are likely to be **beneficial for local food webs** (Mavraki 2020). These types of studies have shown that looking at ecological processes and interactions between different ecosystem components is the way forward for a more holistic view including the ecosystem-approach to environmental management of OWFs. However, further work is needed to support studies of trophic relationships and the transfer of organic matter from producers to consumers (Brickhill *et al.* 2005), coupled with fish movement assessments (Reubens *et al.* 2014).

2.1.4. Changes in hydrography

Depending on the characteristics of the area and, primarily, the hydrodynamics, the water column could be influencing the seafloor communities directly and indirectly.

Hydrodynamics could directly influence the benthos via the transport and dispersal of larvae, juveniles and adults, with repercussions for population dynamics (Levin 2006). Hydrodynamics could directly influence the primary and secondary production in the water column and the transport pathways of these **food sources** to the benthic system (Rosenberg 1995). Offshore structures and construction activities will create local changes in hydrodynamics and sediment transport, affecting turbidity, fine-grained sediment dynamics and bed shear stress (Whitehouse *et al.* 2011; Nielsen *et al.* 2013).

2.1.5. The life cycle of a wind turbine (construction, operation and decommissioning)

During the different stages of OWFs (i.e. pre-construction, construction, operation and decommissioning phases), the benthic environment can be affected and/or modified (Table 1). Several effects are at play during these different phases and have been documented quite extensively in the past (e.g. Dannheim *et al.* 2020).

Construction activities (including drilling of the piles, foundations, score protection layer, cable grid) will disturb the sediment and can affect the hydrography, depending on the scale and duration of the activity. The presence of vessel activity (e.g. anchoring) and cable laying modifies the seabed in the area during construction. Some research has tested the changes directly produced by cables on seabed communities (Taormina *et al.* 2020). However, this evidence is limited. In most cases, the research has been targeted at assessing the effect of dredging and/or sediment removal during construction and cable laying on species and habitat, and has documented colonization, succession patterns and overall recovery from these activities. The degree of this disturbance and the consequent habitat modification that may result depends on the spatial extent of the disturbance, the natural dynamics of the site and the time taken for conditions to return to the previous state. The potential recovery of these areas is influenced by the remaining sediment types, the hydrodynamics of the local environment and the pool (e.g. larvae and adult) of colonizers in these areas. In high-energy environments (e.g. parts of the North Sea), these effects are likely to be temporary and localized in comparison to low-energy environments, as some research has shown in Belgium (see Coates *et al.* 2014).

During the **operation** phase, introduced structures and/or foundations will change the local characteristics by providing a surface for colonization and potentially acting as an artificial reef (Boehlert and Gill 2010). Scour effects (defined as the removal of sea floor sediment by hydrodynamic forces) are likely to be relatively high around the structures in some OWF areas and will be affected by the type of foundation design (ICF 2020). Scour results in high turbidity and increased suspended sediment concentration around the turbine, leading to the removal of substrata, changing the habitat morphology and species composition (Callaway *et al.* 2002). To counteract this, a scour protection layer is often installed at most OWFs, leading to an **artificial reef effect**. OWFs and their scour protection layer have been observed to be colonized by high densities of fouling species. Several studies have documented the presence of suspension feeder species such as mussels, anemones and amphipods (e.g. Wilhelmsson and Malm, 2008; Krone *et al.* 2013; Slavik, *et al.* 2019, Mavraki 2020). The presence of structures and their colonizing fouling communities will facilitate the presence of mobile organisms. Mobile benthic and demersal species, like Atlantic cod (*Gadus morhua*), pouting (*Trisopterus luscus*), European lobster (*Homarus gammarus*) and edible crab (*Cancer pagurus*), as well as pelagic fish like mackerel (*Scomber scombrus*), seabirds like sandwich tern (*Thalasseus sandvicensis*), and marine mammals such as the harbour seal (*Phoca vitulina*) and grey seal (*Halichoerus grypus*) are often observed in high densities in the proximity of these structures (e.g. Soldal *et al.* 2002; Krone *et al.* 2013; Reubens *et al.* 2014; Russell *et al.* 2014). These species are assumed to take advantage of the 'locally enriched' areas for feeding and shelter activities around structures. These aggregations and the combined effects are known as the 'artificial reef effect' (Reubens *et al.* 2013a & b, Dannheim *et al.* 2020; Birchenough and Degraer 2020 for a summary of effects).

The process of **decommissioning** of an OWF could have similar effects on benthic communities as those identified during the construction phases (Gill, 2005; Bergström *et al.* 2014). However, some additional effects are to be expected, as, with the removal of long-term underwater structures (Fowler *et al.* 2018), all the fauna colonizing in and around this area will be affected, with expected changes in abundance and repercussions for overall biodiversity (Birchenough and Degraer 2020).

2.1.6. Effects of fishery exclusion

The presence of a fixed structure and provision of an artificial reef effect have also been studied as the effects of the 'de facto' closure for fisheries within a 500 m radius of the construction (UNCLOS Art. 60, paragraph 5). In Europe (except in the UK), all OWFs are currently closed to trawl fisheries (Gray *et al.* 2016). This regulation provides an opportunity for the surrounding seafloor **to recover** from the **disturbance** following the introduction of the structure (this is known as the *fisheries exclusion effect*). Available knowledge on fisheries exclusion effects, and specifically on benthic ecosystems, in windfarm areas is scarce (Van Hoey *et al.* 2020). However, some studies have considered these early effects (Jak & Glorius 2017; Lefaible *et al.* 2019). The evidence suggests that these effects are minimal for benthic communities (e.g. on their diversity, density and biomass). It has also been observed that demersal fish species inhabit the foundations (e.g. Reubens *et al.* 2011).

The Belgian OWF monitoring program has shown the presence of larger plaice within the windfarm when compared to the surrounding areas (Vandendriessche *et al.* 2015; De Backer *et al.* 2019; De Backer *et al.* 2020). To date, **it remains difficult to demonstrate** that **fishery exclusion** zones could **influence seafloor communities in OWFs**. This is due to the fact that most monitoring studies are conducted over short time frames and certain types of species (e.g. K-strategists) has slow recovery time (Bergman *et al.* 2015). Indeed, in Belgium where a longer monitoring program takes place, first signs of a refugium effect for certain fish species (e.g. plaice, lesser weever,…) only became apparent after nine years of monitoring (De Backer *et al.* 2020). Additionally, the current wind farm licensed areas are probably not large enough to demonstrate (positive) effects of fisheries exclusion beyond the immediate vicinity of the turbines. Nevertheless, the example of the European lobster (Roach *et al.* 2018) and, in some studies, the occurrence of larger bivalve species (*Spisula* sp., *Tellina,* sp.) (Jak & Glorius 2017) and fish, may indicate a **size effect**, potentially related to fishery exclusion. It is evident that offshore wind farms **offer a shelter area**, helping to safeguard commercial fish stocks. Recent studies have described some of the benefits associated with this protection, for example, in supporting the sustainable exploitation of artificial reefs (see Pitcher *et al.* 2002; Claudet & Pelletier 2004).

2.1.7. Considerations about the ecological effect assessments

Most of the ecological understanding of the effects on benthic species and fish has focused on studying their structural properties (e.g. their distribution and presence/absence). However, as structures are introduced over a long time (e.g. 20 to 25 years), there is a need to understand the cumulative context and the extent to which this increased level of human activity exerts further pressure on these ecosystems. Undertaking targeted ecological studies to **understand these effects on ecosystem structures, processes, and functions** (Thrush and Dayton, 2002; Lindeboom *et al.* 2015) is a pressing need. To date, most of the ongoing monitoring work conducted in OWFs is aimed at complying with Environmental Impact Assessments (EIAs), often targeting specific regulatory needs on specific ecosystem receptors rather than ecosystem services (Lindeboom *et al.* 2015; Wilding *et al.* 2017) and not dealing appropriately with cumulative environmental effects (Willsteed *et al.* 2017). While the current effects have been studied over time, responses for some aspects are still unclear and need to be assessed in detail. Current knowledge indicates that some aspects have positive effects (e.g. fisheries) where aggregations of species favour the presence of OWFs (Reubens et al. 2013a &b). While these patterns are potentially positive, further work is needed to properly describe and assess these responses across all OWFs and to determine if they can be classed as positive (or not). Some of the literature also highlights that there is a variable level of monitoring (Willsteed *et al.* 2017). Therefore, some effects could only be observed on specific species over the short term (e.g. noise effects in the proximity of some species, see Thomsen *et al.* 2006 for an overview of potential effects). Ongoing monitoring efforts aim to collect data to bring all the current observations together and distil site-specific and ecological responses across areas, developments and species, thereby allowing the type of effect to be interpreted as a meaningful impact that may require management (Boehlert and Gill 2010; Wilding *et al.* 2017).

2.2. Management

The North and Baltic Seas will experience large-scale expansion of (OWFs) between 2020 and 2030 (5-fold) and 2050 (25-fold). This will lead to increased spatial competition and displacement for fisheries and aquaculture but will also create opportunities. Within this chapter is a description of possible fishery and aquaculture management strategies that could aid in mitigating and adapting to the expansion of OWFs in the North and Baltic Sea. The focus is on **good practices** in **management** and **consultation** of fisheries and aquaculture in the case of OWF expansion, gathered through a dedicated literature review. Our recommendations are geared towards **practical measures or policies** that could be implemented at a Member State or EU level.

2.2.1. Literature selection

For the literature review, a long list was compiled based on a literature search in Google Scholar and Scopus using the following search terms (and several combinations of these terms): offshore wind farms, OWF, wind farms, renewable energy, multi-use, fisheries, fishery, fishing, aquaculture, mariculture, management, marine spatial planning, MSP, adaptation, mitigation, spatial. Based on these searches, a long list of 107 articles was gathered, all of which, apart from three exceptions of grey literature, were published in peer-reviewed journals. The long list consists of articles that relate to OWFs and fisheries and/or aquaculture. However, most articles had a strong socio-economic, governance or ecological focus. Based on the title and abstract of the article, we selected the articles that were expected to provide recommendations for management of fisheries and aquaculture activities that are influenced by OWF construction. Following this, a short list of 16 relevant articles was selected, most of which are explorations of possible policies and management strategies.

Most of the articles on fisheries **recommended** '**better consultation processes** but did not elaborate on what such a process should look like. Therefore, an additional search in Google Scholar was conducted, using the keywords consultation, fisheries and wind. This resulted in three relevant articles discussing consultation processes. A recently published technical report (De Koning & Trul, 2020) on challenges and opportunities for OWF and mussel farm integration at the North Sea was added to the three on fisheries consultation. In total, **20 articles were evaluated in detail**, and this chapter is based on these. From the 20 articles, 11 used qualitative methods, 6 quantitative methods and 3 both qualitative and quantitative methods. Qualitative methods include interviews, workshops, open questionnaires, policy reviews and literature reviews. Quantitative methods include (spatial) modelling, closed questionnaires and ecological fieldwork. Except for one Taiwanese case, all case studies were performed in Europe. Different types of fisheries were covered, such as beam trawl, flyshoot, dredging and static gears. The articles on aquaculture mainly focused on molluscs and algae cultivation; only one article related to finfish aquaculture (Adriatic Sea).

2.2.2. Opportunities for fisheries and aquaculture in OWF

OWFs can be used as a tool for conserving fish stocks, for instance, by limiting access to OWFs for commercial and/or recreational fisheries using a permit system (Fayram *et al.* 2007). A study in an OWF on the English North Sea coast (Westermost Rough) also shows that OWFs can be used as an easily delineated area for rotational closures of lobster fisheries, which can help prevent overfishing (Roach *et al.* 2018). Hooper & Austen (2014) show that the potential of OWFs to increase lobster populations depends on the design of the OWFs; that potential being related to not having scour protection on certain parts of the turbines or installing additional rock armouring. Within the literature reviewed, co-location of OWF and fisheries was only mentioned in relation to static gear such as pots. There is no mention of static gears in OWF aimed at finfish, such as gillnets, maybe because it is not optimal to use within OWFs.

Combining aquaculture with OWFs can result in a cost reduction for aquaculture operations (Wever *et al.* 2015; Michler-Cieluch *et al.* 2008; Buck *et al.* 2017; Buck *et al.* 2004) if operations are co-managed instead of designed as separate activities in the same space. By cooperating, wind farmers and aquaculture companies can benefit and learn from each other's skills, knowledge and perspectives (Michler-Cieluch *et al.* 2009).

2.2.3. Adaptation and mitigation strategies for (displaced) fisheries

OWF expansion can impact North and Baltic Sea fisheries in several ways. Depending on national regulations, fisheries can, cannot or can partly access OWFs, which leads to a loss of fishing grounds, displacement or co-location of fisheries and OWFs. Loss of fishing grounds and displacement of fisheries can lead to a decrease in income (see section 2.4.2.1) not only for the displaced fishermen, but also for other fishermen who might experience increased competition in other areas (Gray *et al.* 2005). Co-location can be an opportunity for fishermen; however, the fishermen that currently fish in planned OWF areas are not always the same type of fishermen that are allowed to fish in OWFs (Hooper & Austen 2014). Except in the UK and maybe in France , bottom trawling in OWFs is not allowed in most countries. Passive and transit fishing in OWFs is, under certain restrictions, allowed in the UK, Germany, Belgium and the Netherlands, but not in Denmark[7]. In the EU, all Member States are obliged to develop **Maritime Spatial Planning** (MSP) plans for their territorial waters and Exclusive Economic Zone (EEZ). MSP can aid in creating co-location of different activities, such as OWFs and fisheries, but also lays the foundations for consultation processes. Within this section, the good practices within MSP processes are summarized with regard to adaptation to and mitigation of the impact of OWF construction. Here, the focus is on consultation processes, as the literature stressed the importance of transparent and legitimate consultation processes.

An **example** of an **MSP process** geared at mitigating the effect of OWFs on fisheries (among other things) is the **North Sea Agreement** in the **Netherlands**. In the Netherlands, OWF expansion will have a substantial spatial impact on its EEZ, as up to 26% of the Dutch North Sea surface will be used for OWFs (based on a capacity of 60 GW in 2050; Matthijsen et al., 2018). Therefore, the Dutch government initiated the North Sea Dialogue to develop a new MSP for the Dutch EEZ. Dutch stakeholders, such as fisheries organizations, nature organizations, the oil and gas industries, shipping and OWF developers, were involved in this dialogue[8]. The different ministries concerned with North Sea policies were partners at the table, and a special governmental institution guided the process as facilitator. The North Sea Dialogue resulted in the North Sea Agreement (NSA), which was signed by all parties except the fisheries organizations, who did not agree with the final agreement. For fisheries, the implementation of the NSA will result in a decrease in fishing grounds due to OWF and nature conservation area expansion. The fishermen will be compensated through a so-called Transition Fund. This fund will be used to **develop a decommissioning scheme** to adapt the **Dutch fleet** in size to suit the remaining space for fisheries and to **finance sustainability innovations** for the vessels that do not opt for decommissioning[6]. The North Sea Agreement was based on a participatory approach and available knowledge at that time. Although the fisheries sector was part of the dialogue and decision-making process, albeit as a participant rather than a consulted party, it did not sign the agreement in the end. Similar processes and obstacles are encountered in MSP processes across EU Member States.

Within participatory approaches, **decision support tools** can aid in testing and understanding the possible consequences of certain strategies or policies. Decision support tools are models which can be used to inform decision-making (see for instance

[7] Source: WindEurope

[8] Overlegorgaan Fysieke Leefomgeving, 2020. https://www.overlegorgaanfysiekeleefomgeving.nl/default.aspx

Dijkshoorn-Dekker *et al.* 2020). For managing OWFs and fisheries, models on **fisheries behaviour**, and specifically **fisheries displacement**, can aid in developing suitable management strategies (Campbell *et al.* 2014; De Groot *et al.* 2014; Bastardie *et al.*, 2015). In an ideal scenario, these models combine biological and economic data (Bastardie *et al.* 2015). It is important to include gear-specific, high-resolution fisheries data in such analyses to evaluate different scenarios of OWF placement, which can inform decision makers and stakeholders on how to minimize environmental costs and maximize economic benefits of closure (Campbell *et al.* 2014). Bastardie *et al.* (2015) show in their study on the Baltic Sea that spatial modelling can aid in developing MSP which minimizes the economic impact of OWF expansion on fisheries, for instance, by combining OWFs with marine protected areas. To increase the accuracy of fisheries (displacement) models, there are several data needs, as identified by De Groot *et al.* (2014). Data on spatial distribution of (commercial) fisheries must cover different temporal and spatial scales and must also be gear-specific (De Groot *et al.* 2014). Furthermore, in assessing fisheries displacement related to OWF expansion, other developments impacting fisheries displacement must be incorporated, to understand the cumulative effects. Although Vessel Monitoring System (VMS) data is valuable, its resolution is not optimal, therefore, GPS chart plotter data is preferred. This data can show the footprint of fisheries, the time in which fisheries activities are carried out, key activity areas and seasonal variation (De Groot *et al.* 2014). Besides also factors as the market and weather determine the operability of the sector. The knowledge gap of understanding the behaviour of displaced fishermen as defined by De Groot *et al.* (2014) is frequently mentioned in literature, and an increased understanding of displacement behaviour can aid in creating better mitigation strategies.

Consultation of the fisheries sector is key when developing management strategies for adapting or mitigating the effects of OWF expansion on fisheries (De Groot *et al.* 2014; Reilly *et al.* 2016). It is not only advisable; it is also a requirement for constructing OWFs (European Directives SEA (2001/24/EC) and EIA (85/337/EEC); Reilly *et al.* 2016). Consultation can be regarded as a mitigation strategy, as it can aid in decreasing the effect of OWF construction on fisheries by helping avoid important fishing grounds (Reilly *et al.* 2016). Therefore, it is important to **avoid** '**tokenism'**, which is consultation as a mere prerequisite instead of a tool within decision-making (Gray *et al.* 2005; Alexander *et al.* 2013; De Groot *et al.* 2014; Reilly *et al.* 2016). Consultation should take place as early as possible (Reilly *et al.* 2016) and only if the organizing party is really interested in the results (De Groot *et al.* 2014). It must be clear how much participants can influence the consultation process (De Groot *et al.* 2014). Next to that, within the consultation process, mitigation options can be discussed, to show fishermen that effort is being put into the development of mitigation measures (Chen *et al.* 2015).

Fishery participants are preferably **local representatives**, and not only the loudest fishermen, but a diverse group that can represent the different types of fishermen. This can, for instance, be done by forming Fisheries Groups, in which specific gear and vessel types are represented. These groups must have a clear point of contact and agreed aims, and must be supported by an objective and legal representative (De Groot *et al.* 2014; Reilly *et al.* 2016). It is reported that it is important for fishermen to have **face-to-face meetings** with OWF developers, instead of only participating in public meetings (Gray *et al.* 2004). Another issue raised by fishermen is that there should be **enough time** for consultation. In the study of Gray *et al.* (2005), it was mentioned that, whereas consultation processes around oil and gas development typically took around a year, OWF consultation happened within a month on some occasions. However, too many consultation meetings can also lead to stakeholder fatigue and inhibit fishermen involvement (Reilly *et al.* 2016). Topics which can be addressed within the consultation process with fisheries and other relevant stakeholders (marine energy industry, marine management organizations, local planning organizations, research institutes, Non-Governmental Organizations) are (De Groot *et al.* 2014):

- Identification of locations where the displaced fishermen will go;
- Assessment of new activities in the displaced area;

- Assessment of changes in the pressure on fish stocks.

Adding to the above-mentioned topics, the consultation process could start by **mapping fisheries activities together** with fishermen, thereby creating the opportunity to locate OWFs in areas which are not considered the most important fishing grounds. This would require flexibility on the part of the planning process (Reilly *et al.* 2016). For fishermen, engaging in consultation processes can lead to direct costs, through lost days at sea. Therefore, **monetary compensation for participation** can help to ensure that all fishermen who wish to participate are able to do so (De Groot *et al.* 2014).

When planning OWFs and developing adaptation and mitigation strategies for fisheries, **co-location** of OWFs and fishery activities could be considered as a way of keeping economic losses for the fisheries sector to a minimum. A case study in Northern Ireland showed, using decision support tools, that when fishermen are allowed to fish in 25% of the OWF surface area, the economic losses of the fishery sector could decrease considerably (Yates *et al.* 2015). Access options and risks should be evaluated to enable co-location of fisheries and OWFs in the case of static gears. These are regarded as more suitable for co-location within OWFs than towed or encircling gears, such as seines (Hooper & Austen 2014). More information on co-location is provided in section 2.4.2.1 (socio-economics).

Within the before-mentioned North Sea Agreement, **compensation measures** were aimed at decommissioning individual vessels and investing in sustainability innovations for the remaining fleet (footnote 8, page 16). Alexander *et al.* (2013) show that there are diverging ideas within the fishing sector on what proper compensation for loss of fishing grounds due to OWF expansion should look like. On the Scottish west coast, fishermen were not in favour of compensation by means of stimulating or investing in alternative livelihoods for fishermen affected by OWF expansion (Alexander *et al.* 2013). As fishing communities are often located in rural areas, alternative employment opportunities are not always available. Therefore, the fishermen suggested that compensation must focus on the **long-term wellbeing of the fisheries communities**, for instance, by investing in local education opportunities (Alexander *et al.* 2013). The study by Gray *et al.* (2005) shows that direct compensation of fishermen is not a simple matter, as there are different opinions on who is eligible for compensation. Some OWF developers in this study mentioned that only fishermen who were fishing within the planned OWF area should be compensated (Gray *et al.* 2005). This attitude gives no consideration to the effect of increased fishing pressure on other areas when the total amount of available fishing grounds decreases. Within this study, **collective compensation** was also mentioned as opposed to individual compensation (Gray *et al.* 2005). Another example of such collective compensation is worked out for the St Brieuc[9] OWF in France, where the national fishery organization get a yearly compensation over a period of 20years.

2.2.4. Management strategies for aquaculture development in OWFs

Co-management of OWFs and aquaculture shows that multi-use management systems are very complex, and actors often struggle to develop co-management in a way that it is compatible with the requirements for both activities (Michler-Cieluch *et al.* 2008). Interviews with wind and mussel farmers show that wind farmers are mainly concerned about the effect of aquaculture on 'normal' wind farm operations, whereas mussel farmers are mainly concerned about the economic and technical challenges related to the integration. Moreover, they are also concerned about whether the biological conditions within OWFs are suitable for mussel farming. These findings are similar to findings from a Dutch case study (De Koning & Trul 2020), which showed that mussel farmers were mostly worried about the business case for offshore aquaculture production and about the

[9] https://ailes-marines.bzh/en/environnement-marin/le-parc-eolien-et-la-peche/

technicalities of OWF-aquaculture integration. Wind farmers showed no interest in cooperation with aquaculture companies, as they do not regard food production as their core business. However, they would be more interested in seaweed production for biofuels, as this relates to renewable energy production (De Koning & Trul 2020). Other studies, such as Buck *et al.* 2017, confirm that from the aquaculture perspective, technical and economic concerns are more prominent.

Figure 1 shows the requirements for setting up a management framework for OWF-aquaculture integration, based on interviews with wind and mussel farmers (Michler-Cieluch *et al.* 2008). What is needed from the government, according to the respondents, is financial and logistic support, laws that are better suited to multi-use, concession and permit procedures that are better geared towards multi-use, and governmental bodies that actively advise and observe the multi-use process (Michler-Cieluch *et al.* 2008). A **clearer licensing procedure** and **financial support** from the government was also mentioned by stakeholders in the research of Stuiver *et al.* (2015) on opportunities for combining trout, salmon, seaweed and mussel farming with energy production. Buck *et al.* (2004) also show that a lack of legal right to closed, defined user groups for offshore areas and the uncertainty around **aquaculture tenure rights** make aquaculture development in and outside of OWFs very difficult. In the Dutch case regarding offshore mussel farming, respondents also requested a stronger role from the government to be able to realize the multi-use potential of OWFs (De Koning & Trul 2020). A way in which the Dutch governments aims to stimulate multi-use in OWFs is through the obligatory development of so-called area passports (De Koning & Trul 2020, footnote 8, page 16). If an area is designated for OWF construction, current users and potential users must be considered in the development and design of the OWF (footnote 8). Stakeholders from both the aquaculture and OWF sector are worried that the area passports will only lead to explorations, instead of actions, as it is not yet known whether the exploration will be coupled with obligatory actions (De Koning & Trul 2020). An obligation of multi-use has also been determined by the government of Belgium for the new OWF area in the Belgian waters (see section 2.3.2).

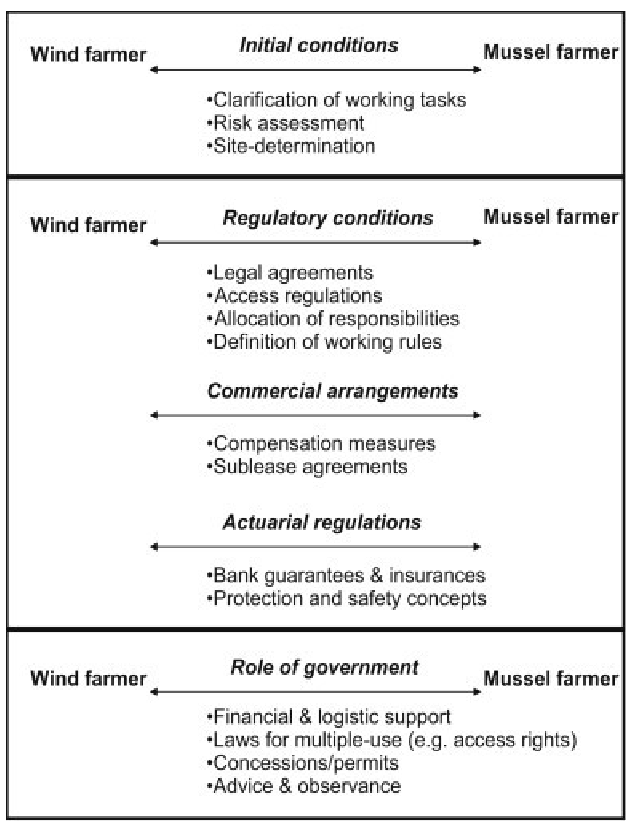

Figure 1: Requirements for the management of OWF and aquaculture integration. The figure shows an example of OWF and mussel farming integration (Michler-Cieluch *et al.* 2008).

Respondents from both studies (Michler-Cieluch *et al.* 2008; De Koning & Trul 2020) recommend that any attempt at multi-use or co-management should start with **experimental pilots**, to deal with technical uncertainties. Next to that, Michler-Cieluch *et al.* (2008) recommend that two management strategies be combined in developing co-management of OWF and aquaculture: a process-oriented one and a results-oriented one. The **process-oriented approach** is aimed at dealing with uncertainties in the socio-cultural and policy category, such as the structure of decision-making, political support and trust. The **results-oriented approach** is focused on dealing with uncertainties in the economic and technical category, such as technical capacity, practical application and cost-effectiveness (Michler-Cieluch *et al.* 2008). Within this results-based approach, an interdisciplinary and participatory risk assessment informed by natural, technical and social science and stakeholder experiences can aid in understanding and managing risks and uncertainties (Van den Burg *et al.* 2020). A part of the process-oriented approach is the experimental phase of **developing pilots together**, which can enhance collaborative learning, which can also feed into the risk assessment within the results-based approach. In an ideal scenario, both approaches are used simultaneously, thereby focusing on the importance of creating a good process of co-management and technical innovation with both parties and external advisors (Michler-Cieluch *et al.* 2008). To keep co-management comprehensible, it must be confined to a specific area or topic (Buck *et al.* 2004). An interdisciplinary management team can be established to guide the cooperation process. This team should consist of people from the wind and aquaculture sector, people from the government who can participate as legal advisors, and external consultants who can aid in the development of the co-management approach as independent facilitators (Michler-Cieluch *et al.* 2009).

In deciding on multi-use development, **consultation is key** (Stuiver *et al.* 2016). As mentioned before, in the paragraph of fisheries, geographical information systems can aid within the consultation and development of OWF-aquaculture integration (Buck *et al.* 2004). Therein, and in consultations around OWF and aquaculture in general, it is important to include participants who are opposed to the multi-use of OWFs (Wever *et al.* 2015), such as fishermen (Buck *et al.* 2004). In a real co-management approach, participants must be able to participate in strategic policymaking regarding the multi-use development (Buck *et al.* 2004). Governments can be regarded as participants in co-management approaches; however, they will still largely influence the outcomes through policies and legal frameworks. Therefore, it is necessary that policymakers clearly state their priorities in multi-use projects and co-management approaches, for instance, through priority ranking (Michler-Cieluch *et al.* 2008).

2.2.5. Knowledge gaps and recommendable management strategies

Based on the literature search, the following general remarks can be made. There are few examples of real management approaches for adaptation to and/or mitigation of the effect of OWFs on fisheries and aquaculture. The two main reasons for this are the lack of real-world cases and the lack of grey literature found in our systematic search. It seems that, in most cases, **no tailored management approaches** have been **developed yet** for fisheries and aquaculture in the OWF development process. Grey literature, like policy documents, generally offers many more hands-on examples of management approaches or specific policies, whereas scientific literature tends to focus on more abstract and general recommendations.

Most articles on fisheries focus on the displacement of fisheries and how mitigation of displacement can be improved. Scientific literature emphasizes a large knowledge gap regarding how the behaviour of fishermen will change due to OWF construction and how this influences the effect of OWF construction on displacement. Scholars argue that effective mitigation measures will be difficult to establish without **understanding fisheries behaviour** thoroughly. Another important recommendation, given by several authors, is the need for **early consultation processes** in which the fisheries sector can give input on marine spatial planning processes. It is important that there is room for such input at the beginning of the process, so that there is real consultation and the fisheries sector are not just presented with a fait accompli. Preferably, the involvement of fisheries goes beyond consultation to higher levels of participation (see Arnstein 1969) in which fishermen and fisheries organization can take part in the decision-making process. Thereby, it must be clear how much influence the fishermen can potentially have. The development of standardized consultation and compensation processes for all EU Member States can facilitate this. The roles of governments, wind farm developers and fishermen should be defined, just like the different steps of the process. **Decision support tools** can be integrated in the standard consultation and compensation procedures. They can aid in creating a participative planning process in which stakeholders can explore different scenarios in a collaborative fashion and mitigation of negative effects of OWFs on fisheries can take place. Furthermore, **compensation** could follow a more **standard procedure**, so that fishermen **throughout the EU** are compensated and therefore treated in the same fashion. Within the development of a standard compensation procedure, the EU can opt for individual-based compensation (individual fishermen), fishery-based compensation (fishermen with the same métier) or **community-based compensation** (fishery communities). Based on the literature, it is advisable to explore forms of community-based compensation with fishermen and fisheries communities.

The majority of articles on the effect of OWFs on aquaculture focus on the **potential** of **offshore aquaculture** in OWFs. To date, there are no areas in the North and Baltic Seas in which current aquaculture practices seem threatened by OWF construction. On the contrary, OWF expansion is seen as an opportunity for Blue Growth activities like aquaculture and other forms of marine energy production such as tidal energy or solar energy. To develop offshore aquaculture in OWFs, co-management of multi-use initiatives by wind developers and the aquaculture sector can be developed and **stimulated by governments.** These need to participate in the management team, for instance, in a role as legal advisor. If the aquaculture and OWF sector opt for a co-management approach, they must focus on the process of collaboration on the one hand, and on tangible results on the other hand, for instance, through the development of pilots by wind developers and the aquaculture sector. To stimulate multi-use of aquaculture in OWFs, Member States can make an exploration into multi-use opportunities obligatory, as part of the biding process for example. The concept of area passports, which is currently being developed in the Netherlands, can form the basis of such explorations. Several studies showed that wind developers are not intrinsically motivated to engage in multi-use, as this might increase their operation costs and is not related to their core business of energy production. Therefore, to enhance opportunities for aquaculture, Member States might create incentives for engaging in multi-use activities, for instance by adding this as a criterion in tender procedures.

2.3. Legal

2.3.1. General context

The right of Member States to regulate fisheries and aquaculture activities in and around offshore wind farms derives from the United Nations Convention on the Law of the Sea[10] (UNCLOS). All of the Member States are party to UNCLOS, which entered into force on 16 November 1994.

UNCLOS gives coastal States the right to claim maritime zones in the waters adjacent to their coasts. Of relevance to the regulation of offshore windfarms are: (a) the 'territorial sea', which may extend up to 12 nautical miles (nm) from the 'baseline', which is usually the low tide mark; and (b) an 'exclusive economic zone', which may extend up to 200 nm from the baseline. The Member States have all claimed EEZs in the EU waters of the North Sea and the Baltic Sea.

In accordance with UNCLOS, a coastal State has full sovereignty over its **territorial sea** (article 2), subject only to the right of 'innocent passage of foreign ships. Consequently, a coastal State may adopt laws and regulations on activities within its territorial sea, including the safety of navigation, maritime traffic, the protection of facilities or installations, cables and pipelines as well as the construction of wind farms and the conservation and management of fisheries and other natural resources. A coastal State may, in addition, adopt laws and regulations relating to innocent passage through its territorial sea in respect of the safety of navigation, the regulation of marine traffic and the protection of facilities and installations, among other matters (article 21). UNCLOS does not specify the maximum breadth of safety zones in the territorial sea.

Within its **EEZ,** a coastal State has 'sovereign rights' for the purpose of exploring and exploiting, conserving and managing the natural resources there, including living resources, as well as 'other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds' (article 56(1)). A coastal State also has the exclusive right to construct (or authorize and regulate the construction), operate and use 'installations and structures' necessary for such activities within its EEZ. Moreover, a coastal State may, where necessary, establish safety zones of up to 500 metres around such artificial islands, installations and structures, except in cases where these installations, structures and safety zones may interfere with the use of recognized sea lanes essential to international navigation (article 60).

In other words, UNCLOS clearly recognizes the right of a coastal State to adopt laws and regulations relating to offshore energy, navigation, fisheries and aquaculture and the protection of the marine environment within its respective territorial sea and EEZ.

Although the EU is also party to UNCLOS, as it is not a state, it has no right to claim maritime zones. Any legal rights that the EU may have to regulate fisheries and aquaculture activities in and around offshore wind farms will depend on powers conferred upon it by the Treaties (the Treaty on the Functioning of the European Union and the Treaty on European Union). Fishing activities in the EU waters of the North Sea and the Baltic Sea, including in areas around windfarms, are of course in general terms subject to the rules of the Common Fisheries Policy[11] and any restrictions imposed in accordance

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[10] United Nations Convention on the Law of the Sea, Montego Bay, 10 December 1982. In force: 16 November 1994, 1833 *United Nations Treaty Series* 396; www.un.org/Depts/los.
[11] Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and

with EU environmental legislation (relating, for example, to the establishment of marine protected areas, including Natura 2000 sites[12]). The exercise of balancing the spatial effects of new wind farms with other uses of the sea, including fishing, takes place in accordance with the EU maritime spatial planning framework[13]. Aquaculture activities within and around windfarms are also subject to EU environmental[14] and maritime spatial planning legislation, as well as EU legislation concerned with aspects of animal health[15], feed etc. However, the EU has not sought to specifically legislate on fisheries and aquaculture activities in and around windfarms. Indeed, it is not entirely clear that an appropriate legal basis for such legislation under the Treaties exists.

2.3.2. Member States overview

Within the framework presented above, European coastal States have adopted specific legislation relating to fisheries and aquaculture activities in and around offshore wind farms. Based on an analysis of the limited literature on the topic, the relevant legislation and the (rather few) replies to the survey sent to the Member States and the UK, it transpires that such legislation is primarily concerned with the restriction of navigation and/or fisheries activities in and around offshore windfarms (Table 2).

Within **Belgian** waters – in accordance with article 14(4) of the Royal Decree of 20 March 2014 establishing the marine spatial planning for the period 2020 to 2026 in the Belgian sea areas (the MSP Decree)[16] and the Royal Decree of 11 April 2012 establishing a safety zone around the artificial islands, installations and constructions for generating, storing and transmitting energy from renewable sources in the sea areas under Belgian jurisdiction[17] – all vessels (except maintenance vessels, warships etc.) are prohibited from entering a 500 m security zone around each wind park. The MSP Decree goes on to provide that passive fishing may be permitted in renewable energy zones 2 and 3 (Noordhinder North & South) and that aquaculture is authorized in all of the renewable energy zones subject to: (a) the consent of the holder of the concession for wind farm construction and operation; (b) the taking of necessary measures; (c) aquaculture reducing the level of eutrophication within the energy zone concerned; (d) the designation of control zones; and (e), in the case of two of the zones, the necessary environmental authorizations being obtained. What is not entirely clear from the MSP Decree is how access to these zones for

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repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC (OJ L 354, 28.12.2013, p. 22).

[12] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (OJ L 20, 26.1.2010, p. 7) and Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7).

[13] Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning (OJ L 257, 28.8.2014, p. 135).

[14] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance) (OJ L 164, 25.6.2008, p. 19) and Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (OJ L 327, 22.12.2000, p. 1).

[15] Council Directive 2006/88/EC of 24 October 2006 on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals (OJ L 328, 24.11.2006, p. 14); Regulation (EC) No 767/2009 of the European Parliament and of the Council of 13 July 2009 on the placing on the market and use of feed, amending European Parliament and Council Regulation (EC) No 1831/2003 and repealing Council Directive 79/373/EEC, Commission Directive 80/511/EEC, Council Directives 82/471/EEC, 83/228/EEC, 93/74/EEC, 93/113/EC and 96/25/EC and Commission Decision 2004/217/EC (*OJ L* 229, 1.9.2009, p. 1).

[16] Koninklijk besluit tot vaststelling van het marien ruimtelijk plan voor de periode van 2020 tot 2026 in de Belgische zeegebieden.

[17] Koninklijk besluit van 11 april 2012 tot instelling van een veiligheidszone rond de kunstmatige eilanden, installaties en inrichtingen voor de opwekking, de opslag en het transport van energie uit het water, de stromen en de winden in de zeegebieden onder Belgische rechtsbevoegdheid.

the purpose of passive fishing or aquaculture is to be reconciled with the prohibition on navigation within windfarms.

In **Denmark**, in accordance with the Promotion of Renewable Energy Act (Act no. 1392 of 27 December 2008), wind farms follow the practice of establishing 500 m safety zones around wind farm installations and activities during construction, but do not typically extend these into operation[18]. Interestingly, in accordance with articles 76–80 of the Fisheries Act, no. 568 of 21 May 2014, compensation may be payable to fishermen in respect of documented losses as a result of offshore windfarm construction. It was not possible to identify any specific legislation relating to aquaculture in offshore windfarms in Danish waters.

In **Germany,** navigation is prohibited within a 500 m safety zone during construction. After construction, the General Direction for Waterways and Shipping[19] issues rules on safety zones in the form of individual decrees on the basis of the Ordinance on installations seaward of the boundary of the German territorial sea[20] and the Ordinance on the International Regulations of 1972 for the Prevention of Collisions at Sea of June 13, 1977[21] as amended. However, small craft less than 24 m in length are in general exempted from the requirements of the safety zone, subject to good weather conditions and a restricted top speed. It has not been possible to identify any specific legislation relating to aquaculture in windfarms in German waters; indeed, the limited literature suggests that this may be partly because, as a result of Germany's federal structure, the legal framework for offshore aquaculture is incomplete[22].

In the case of the **Netherlands**, in accordance with the Offshore Renewable Energy Act and the Water Act, navigation is in principle prohibited in a 500 m safety zone during operation of a windfarm. However, the Dutch government is currently investigating the possibility of modifying the current rules, including the use of pilot projects. Options being considered include permitting recreational and commercial fishing using passive gear within offshore windfarms. It has not been possible to identify any specific legislation on aquaculture in offshore windfarms.

The construction of offshore windfarms in **Swedish** waters requires a permit issued in accordance with the Environmental Code. Different procedures must be followed depending on whether the project is to take place in the territorial sea or the EEZ; in the latter case, a special government issued permit is necessary in accordance with the Economic Zone Act, 1992. According to the website of the Swedish Energy Agency, fishing with draft nets and trawl nets is not permitted within windfarms while all fishing may be banned during the construction stage[23].

As regards the **United Kingdom**, navigation is prohibited in a 500 m 'safety zone around offshore windfarm structures during construction, major maintenance and decommissioning. While the Energy Act 2004 provides for the possible establishment of permanent safety zones of 50 m around each pylon of windfarm, in practice, these

[18] Søfartsstyrelsen/Danish Maritime Authority Review of Maritime and Offshore Regulations and Standards for Offshore Wind: Summary report on North Sea regulation and standards Report No.: 2015-0886, Rev. 1 Document No.: 1SMV3FB-12 Date: 2015-11-25.
[19] Wasser- und Schifffahrtsverwaltung des Bundes.
[20] Seeanlagenverordnung-SeeAnlV.
[21] Verordnung zu den Internationalen Regeln von 1972 zur Verhütung von Zusammenstößen auf See vom 13. Juni 1977 (BGBl. I S. 813).
[22] Buck, B. H., Krause, G. and Rosenthal, H. (2004). Extensive open ocean aquaculture development within wind farms in Germany: the prospect of offshore co-management and legal constraints. Ocean & Coastal Management, 47, (3–4): 95–122.
[23] http://www.energimyndigheten.se/fornybart/vindkraft/vindlov/planering-och-tillstand/svenskt-vatten/naringsverksamhet/fiske/

provisions have seldom been used. The result is that fishing within UK offshore windfarms is permitted, although the evidence suggests that fishermen avoid fishing there for safety and insurance reasons[24]. No specific legislation on aquaculture in offshore windfarms has been adopted.

2.3.3. Conclusion

As described in this section, a range of different approaches within the EU Member States have been taken regarding fishing within and around offshore windfarms. Restrictions, where they apply, tend to apply to navigation in general, especially during the construction phase. The legal basis regarding navigation during the operation phase seems less clear. Although, the possibility of restricting fishing to certain types of techniques, using passive gear, is being considered or is potentially provided for in Belgium and Netherlands. However, the experience of the UK suggests that fishermen are cautious of using active fishing gear within offshore windfarms, meaning that the legal restrictions on navigation/fishing that exist may have little practical impact.

The only identified explicit reference to aquaculture within offshore windfarms in legislation relates to the recognition that this may be possible in certain renewable energy zones in accordance with the Belgian MSP Decree. The absence of information on this issue may in turn be due to the limited experience of aquaculture in offshore windfarms to date. Two separate issues potentially arise. First, whether the scope of regulatory legislation on aquaculture applies beyond the territorial sea. Second, whether the relevant legislation is capable of conferring rights to use the seabed for aquaculture facilities within the EEZ (in the case of the UK and Germany it appears that it is not) whether or not in conjunction with rights granted to an offshore windfarm developer.

[24] Gray, M., Stromberg, P-L., Rodmell, D. 2016. 'Changes to fishing practices around the UK as a result of the development of offshore windfarms – Phase 1 (Revised).' The Crown Estate, London.

Table 2: Summary of the legal settings on fishery and aquaculture activities in OWFs.

Country	Fisheries	Aquaculture
Belgium	All vessels are prohibited from entering a 500 m security zone around each wind park (except maintenance vessels, warships etc.)	Royal Decree on MSP (Art 14): Aquaculture is authorized in the Eastern renewable energy zone if inter alia the holder of the concession for the construction and operation of a wind farm agrees and, where necessary, measures are taken
Denmark	Navigation prohibited in a 500 m safety zone during construction, but restriction not usually continued during operation.	No information
Germany	Navigation prohibited in a 500 m safety zone during construction. After construction General Direction for Waterways and Shipping (GDWS) issues rules on safety zones.	No information
Netherlands	Navigation prohibited in 500 m safety zone during operation. Situation under review	No information
Sweden	Navigation restrictions during construction. Prohibition on the use of drift nets and trawls during operation.	No information
United Kingdom	Navigation prohibited in 500 m 'safety zone' around structure during construction, major maintenance and decommissioning. Possibility to establish permanent safety zones of 50 m around each pylon	No information

2.4. Socio-economics

The socio-economic effects of OWFs on the fisheries and aquaculture sectors, as identified through a systematic review of available literature, is presented here.

2.4.1. Literature selection

To identify the most relevant literature, the following steps were taken:

Step 1: A literature long list was prepared using the following search terms: Offshore AND Wind; Fisheries OR Aquaculture; Social OR Economic. A total of 92 scientific literature were selected using SCOPUS, and another 42 using Scholar. Every article found in SCOPUS and/or Scholar was added to the long list until no more relevant literature could be found in either search engine. Three relevant additional articles, suggested by the Study team, , were added to the long list. The final long list consisted of 137 articles.

Step 2: A short list was prepared by reviewing the abstracts of each article on the long list. Each article was then rated for 'Relevance' with a 'Yes' or 'No'. After this first screening, 63 articles were catalogued as relevant. An inter-coder reliability test (cross-check by two other researchers) was carried out to check this relevance classification. This revealed that four articles could be considered as irrelevant and one article was considered relevant due to the studied methodology (a study using social impact assessment). The project team of three researchers agreed on the criteria for further selection and the process continued.

Step 3: The 60 articles that remained were assessed a second time by reviewing the results and conclusion sections. Many of the articles that were initially catalogued as relevant from their abstracts discussed ecological, technological or other effects, which do not fall under the scope of this literature review. After this final selection process, 23 articles remained that explicitly study socio-economic effects on either fisheries or aquaculture, or that discussed related effects or contained insightful methodologies. Of these, 16 publications discuss effects on fisheries, 6 discuss the effect on aquaculture and 1 discusses both aquaculture and fisheries.

2.4.2. Economic effects

The project team defined possible economic effects that are likely to be mentioned in relation to fisheries and aquaculture. In total, 15 articles studied the economic effects of offshore wind on fisheries and aquaculture. Some papers discussed more than one effect. Figure 2 visualizes how often each of these economic effects were studied in the reviewed articles. The review confirmed the relevance of **loss of fishing grounds** and effect on **catch volume**. Only one article discussed **longer travel times**. The effects discussed in the 'other' category related to the economic feasibility of mussel cultivation and seaweed production in offshore wind farms (Buck *et al.* 2010; Van den Burg *et al.* 2016). None of the articles discussed the effects on sales value, increased efforts or effects along the value chain. Most studies were also conducted in a qualitative manner, with six studies having quantitative aspects (Buck *et al.* 2010; Soukissian *et al.* 2017; Van Den Burg *et al.* 2016; Hooper *et al.* 2015; Stelzenmüller *et al.* 2016; Roach *et al.* 2018).

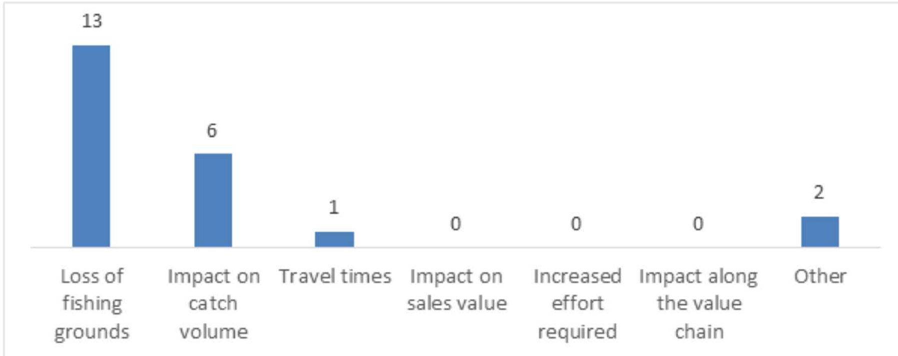

Figure 2. Frequency with which possible economic effects of OWFs on fishery and aquaculture are discussed in reviewed scientific literature.

2.4.2.1. Fisheries

According to the studied literature, wind farms can have both positive and negative effects on fisheries. Alexander *et al.* (2013) identify three key effects of OWFs on fishery practices: i) a potential loss of fishing grounds (and influencing/therefore income, catch volume); ii) gear conflicts with OWF infrastructure; and iii) safety implications for fisheries.

Offshore wind farms can result in the **loss of fishing grounds**, with an influence on the catch volume. This can be due to the total closure of a wind farm to fisheries or due to the 500 metre safety zone, meaning that fishing activity within 500 metres of a wind farm is prohibited. The fishing grounds that are lost due to OWFs are often valuable; Stelzenmueller *et al.* (2016) find that 90% of Danish and 40% of German annual plaice landings in the German EEZ overlap with areas where offshore wind farms are and will be developed. International gillnet fisheries can lose up to 50% in landings within the North Sea German EEZ, where wind farms are closed entirely to these fisheries (Stelzenmueller *et al.* 2016). s

It is often suggested that **static fisheries** should be safe and possible within OWFs. A study by Ashley *et al.* (2014), who conducted face-to-face semi-structured interviews with 67 fishermen and 11 OWF developers, argues otherwise. The fishermen reported a loss of fishing grounds due to OWF development. They also lose flexibility in fishing and are restricted in their operability, as they, for example, need to move gear during OWF maintenance operations. Second, a shift in fishing métier is also uncommon, as outlined in the Hooper *et al.* (2015) report. The authors conclude that it seems unlikely that the effects of displacement would include a significant number of fishermen changing from mobile gear to crab or lobster potting. Twenty-one respondents did not currently fish for crab or lobster, and 81% of these expected to lose fishing grounds if proposed OWFs were built. Less than 20% would consider changing to crab/lobster fishing if it was demonstrated that the OWFs supported good stocks of these crustaceans (Hooper *et al.* 2015).

Section 2.1.6 indicates that an offshore wind farm can act as an artificial reef or marine protected area (Busch *et al.* 2011; Soukissian *et al.* 2017), as fishermen are not allowed within OWFs. Some studies suggest that this will lead to a **'spill-over' effect** in the medium to long term, where an undisturbed population can reproduce and spill-over to other areas (Soukissian *et al.* 2017; Ashley *et al.* 2014). Fishing near the edges may therefore be lucrative. Only one study (De Backer *et al.* 2019) shows evidence of this, as it seems that Belgian and Dutch trawlers are attracted to the edges of wind farms for two target species *sole* and *plaice*. Plaice landings seem to be even higher around operational wind farms.

The second key effect is the **gear conflict issue**, which is also linked to the third effect, the **safety implications** (see also section 2.2.3). Fishermen are concerned that their fishing gear may become trapped in OWF infrastructures, which may lead to the capsizing of vessels and/or loss of gear, resulting in 'ghost fishing'. The majority of the fishermen in the study by Ashley *et al.* (2014) also had strong concerns that bad weather and strong tides would lead to nets and pots becoming entangled with OWF infrastructure, and that retrieving these leads to unsafe situations. This is a key impact also identified by Alexander *et al.* (2013): the safety implications of potential collisions with wind turbines (Ashley *et al.* 2014). This has consequences for the economic viability of fishing activities within OWFs, which is not optimal at all moments. The key needs of fishermen are continued security of employment and income, and control of their 'own lives through decision-making based on facts (Alexander *et al.* 2013).

2.4.2.2. Aquaculture

Research on the economic effects of wind farms on aquaculture is limited. Reasons for this can be that there is no spatial conflict between OWFs and aquaculture areas, and that aquaculture developments within wind farms are not yet in a commercial phase. There are several desk studies investigating the combination of aquaculture with wind farms, yet there are only a handful of pilot studies that put theory into practice. Van den Burg *et al.* (2016) state that offshore seaweed production was, at the time of writing, not economically feasible. Combining the production of seaweed with offshore wind energy production does not change this. Adding to that, the risks of co-use are significant and render development of co-use concepts difficult (see section 2.2.4). Van den Burg *et al.* (2016) argue that other types of aquaculture, such as mussels or fin fish, might be more profitable.

Another cultivation target is flat oysters, as described by Kamermans *et al.* (2018). The authors describe how a number of wind farms in the Dutch section of the North Sea are suitable locations for flat oysters and for the development of flat oyster beds. However, this research is limited to describing the best technical and biological locations for potential pilot studies. No socio-economic data is available yet.

2.4.3. Social effects

Social effects of offshore wind farms on fisheries and aquaculture are less frequently studied than, and are usually discussed in relation to, economic effects. Figure 3 shows the frequency of the social effects defined by the project team. Three studies refer to the loss of employment for the fishery sector, two studies to the fishermen's resistance to OWF and two to the required change in fishermen's fishing behaviour. The 'other category is a study on the social dimensions of multi-use offshore aquaculture. Two social effects expected by the project team, 'loss of historic fishing grounds' and 'emotional impact', were not mentioned in the reviewed literature. This suggests that the loss of fishing grounds is discussed mainly in relation to economic effects, and that both the loss of grounds and emotional impacts are likely to be discussed in relation to resistance.

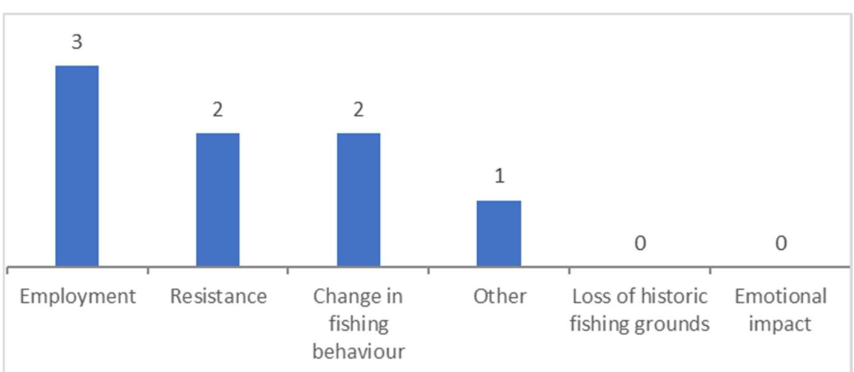

Figure 3. Frequency with which possible social effects of OWFs on fishery and aquaculture are discussed in the reviewed scientific literature.

2.4.3.1. Fisheries

Fishing grounds are not only economically valuable, but often have a **historic, cultural value** as well. Fishing practices and family businesses are often passed on to the next generation. There is **resistance** against this loss of fishing grounds due to OWFs. A Taiwanese study (Shiau & Chuen-Yu 2016) developed indicators to measure the social sustainability of OWFs for a social impact assessment (SIA). The study showed that only 9% of fishermen supported the development of a wind farm. Fishermen expressed concerns regarding reduction of fishing grounds, electromagnetic waves resulting from the OWF cable grid and noise. In this study, these aspects were regarded as negative for fisheries by academia. This was countered by representatives from industry and government who asserted that wind farms would produce artificial reefs and fish aggregation effects (Shiau & Chuen-Yu, 2016).

Job opportunities created by multi-use are sometimes raised as a positive effect of wind farms. Fishermen can be employed to maintain and inspect devices. Four of the seventeen fishermen from the study by Alexander *et al.* (2013) suggested this. Fishing association representatives point out that wind farm developers promote this idea. However, the majority of the fishermen disagreed that this would be an opportunity. "Fishermen have a skill, and that's fishing … it's really not possible to take a skilled fisherman and turn him into a wind farm engineer or a tidal turbine engineer, it's not going to happen*."* one fishing association representative stated. One of the main reasons that there will not be alternative employment is the belief that fishing boats are not suitable for marine renewable energy devices (or OWF) work. Eight out of seventeen fishermen also pointed out the lack of qualifications, which would prevent them from undertaking alternative employment.

An American study showed an increase in recreational fisheries around wind turbines. "Some days, when the fluking was really good out there, you'd see 50, 60 boats out there; where years ago, you might only see 20", according to one commercial fisherman. In turn, commercial fishermen fear this increase in recreational fisheries leads to a loss of fishing grounds. They state that this increase can lead to safety hazards due to overcrowding and possible loss of fishing gear. Commercial fishermen dare not go into wind farms anymore (Ten Brink & Dalton 2018).

The fishery sector also fears a **loss of new employees**, as skills shortages are a potential problem should a loss of livelihood occur (Alexander *et al.* 2013) or other maritime sectors (e.g. OWFs) offer better job opportunities.

2.4.3.2. Aquaculture

The reviewed literature emphasizes that aquaculture, also in the context of OWF, offers a **variety of socio-economic benefits** through the supply of highly nutritious foods and commercially valuable products, providing jobs and creating income, especially in remote areas. A paper by Buck *et al.* (2018) provides an example from South Africa, where the employment of a large number of unskilled and semi-skilled personnel in the aquaculture sector has had a large positive socio-economic effect in coastal communities with traditionally high unemployment rates. Next to these direct economic contributions, aquaculture has added value in that it generates additional employment and income in the form of spin-off and support industries that deal with marketing, supply, product distribution, processing, packaging, etc. Negative effects come in the form of a lack of local and regional planning and a failure to fully understand how the aquaculture activity is interlinked with and affects natural systems and people depending on these (Buck *et al.* 2018). The study also states that improvement in public acceptability of the aquaculture industry (and wind industry) and the potential creation of additional jobs, income protection through diversification and access to new markets may create positive long-term outcomes for integrated multi-trophic aquaculture. Abhinav *et al.* (2020) describe how public opposition to wind farms mainly reflects social concerns like visual pollution and the effect of noise. Promoting the positive effects mentioned by Buck *et al.* (2018) could therefore reduce social resistance to OWFs. Nevertheless, no explicit studies exist that quantify the employment benefits of offshore aquaculture within OWFs.

2.4.4. Conclusion

Three key economic effects of wind farms on fisheries were identified: non-static gear conflict with the installations, safety implications and loss of access. The results of this literature study tell us there are enough studies that theorize the possibilities of co-use of OWFs with fisheries or aquaculture, but that there is **a lack of business cases or practice**. These three economic effects combine with the widespread belief among fisheries that coexistence is not possible or feasible leads to high resistance to OWFs among fishermen. The **economic viability** of the fishery sector is anyway **influenced** by the large-scale developments of OWFs, but quantitative predictions of it are rare because complex and uncertain ecosystem dynamics and uncertainty regarding fishermen behaviour. This is further complicated by the myriad of challenges the fisheries sector faces, rendering historical data on catches and value less representative.

Fishermen may lose fishing grounds due to OWF development. The consequences of this, however, are not always clear. The fishery landings may decrease in areas where OWFs are constructed, but little is known about the loss of businesses, jobs and income. **Further research** should therefore be oriented towards identifying the effects of the loss of fishing grounds on **jobs, income and changes in the fishing behaviour of fishermen**. The latter is important to consider, as studies show that fishermen currently mainly move to other places in the neighbourhood. For example, the edges of OWFs are lucrative for fishermen, as OWFs have the potential to act as a marine protected area (e.g. the spill-over effect where fish mature in the OWF and leave the site once grown up). This is, however, based on limited empirical evidence. The impact on the fisheries sector is hard to attribute to OWF, due to the challenges the sector faces. Furthermore, an increase in crustaceans, like crab or lobsters, due to the artificial reef function of OWFs means static fisheries can become lucrative in OWFs. Nevertheless, gear conflict and safety implications seem to be factors that reduce the economic viability of static fishery in OWFs.

The socio-economic effects of OWFs on aquaculture have been documented much less than the effects on fisheries, and often solely the socio-economic effects of aquaculture itself are studied. This is because large-scale and applied offshore aquaculture itself is in its infancy. Studies argue that OWFs can be combined with aquaculture, but there have been no real business cases that prove this to be the case. Conversely, there is currently no spatial conflict between ongoing aquaculture activities and OWF developments. In general, aquaculture will create jobs, income and new markets, and the social acceptability of OWFs and aquaculture can increase because of this.

During this literature study, a new report by Stelzenmüller *et al.* (2020) on the effect of offshore wind on European fisheries was developed. The key findings of this study largely confirm the potential concerns raised in our literature review on the socio-economic effects of offshore wind on fisheries and aquaculture:

- An overlap analysis suggests a sharp increase in the potential for spatial conflict in the North, Baltic and Mediterranean Seas over the next five years;
- The current and future cumulative development of offshore renewables affects mostly trawling fleets targeting mixed demersal species and crustaceans, whereas the composition of fishing effort varied greatly across fleets at individual planning sites;
- Economic impact assessments on the effects of offshore renewables on fisheries need to address the direct and indirect costs of lost fishing opportunities.

2.5. Stakeholder & Governance

2.5.1. Stakeholders

A list of key stakeholders at the regional, national and international level who have responsibility for the planning, implementation and operation of OWFs in the North and Baltic Seas was compiled through past projects, directories of wind farm developers, energy associations and aquaculture industry, and online searches. Following a review by the EU, some additions were made to the list (Annex chapter 1.1). At the EU level, these stakeholders include the European Fisheries Control Agency and advisory councils such as the North Sea and Baltic Sea Advisory Councils. At the Member State level, they include different ministries and control agencies such as the FOD Environment in Belgium, Ministry of Agriculture, Nature and Food Safety in the Netherlands, the Danish Ministry of Environment & Food, and The Crown Estate in the UK. OWF stakeholders also include national and international federations and producer organizations such as Redercentrale in Belgium, VisNed and Netviswerk in the Netherlands, the Danish Fishermen Producer Organization (DFPO), and the National Federation of Fishermen's Organisations (NFFO) in UK; and national and international marine environmental oriented NGOs, for example, Natuurpunt in Belgium and Stichting de Noordzee in the Netherlands. There are also various research institutes and programmes, such the Offshore Renewables Joint Industry Programme (ORJIP) in UK, which undertake research projects in OWFs. The wind farm industry itself is another key stakeholder, comprising different developers (e.g. Eneco in Netherlands, Energinet, Vattenfall and NIRAS Consulting in Denmark, and RenewableUK, DONG, Vattenfall and E-ON in UK) and associations such as the Belgian Offshore platform, European Subsea Cables Association and Wind Europe. Other stakeholders include the aquaculture industry, including Brevisco in Belgium, PO Mosselcultuur and Stichting Noordzeeboerderij in Netherlands, the Danish aquaculture industry, the Scottish Salmon Producers' Organisation and European Algae Biomass Association. These stakeholders play key roles during all stages of the OWF, including during planning, implementation and operation. Their perceptions of the effects of OWFs on fisheries and aquaculture were gathered through interviews and are presented in chapter 3.

2.5.2. Governance: good practices

This study identifies best practice in governance arrangements to understand how key stakeholders are involved in wind farms. Fisheries and aquaculture stakeholders' specific perceptions of best practice were gathered during interviews and are presented in chapter 3. In this part of the report, **successful and unsuccessful practices** from **three** wind farm case study sites are summarized.

The first example focuses on the **Belgian Fishery sector** and on how the sector is involved in the OWF consultation process in Belgium and in other countries. The spatial OWF zones in Belgian waters are indicated through the Marine Spatial Plan (MSP) process, so no separate consultation occurs between the OWF sector and fishermen at any stage. Any objections must go through the public consultation process of the Belgian MSP process. For OWFs in UK waters, the Belgian fishery sector must make a 'statement of common ground' between its representatives and the OWF operator. Through this act, they can send concerns directly to the operators. No consultation with the Belgian fishery sector is done for OWFs in French and Dutch waters, indicating that consultation at international level is not a standard practice. The main concerns for the Belgian fishery sector are loss of fishing grounds (nothing can be done against it), rock dumping on cable lanes (which hamper fishing and is a high risk for the beam trawl fleet), spacing between OWF areas, and the presence of corridors between OWF areas (to allow fishing grounds to be reached easily).

The second example focuses on the **Scottish Fishery sector**. The Fishing Liaison with Offshore Wind and Wet Renewables (FLOWW) is a national initiative set up to foster good relations between the fishing and offshore renewable energy sectors and encourage coexistence between both industries. It is comprised of representatives from organizations that play key roles in managing the seabed, fisheries and aquaculture managers, fishermen's representatives, inshore fisheries managers, wind farm trade associations, submarine cable owners, operators and suppliers, providers of information services, health and safety experts, and offshore wind developers.

The aims of FLOWW are to:

- foster good relations between the fishing and offshore renewable energy sectors;
- encourage coexistence between both sectors;
- provide a forum to discuss and take forward a range of OWF- and fisheries-related issues, agree and disseminate best practice.

The key characteristics of FLOWW include:

- Members usually meet three times each year.
- Member organizations make a commitment to attend and participate in the group.
- Members propose topics for discussion and (where necessary) prepare papers to support these topics.
- There are specific working groups within FLOWW e.g. Commercial Fisheries Working Groups (CFWG) that are established on a need and case-by-case basis.
- Experts are usually invited to specific meetings to provide advice or information which is of relevance to the group

The UK's Best Practice Guidance produced by the FLOWW group is currently undergoing a significant update, and a new version is expected for 2021. The updated guidance will cover the following:

- Module 1 – Introduction
- Module 2 – Developments, incorporating windfarms, offshore transmission operators, cable development and through-life management.
- Module 3 – Fisheries Liaison.
- Module 4 – Mitigation and Managing Coexistence, incorporating a wide variety of topics including transit planning, dropped objects, local notifications.
- Module 5 – Compensation/Cooperation, dealing with options for cooperation payments, compensation for damages/loss of gear.

The third example is illustrating the lack of involvement of international bodies in the OWF consultation processes.. Email exchanges with the secretariat of the Baltic Sea Advisory Council (BSAC) indicate that the BSAC was not consulted ahead of the Danish case study (Kriegers Flak) in 2016. The BSAC perceives that there is a considerable lack of transparency on how settlements for marine infrastructure are put in place in the maritime space. The BSAC considers that early meeting with stakeholders is essential. Twenty individual fishermen were, however, interviewed as part of the environmental impact assessment (EIA) at the time. A public consultation was also undertaken by a consulting company so that the public and various entities had a chance to react to the impact assessment, together with the answers from the body that conducted the assessment.

Table 3. List of stakeholders that were interviewed during the study in the different Member States and their roles.

Type of stakeholder	Name of stakeholder	Member State	Name of organization	Role	Remarks
Advisory Council	Baltic Sea Advisory Council	RAC	Secretariat of the Baltic Sea Advisory Council	To prepare and provide advice on management of Baltic Sea fisheries	Did not fill in the questionnaire due to work commitments but provide information on stakeholder consultation (email)
National administration	Ministries and control agencies	UK	The Crown Estate	All stages of wind farm development as the Marine Consents Manager	
			Marine Scotland	All stages of offshore wind farm development from planning to decommissioning	
		BE	FOD Environment	Planning as a maritime spatial planner	
Fishing industry	National federations and producer organizations	UK	National Federation of Fishermen's Organisations (NFFO)	All stages as a representative of the fishing industry	
			Scottish White Fish Producers Association (SWFPA)	All stages representing fishermen	
			Scottish Fishermen's Federation (SFF)	All stages representing fishermen	
		BE	Redercentrale	All stages representing the Belgian fisheries sector	
		NL	VisNed	All stages representing the Dutch fisheries sector	

	Fisheries liaison	UK	Fisheries Liaison Officer on multiple windfarm projects	Liaison for the commercial fisheries sector	
Wind farm industry	Wind farm developers	UK	RWE Generation UK	All stages as a wind farm developer	
			Vattenfall	All stages as a wind farm developer	Did not fill in the questionnaire due to work commitments but some information on adaptive/ mitigation strategies and best practice (mail)
		BEL	Belgian Offshore Platform	All stages as a wind farm developer	
		NL	Eneco	All stages as a wind farm developer	
	Wind farm association	NL	NWEA	Branch specializing in wind energy at sea that serves the interests of all actors in the value chain	
Aquaculture	Sector representative	UK	Scottish Salmon Producers' Organisation	Offshore salmon aquaculture	
		BE	ATSEA Nova	Seaweed farming in offshore wind farms (Wier & Wind project) as well as via requests from potential customers who are interested in investing in seaweed farms in OWFs	
		NL	PO mosselen Nederland	To execute their vision of the future of the aquaculture industry	
		DK	Dansk Akvakultur	Responsible for hatcheries, smolt stations and sea farms	
NGO	NGO	BE	Natuurpunt	Every stage, including dismantling and/or decommissioning	

3. INTERVIEWS

A questionnaire was designed to assess the perceptions of key stakeholders on the effects of offshore wind farms on fisheries and aquaculture, and to gather additional information to supplement the literature review. The questionnaire included open and closed questions to identify the effects of wind farms on fishing and aquaculture. The questions were grouped into five broad sections as follows:

- The first section required basic information from the respondent, including their position, how long they have been involved in OWFs and whether there is a specific stage of wind farm development that is more critical to their role.
- The second section of the questionnaire focused on the ecological effects of OWFs, with questions asking respondents to relate changes they have observed from the implementation and operation of wind farms on aspects such as gain/loss of species, effects on commercial important species and sea-bottom fauna.
- The third section focused on fisheries and aquaculture management. It explored interviewees' perceptions of how fisheries and aquaculture activities are influenced by OWFs, approaches being used to offset negative effects and the adaptation/mitigation strategies being used to ensure coexistence and the potential for multi-use of the marine space between OWFs and fishing/aquaculture activities.
- The fourth section focused on the socio-economic effects of OWFs, with questions asking stakeholders to relate changes that they have noticed since wind farm construction to fishing grounds, gear used, species and size composition of the catch and travel times to fishing grounds. Stakeholders were also asked whether they knew of any compensation mechanisms for displaced fishing and aquaculture activities.
- The final section of the questionnaire focused on best practice in stakeholder governance, with respondents asked to state what they considered to be the key principles and success criteria in managing fisheries and aquaculture stakeholders of a wind farm, and to provide any standard guidelines or common best practices that they follow in their stakeholder involvement. The stakeholders were also asked whether they could think of any specific gaps in governance.

Responses to the questionnaire are summarized for each section, grouped by stakeholder category. An overview of the stakeholders is given in Table 3.

3.1. Fishing industry

Five questionnaires were completed by fishing industry representatives: a Fisheries Liaison Officer (FLO) involved in multiple wind farm projects, and three representatives of fishermen's federations from UK (NFFO, SWFPA and SFF), one from Belgium (Rederscentrale) and one from the Netherlands (VisNed). Respondents from the fishing industry participated in all stages of the wind farm development process (planning, implementation or operation) and had 3–13 years' experience.

3.1.1 Ecological effects of wind farms

Fishing industry respondents provided a mixed picture in their perceptions of the ecological effects of OWFs. Some suggested that these are still being researched by, for example, the Scottish Marine Energy Research Programme (ScotMER). Others did not respond to questions in this section, saying that scientists should assess the ecological effects of wind farms. Some indicated that there were direct effects on commercially important species and pointed towards: i) the recovery of crab stocks in the Westernmost Rough OWF (Roach *et al.* 2019); ii) increased occurrence of commercially important fish (gadoids); and iii) positive effects for sea bass from the London array as reported by sea angling vessels. Regarding the effects on invasive species, one respondent noted that oysters, previously rare in the area, now grow on the monopiles at Thanet windfarm. Some respondents however, indicated that OWFs have a negative effect on fish behaviour, noting that: i) shoals of fish were driven apart by noise (during construction and operations); ii) the way windfarms are lit also has a considerable effect on fishing vessel navigation; and iii) the use of scour and other activities to reverse or stop environmental damage increases the loss of fishing ground. For example, Britned, London Array, Gunfleet, Gabbard and Nemo OWFs have reported scour effects that have led to loss of ground.

3.1.2 Fisheries and aquaculture management

Fishing industry representatives stated that they are regularly involved in stakeholder consultation during the wind farm development process. Belgian, Dutch and British fishermen have fishing activities in the North Sea, North Western Waters and South Western Waters, and respondents indicated that they are usually consulted for each individual wind farm project. In the UK, stakeholder consultation is a legal requirement. Responses also show that the fishing industry collaborates with wind farm developers in various ways, either as individuals, through FLOs or through the Commercial Fisheries Working Group (CFWG) that is a requirement for licence conditions. At a national level in the UK, fishermen are part of the Commercial Fisheries Working Groups under FLOWW (Fishing Liaison with Offshore Wind and Wet Renewables). In the Westernmost Rough OWF, the fishing industry is involved in research projects and in providing their fishing vessels for safety work. Navigation is probably the key area where commercial fisheries are involved with other stakeholders. For example, shipping would like to see less lighting of turbines, whereas small-scale fishermen would like more lighting. A compromise between the pilotage/shipping and fishing stakeholders on lighting and buoyage is therefore essential. Respondents however, noted that while they are always consulted, it tends to be limited and at a late stage. The footprint would have already been chosen before the fishermen are made aware of the site, and therefore their input and influence are minimal. Some were pessimistic, stating that it is difficult for the fishing industry to change existing plans due to the power of the wind farm industry. This situation led some to suggest that there are polarized views and little interest in finding a way out.

The responses show that many fishing activities take place in the vicinity of OWFs, the scale of which varies case by case. One respondent noted that fisheries are larger than the OWFs in sector size. In Belgium and the Netherlands, fishing inside OWFs is not allowed, while fishing activities are allowed in the UK. The findings show that, even when fishing activities are allowed within the wind farm, some fishermen still cannot fish inside for several reasons: i) due to safety zones of around 50 m at the turbine base; ii) when major maintenance zones are triggered in the area; and iii) certain gear types, e.g. trawlers, are not keen to fish inside OWFs. Therefore, commercial fishing continues within the sites but to a smaller extent after construction.

Some respondents stated that the fishing industry has never been compensated for loss of fishing grounds due to OWFs. This is in part because it is not a legal requirement, and in certain areas, e.g. the UK, fishermen are not barred from fishing inside a wind farm. Some stated that this could also be because most of the effects involving fisheries are concluded to be minor in the environmental impact assessment (EIA). Others, however, indicated that static gear fisheries have been compensated based on claims of tenure, i.e. who owns the space. Therefore, compensation is paid only when fishermen have to move their static gear for a developer. In certain wind farms, e.g. London Array and Thanet, negotiations by the FLO are ongoing and aim to secure disruption payments for loss of ground/interruption. In some cases, developers have donated to fisheries science, as requested by the fishing industry.

Different adaptation/mitigation strategies are being employed in the various OWFs. In the UK, some wind farm developers have set up a good-will fund to the communities that supports different projects of interest to the fishing industry, e.g. in Barrow and Westernmost Rough OWFs. In the later, the good-will fund to the community was integrated with the Holderness Fishing Industry Group (HFIG) research project where it was used to fund a research vessel. Apart from funds for community projects and disruption payments for static gear, adaptation/mitigation strategies also include: i) the appointment of FLOs to lead communications/interactions with the fishing industry; ii) the setting up of fishing working groups that meet periodically to discuss key issues, including transit routes to avoid conflict with static gear, procedures for communication, notices to marinas and snagging protocols for fishing gear.

3.1.3 Socio-economic effects

The fishing industry in Belgium stated that OWFs have had negative effects by changing their fishing grounds through limiting the open space for fishing activities. Travel times to reach fishing grounds are also longer, as some shipping routes are blocked by wind farms. The fishing industry representative stated that fishermen usually track and follow the fish, and the wind farms acts like a wall that they have to go round. This results in the fish being lost of taking a longer time to catch. Similar perceptions were provided by the fishing industry stakeholder in the Netherlands, who stated that fishermen have to change their fishing grounds because fisheries are banned from wind farms. Some fishing grounds have been used for generations, and respondents stated that OWFs have led to a loss of historic fishing grounds. Fishing industry representatives also stated that, given that the future of fishing does not look promising, less people are becoming fishermen; therefore OWFs have negative effects on employment in the fishery sector.

In the UK, Gray *et al.* (2016) have reported on the displacement of fishing with Nephrops trawls during OWF construction and gear changes (i.e., the shortening of long liners as part of the agreed approach to dealing with fisheries issues) due to OFWs. Perceptions from the fishing industry also show that there has been no substantive evidence on the return of mobile gear after wind farm construction, but static gear tends to carry on. Scallops and Nephrops are prime species in many licensed offshore wind farms in Scotland. While there is no research yet to prove how the OWFs have affected these species, many in the fishing industry assume they have been negatively impacted. There have been changes in types of gear used within wind farm areas. For example, the Hywind area was used by trawlers targeting haddock and herring, but is now mainly exploited by fishermen using creel for lobster and crab. In these cases, there is substitution of fishing vessels before and after construction. Respondents indicated that there has not been enough research to provide concrete evidence on some of the aspects under study, e.g. changes in species/size composition. For instance, in Scotland, only the Beatrice wind farm is fully constructed, and it has not yet generated enough data to reach conclusions.

The UK fishing industry feels that there has been a lack of planning and a misunderstanding of fishing patterns, especially as many areas are not targeted for fishing every day of the year but may be very important for several months. OWFs therefore have negative effects as they lead to loss of historic fishing grounds. Respondents stated that OWFs are an emotional topic, associated with stress, especially for older fishermen. Competition for space has increased, not only due to wind farms but also through increased creel levels, aquaculture, MPAs and other marine uses, meaning that the cumulative stress is high. While OWFs are generally accepted by the public, the fishing industry views them negatively, and many within it have become more resistant as more OWFs are constructed. While fishermen can often return to an OWF site after construction, it cannot always be fished as efficiently or effectively as before construction. Some fishermen have been employed by the windfarms, but this can mean loss of crew to fishing vessels.

Respondents also stated that some fishermen are anxious about fishing within wind farm areas for both personal safety reasons and insurance reasons, as they fear that a cable could be damaged. This makes coexistence difficult. Furthermore, there is not enough distance between the wind turbines, so fewer fishing activities take place after construction.

3.1.4 Best practice in stakeholder governance

The fishing industry provided the following key principles and success criteria for managing fisheries and aquaculture stakeholders of a wind farm:

- clear guidelines from the government, with similar standards for both wind farm developers and fishermen;
- a good stakeholder involvement process;
- early engagement in the planning process;
- a focus on solving problems and a shared understanding of the problems related to coexistence;
- established lines of communication; and
- establishing an agreement on how the problems will be resolved and documenting it.

Other principles suggested included having minimal distance between the individual turbines (for example 1.5 km) and creating shipping routes to maintain access to other fishing grounds. As already indicated, the UK is in the process of updating the FLOWW guidelines to include best practice on fisheries liaison, displacement community funds, and fisheries–cables interactions.

Stakeholders were asked to think of any specific gaps in governance. In Belgium and the Netherlands, fishing industry representatives stated that they would like OWFs to be designated in a multi-use setting. In all Member States surveyed, the fishing industry stated that the marine planning system needs improving: it is still too weighted towards OWFs. Some specific statements were: (1) 'Marine planning system is too sectoral led for wind farms'; (2) 'Marine planning decisions are too much in the hands of developers'; (3) 'Marine planning lacks strategic approach to planning cable works'. Stakeholders stated that National Marine Plans tend to have all the right words, but there is no real power to enforce developers to comply. Fishing industry representatives emphasized that development of offshore wind needs to be done in line with principles of evidence and science-based development. They feel that the fisheries sector is usually sacrificed when designating OWFs, as fishermen need space and the OWFs disrupt fishing patterns.

3.2. Wind farm developers and wind farm association

Three questionnaires and one email response were received from wind farm developers based in the UK (RWE Generation UK and Vattenfall), Belgium (Belgian Offshore Platform) and the Netherlands (Eneco). The Netherlands' branch specializing in wind energy at sea, the NWEA, also responded to the questionnaire. The five respondents from this stakeholder category had between 9- and 20-years' experience and were involved in all stages of wind farm development.

3.2.1 Ecological effects of wind farms

In Belgium, an extensive monitoring program, coordinated by KBIN and executed in collaboration with several research institutes (INBO, ILVO, Ghent University), is investigating the effects of offshore wind turbines on the marine ecosystems. The program has been running for over 10 years and is partially funded by the offshore wind parks[25].

While such monitoring programs are a source of information for understanding the ecological effects of wind farms, perceptions of wind farm developers indicate that most of the ecological effects are not yet known. Some pointed towards aspects such as scour protection attracting various species, e.g. anemones, sea stars, lobster and crab. Others indicated that they are aware of fish favouring the sheltered conditions in OWFs, and that therefore the OWFs have positive direct effects on commercially important species. Respondents were, however, not clear on these effects and thus stressed that more research was needed or the exchange of scientific knowledge needed improving.

3.2.2 Fisheries and aquaculture management

In Belgium, several research and innovation projects on aquaculture are being conducted within the wind farms concessions (e.g. Edulis, Wier & Wind). None of these involve commercial fisheries, since fishing is not permitted within the OWFs. Respondents from the Netherlands stated that some commercial species occurred around the OWFs in high density in certain periods (Machiels 2017). A pilot project (Win-Wind project[26]) focusing on crustacean population in the OWFs is working to see whether commercial lobster/crab fishing could be viable in the future. NWEA insisted that there is potential for multi-use in OWFs with nature-based initiatives such as mussel cultivation or seaweed in OWFs but not with bottom trawling. This is not only due to the risks to cables, but also the effects on fish and bottom fauna. Solar energy is another multi-use option that has great potential. Wind and solar energy can be mutually compatible and would enhance use of the electricity export cable.

Wind farm developers indicated that activities within OWFs are managed through the implementation of agreements that are jointly developed with the fishing industry. For example, in the Netherlands, passive fisheries do not require a permit (niet vergunnings-plichtig). Where they do, a different type of management will be put in place. Such activities (including aquaculture) are managed through a 'Besluit Algemene Strekking' (BAS) that is developed for each wind farm. Respondents also stated that they are aware of plans of a wind farm in France that intent to place the wind turbines far apart from each other to allow fisheries space. The plans have been adapted to fit better the needs of fishermen not only for shipping corridors but also reorganizing the park structure to leave major fishing grounds untouched. Respondents argued that this is not cost-effective from an energy point of view, and furthermore, by placing them at such a wide distance,

[25] https://odnature.naturalsciences.be/downloads/mumm/windfarms/winmon_report_2019_final.pdf

[26] https://www.wur.nl/nl/project/Win-Wind.htm

the wind farm occupies a large area, which can also be negative for fisheries. Currently, the Netherlands Government is aiming for denser (higher MW/km^2) windfarms, resulting in less overall space being taken by OWFs.

In terms of adaptation/mitigation strategies, respondents stated that activities that impact on the sea floor, such as regular anchoring and bottom trawling, are not acceptable. Although the cables are covered by sand, cable depth may vary (as sand moves around), so bottom disturbing activities can damage them. Stakeholders are now working on area passports (gebiedspaspoorten) to give multi-users access to the forms of co-use that could take place in various parts of the wind farm. A 'afwegingskader medegebruik', a formal instrument that is part of Programma Noordzee 2022–2027. Draft PNZ 22–27, will also be established by the Cabinet in Feb 2021, and later published for a half year formal consultation.

Wind farm developers stated that they usually involve other stakeholders when developing wind farms. For instance, the following actors were involved in formulating the Besluit Algemene Strekking (BAS): Rijkswaterstaat, Ministeries EZK and LNV, the wind farm owner, fishermen and the Coast Guard.

3.2.3 Socio-economic effects

Wind farm developers stated that the socio-economic effects of OWFs are still unknown, especially when it comes to the cause of changes in fishing grounds. There are many causes of change to fishing grounds, including when warmer seawater caused by climate change changes migration patterns. The question is, how do OWFs fit in to this already changing environment? Developers also noted that many of the effects of decommissioning are not yet known. Some suggested that the foundations in the ground should perhaps remain or that the growth on the foundations should be transplanted onto new permanent structures. However, this may cause other issues for fisheries. Developers stressed that they did not want to enhance the nature in their parks and then have to eliminate it.

Wind farm developers also pointed out that the space between the turbines does not belong to the developer. There is no fence around a wind farm. As such, if you can show that multi-use would lead to benefits, it is possible to have other activities inside OWFs. In terms of insurance, fishing in OWFs is risky, and it is very difficult to insure against these risks. Damage to a cable, for example, is very expensive. Compensation for fisheries is dealt with in the Noordzeeakkoord (NL), which includes a transition fund that is partly meant to help fisheries become more sustainable or use sustainable techniques. Although the fisheries sector did not sign the Noordzeeakkoord in the end, these compensation measures are still in place.

3.2.4 Best practice in stakeholder governance

The key principles and success criteria in managing wind farm stakeholders provided by wind farm developers include cooperation and communication, as well as the fact that stakeholders should be involved from the start. For instance, in the Netherlands, communication between ENECO and the Ministry worked well. There were initial concerns about insurance, but these were addressed in the last stages of the project. In total, four ministries are involved in offshore wind. This is a point of concern, as they have to listen to each other, cooperate and ensure that policy and legislation are well connected.

In the UK, a FLO is required throughout the consenting process. If this is not mentioned specifically in the consent, most wind farms would still recruit this position, so that operations can be clearly communicated to the fishing industry. In addition, a Notice to Mariners (NtM) is also issued to ensure that the users of the marine environment (including fisheries) are informed in advance of any works. The NtM is typically raised internally by the developer of the wind farm (or consultant) and issued to stakeholders (usually 5–10 days in advance of works) and potentially to regulators, including the Marine Management Organisation (MMO) and Marine Scotland. Furthermore, prior to mobilization, wind farm developers usually advise their contractors or employees of any sensitivities, such as any relevant information from the baseline survey work in the EIA (e.g., nature protected areas), along with the locations of any archaeological features. Developers also need to have a licence from the regulator to undertake certain maintenance work. The licence comes with a number of conditions. For example, authorities must be notified when works are being undertaken, and there may be restrictions on when in the year work can go ahead (to avoid fish spawning areas or wintering/breeding birds for example). A robust impact assessment, including effects on fish and other environmental sensitivities associated with such work, must be undertaken to obtain this licence and should also include certain mitigation measures.

Gaps: Wind farm developers stressed the need for uniformity in approach across OWFs, stating that there are different regulations for permitting different OWFs in Belgium, Netherlands, the UK etc. They find this confusing. A similar gap was mentioned in relation to noise standards, which are different everywhere. Wind farm developers concluded that it is too early to call off any initiatives because there is not enough information yet. More time is needed to see whether or not initiatives for multi-use will be popular and economically viable.

3.3. Aquaculture

Four completed questionnaires were received from aquaculture-based stakeholders, from the UK (offshore salmon aquaculture), Belgium (involved in nearshore and offshore seaweed cultivation), Denmark (responsible for hatcheries, smolt stations and sea farms) and the Netherlands (PO mosselen Nederland). Most of these stakeholders were not aware of any aquaculture activities being carried out in the vicinity of wind farms. They therefore found it hard to answer the majority of the questions. Where they were aware of aquaculture in wind farms, since these activities are allowed, they considered the effects to be minor.

3.3.1 Ecological effects of wind farms

Respondents provided some personal experiences of the ecological effects of OWFs, such as observations that OWFs have high densities of different fish and other organisms. However, the majority said that there were no known effects of wind farms on aquaculture. They stressed that it would be speculative to answer these questions.

3.3.2 Fisheries and aquaculture management

Where aquaculture is practised in OWFs, there is good collaboration. For example, in Belgium, the Wier & Wind project consortium collaborates closely with staff at the Norther wind farm. The Wier & Wind project team works according to Norther's high safety standards, which results in extremely high costs for deploying vessels, safety training, etc. The respondent from the UK stated that the closest OWF to any offshore salmon site is more than 100 km away.

3.3.3 Socio-economic effects

In principle, all extractive forms of aquaculture are allowed in wind farms, and there are therefore no compensation mechanisms. In the Netherlands, mussel cultivation does not happen currently in OWFs. However, the Dutch government has mandated that aquaculture should coexist with wind energy in the future and has appointed wind farms as aquaculture grounds. Aquaculture is technically very difficult within wind farms due to the costs associated with longer travel times and the reduced number of actual working days at sea. Furthermore, due to the high safety risks, offshore wind farm operators require mussel farm employees to take a week's training course, after which they are licensed to navigate through wind farms.

3.3.4 Best practice in stakeholder governance

The key principles and success criteria in managing stakeholders of a wind farm provided by aquaculture stakeholders is that all activities need to be managed in a suitable and optimal way to ensure coexistence. There should be transparency and clear communication of legislative requirements. OWFs should therefore be designed for a multi-use setting. For example, cables should be laid in a way that ensures potential co-use. Some respondents stated that, because wind farm owners are given licences first, all other potential users of that area are risk bearers. The question is, can all these actors take those risks? Respondents thought that governments have prioritized wind energy over (sustainable and healthy future) food, so wind farms are all designed solely for wind energy production. Wind turbines are close to each other and cables are all over the seafloor. This makes aquaculture very difficult. Other users also need anchorage places. These kinds of conditions were not discussed when the wind farms were designed. Some stated that the aquaculture sector was not heard or consulted even though the OWFs are meant for co-use while others stated that they were not consulted since the nearest OWF to any aquaculture site is greater than 100km.

3.4. Government policy and marine consent managers

Three completed questionnaires were received from government licensing and policy officials: a UK government employee providing advice on licensing and research; a UK government employee tasked with strategic planning as a marine consents manager; and a Belgium government employee dealing with marine spatial planning policy.

Respondents had 2.5–5.5 years' experience in their roles, which run through all stages of OWF development from planning to decommissioning, and give advice on: i) licensing at different stages; ii) the effects of offshore renewables on commercial fisheries; and iii) designation of the zones for offshore energy and determining whether and where there will be multi-use. Respondents are also involved in the permitting of zones for commercial and industrial activities where aquaculture can be licensed. They also work with stakeholders to identify evidence gaps and research projects to address the evidence gaps.

3.4.1 Ecological effects of wind farms

Policy officials from Scotland indicated that the ecological effects of wind farms are currently identified as research gaps by the Scottish Marine Energy Research Programme Fish and Fisheries evidence map[27].

The Belgian government refers to the Belgian Monit program, and has the perception that most effects are mixed (positive and negative), except for a positive effect on fish occurrence and a negative effect on alien species.

3.4.2 Fisheries and aquaculture management

Like the fishing industry stakeholders, policy officials stated that stakeholder consultation is usually carried out as part of the licensing conditions. Stakeholder collaboration includes networking and cluster organization. In Belgium, the 'Blauwe Cluster' introduces stakeholders to each other and provides a space for possible collaboration. It also sets up research projects into multi-use. In the UK, a wide variety of stakeholders, including the fishing industry, renewables industry, nature conservation bodies, marine navigation and safety regulators, the seabed leasing authority, academia and researchers are involved via various forums. There are a variety of forums for stakeholder consultation and involvement, such as public consultation events, advisory group meetings, research groups and Commercial Fisheries Working Groups.

With regards to the management of fisheries and aquaculture activities in the vicinity of the wind farms, there are monitored safety zones around the wind farms in Belgium, and fines can be given for fishermen who breach the safety zone. Aquaculture is allowed in these zones (with the permission of the offshore operator), but currently no commercial aquaculture is taking place. In the newly designated zones for offshore renewables, research will be done into whether, and how, passive fisheries and aquaculture can be allowed. As already indicated, in the UK, fishing is not restricted within OWFs. However, due to safety and damage liability concerns, it is challenging for some types of fishing to continue in the wind farms after construction. There is currently a lack of evidence for fishing continuing within wind farms and for what types of fishing can be carried out.

In terms of the approaches used to offset negative effects, Belgium currently does not have commercial aquaculture activities in the Belgian North Sea. For fisheries, activity and intensity mapping of the fishing sector are used when determining the optimal location of OWFs. In the UK, Marine Spatial Plans (MSP) and conflict analysis tools are used to

[27] https://www2.gov.scot/Topics/marine/marineenergy/mre/research/fish

determine the areas for development that conflict least with areas of importance to fishing. Alongside this, the government encourages the developer to engage with the fishing industry as early in the planning process as possible. Mitigation measures are also put in place to minimize any negative effects. Compensatory measures are also in place, but these are agreed between the developer and the fishing industry; the UK government does not play a role here.

Responses to the adaptation and mitigation strategies being used show that, by involving all stakeholders in the designation of new zones for offshore renewable energy, aquaculture and passive fisheries, Belgium authorities are clear that the intention is to have multi-use. Similarly, the UK government encourages coexistence and multi-use of marine space. The National Marine Plan sets out policy objectives to facilitate coexistence of sectors and activities. Policy officials indicated that they are currently still exploring the potential for safe coexistence between wind farms and commercial fishing through research projects. One project, for example, is trialling the safe and commercially viable deployment of static fishing gear within a floating offshore wind farm. In terms of mitigation, the government is asking developers to consider the types of fishing that takes place in the area and their minimum operating space requirements (for deploying and hauling gear) and vessel manoeuvrability. This is then factored into wind farm layout, configuration and turbine spacing at an early design process stage. For example, ensuring turbine spacing is at least 800 m to 1000 m allows fishing activity to continue after construction of the wind farm and encourages coexistence between the marine users and industries. We also recommend that a fisheries displacement assessment is carried out to estimate any displacement levels. This assessment should include but not be limited to considering the minimum operating space requirements for the range of fishing activities (deploying and hauling gear), vessel manoeuvrability and the ability to trawl over cables.

3.4.3 Socio-economic effects

The response from Belgium indicated that the socio-economic effects of wind farms have not been well studied. Currently, commercial aquaculture (which lowers eutrophication) is allowed within OWFs if the park operator consents.

Policy officials in the UK stated that the fishing industry and developers have raised the issue of insurance and liability for damage, to cables for example, and that this is something government is working to address. Officials also stated that there are compensation mechanisms for displaced fishing activities. However, these operate between the fishing industry and the developer; the government is not involved. The UK government will soon be publishing best practice guidance documents on fisheries mitigation management and assessing fisheries displacement. These will include a standardized compensatory procedure to best assess and calculate fisheries displacement and compensation in an open, transparent and fair manner.

3.4.4 Best practice in stakeholder governance

The key principles and success criteria provided by policy officials are very similar to those provided by the fishing industry representatives and include early involvement, setting correct expectations, mutual respect for all involved, alongside flexibility in how engagement with fisheries partners is done. At a strategic level, cooperation is important in producing a set of guidance that all stakeholders can buy into.

In terms of specific gaps in governance, policy officials indicated gaps in: i) general guidance between wind farm density and which activities can be allowed depending on densities of the pylons; ii) spatial data underpinning decision-making regarding historic or current fishing practices.

3.5. NGO

Only one response, from Belgium, was received from an NGO. The respondent had worked with the NGO for 11 years, 6 of these dealing with OWFs at every stage, including dismantling and/or decommissioning. The NGO took the specific role of a policy officer with the aim of protecting marine biodiversity through cooperation with industries and/or implementation or adjustment of legislation.

The respondent did not have personal experience of the ecological effects of wind farms.

The respondent did not provide answers to most of the questions, stating that the questionnaire focused on sectoral concerns about the effects of OWF on fisheries and aquaculture. Thus, it is not possible for an NGO to answer most of the questions. For example, Natuurpunt does not conduct research on the effects of OWF on fisheries and relies on scientific research from Belgian institutions to build insight. If there is interest in the opinion of NGOs on this subject, it would be advisable to organize a specific consultation.

4. CASE STUDIES

Two specific offshore wind farm projects (Belgian OWF area & Danish Kriegers Flak OWF) are being used to provide 'real-life' context to the main aspects and outcomes listed under Task 1. One case study, the Belgian OWF, has a long history of scientific research and thus delivers a lot of insights into the aspects studied here. The other case study, the Danish Kriegers Flak, gives a typical example of the environmental impact assessment (EIA) process required ahead of an OWFs implementation, and illustrates how the knowledge gaps on anticipated OWFs effects are currently tackled in such EIAs.

4.1. Belgian case study

4.1.1. OWF description and context

In **2008**, the **first six wind turbines** were **installed** in the Belgian part of the North Sea (BPNS). **Today**, there are 341 electricity-producing wind turbines, giving an **installed capacity of 1,775 MW**. Seven of the farms – C-Power (325 MW), Belwind (171 MW), Northwind (216 MW), Nobelwind (165 MW), Rentel (309 MW), Norther (370 MW) and Northwester II (219 MW) – are already supplying electricity to Belgian users. The eighth offshore wind farm, Seamade (487 MW), is on its way and, by the end of 2020, Seamade's 58 new wind turbines will provide an additional operational capacity of 487 MW. In 2021, the Belgian North Sea will be good for a total installed capacity of 2,262 MW. This will meet no less than 10% of Belgium's total electricity requirements or almost 50% of the requirements of Belgian household consumers[28]. This means that the **238 km²** zone reserved for the production of renewable electricity will be **fully operational by end of 2020**. At the moment, fisheries are not allowed to operate within the operational OWFs; sustainable aquaculture is allowed under certain circumstances.

Recently, a second area of 284 km² reserved for renewable energy (named Princess Elisabeth zone) has been put in place that will be suitable for an additional ~2 GW of installed capacity (Rumes & Brabant 2019). Within this new area, passive fishing as well as sustainable aquaculture are allowed[29]. So, although the BPNS is a small area, 11.5% of the total area will be reserved for offshore renewable energy.

4.1.2. Ecology

The Belgian offshore wind farm environmental monitoring program, **WinMon.BE, started officially in 2008,** at the start of the OWFs operational phase; although, baseline samples had been taken from 2005 onwards. The monitoring program is a single, integrated, **public-authority driven** program, and data is publicly available. As required by the environmental licence, funding comes from financial contributions from all OWF owners. The WinMon.BE program encompasses several ecosystem components, from macrobenthos to epibenthos and demersal fish and from mammals (including bats) to birds. The program is two-fold and **includes both basic monitoring** that aims to objectively evaluate impacts *a posteriori* **and targeted monitoring** that aims to

[28] https://www.belgianoffshoreplatform.be/en/services/supply/

[29] The marine spatial plan 2020–2026

understand the underlying ecological processes of the observed impacts, as advocated by Lindeboom *et al.* (2015)[30].

The WinMon.BE programme is using beam trawl monitoring between the turbines in two OWFs (C-Power and Belwind) to investigate the effect of OWFs on **demersal fish** and **epibenthos** that reside on the soft sediments between the turbines. The latest report (De Backer *et al.* 2020) analysed the entire time series (2005–2019) of epibenthos and demersal fish data and thus presents the most up-to-date information, summarized below. **Nine years after construction no drastic changes** in the epibenthos and demersal fish communities could be detected for the two studied OWFs. The soft sediment assemblages remained mainly structured by temporal variability due to local and large-scale changes in temperature and climate, rather than by the potential small-scale effect of the established OWFs. However, **secondary OWF effects** were seen. These may be interpreted as the **first signs of a refugium effect and an expansion of the artificial reef effect, hinting towards a positive effect of offshore wind farms on epibenthos and demersal fish**. The refugium effect is suggested by the increased fish densities of some common soft sediment-associated fish species, like common dragonet *Callionymus lyra*, solenette *Buglossidium luteum*, lesser weever *Echiichthys vipera* and plaice *Pleuronectes platessa*, in one of the two studied wind farms. This effect was suggested to **result from fisheries exclusion combined with increased food availability**. In earlier studies, fuller stomachs were discerned for these species (plaice not in the study) in the OWF (Derweduwen *et al.* 2012); and increased occurrence of typical hard substrate species, like the amphipod *Jassa herdmani* and long-clawed porcelain crab *Pisidia longicornis*, were found in the stomachs of lesser weever, indicating a diet change and benefits from the presence of the artificial reefs (Derweduwen *et al.* 2016). An expansion of the artificial reef effect is further suggested through the appearance of an increased number of hard substrate-associated species, e.g. edible crab *Cancer pagurus* and seabass *Dicentrarchus labrax*, on the soft sediments (>200 m from piles). Increased densities of common squid *Loligo vulgaris* in one wind farm consisting of jacket foundation wind turbines could be an indication that cephalods use the jacket foundations as substrate for their egg depositions. However, the clearest indication for the artificial reef effect expansion was the increased abundance of blue mussel *Mytilus edulis* and anemones on the soft sediments in between the piles (>200 m); these two taxa dominate the epifouling communities on the turbines (Kerckhof *et al.* 2019). Although mussel densities were still low (max. ~15 ind./1000 m²), they may contribute to a future increased soft bottom habitat heterogeneity, with local biodiversity hotspots linked to patchy mussel drop offs (De Backer *et al.* 2020).

The artificial reef effect on fish species has been studied in targeted (PhD) projects looking at the immediate vicinity of the turbines (i.e. including the scour protection layer) and studying the processes at play in more depth. A first study looked at the benthopelagic species **Atlantic cod *Gadus morhua*** and **pouting *Trisopterus luscus*** (Reubens 2013). It showed that certain age groups of both species (mainly age I for cod and age 0 and I for pouting) are **seasonally attracted to OWFs** (Reubens *et al.* 2011; Reubens *et al.* 2013a). Stomach content analyses demonstrated that they fed on the dominant epifaunal hard substrate species present at the OWFs (Reubens *et al.* 2013b), and that these dominant prey species contained high lipid and protein concentrations, leaving more energy available than required for fish metabolism and enough energy for growth and production (De Troch *et al.* 2013). This implies that the OWFs are **suitable feeding grounds** for Atlantic cod and pouting. Growth was indeed observed, and the general

[30] All reports are available through this website: https://odnature.naturalsciences.be/mumm/en/windfarms/#monitoring

fitness of cod was similar to other areas and even slightly enhanced for pouting (Reubens *et al.* 2013b, Reubens *et al.* 2014). Furthermore, acoustic telemetry data showed a **strong residency and site fidelity** for cod during summer and autumn months; they were also specifically attracted to the scour protection layer (Reubens *et al.* 2013c). Based on the integrated results, **local production** of cod and pouting could be assumed. On a regional scale, however, no increased production has yet been observed. Due to this positive local production effect, it was concluded that no fisheries activities should be allowed within the OWFs to avoid catching undersized fish from the enhanced local productivity, and to preserve a possible spill-over effect (Reubens *et al.* 2014). Mavraki (2020) looked further into the diet of benthopelagic species of cod and pouting. Their analysis also included stable isotope analyses (SIA) and the benthic sculpin *Myoxocephalus scorpioides* and the pelagic fish species horse mackerel *Trachurus trachurus* and mackerel *Scomber scombrus*, all known to occur in high numbers around the turbines. While stomach contents provide a snapshot of the recently ingested food items, SIA provides time-integrated information on the diet composition and thus information on the long-term feeding ecology, which can indicate long-term residency close to the turbines, an indication of attraction, but could also potentially lead to local production. The combined stomach content and SIA analyses revealed that sculpin, cod and pouting used the artificial reefs within OWFs as feeding grounds for a prolonged period of time (Mavraki 2020). This corroborated the previous findings for cod and pouting, that OWFs could increase local production. For the **pelagic species**, however, these **artificial reefs do not serve as feeding grounds**. In the stomachs of **horse mackerel**, hard substrate-associated species were encountered, but SIA analyses revealed that these colonizing species are **only occasionally** consumed, indicating that the artificial reefs are more used as **feeding oases,** providing high availability of food items. Mackerel did not feed at all on the artificial reefs, but continued feeding on zooplankton in close proximity to the turbines, leaving the reason of attraction for mackerel for further investigation (Mavraki 2020).

Flatfish are an important target species for trawling fleets but are, so far, understudied (also internationally) when looking at the effects of OWFs. A targeted PhD project (Buyse, in preparation) is now focusing on the distribution and ecology of flatfish, with a focus on plaice because an indication of increased densities of **plaice *Pleuronectes platessa*** within OWFs was observed in both environmental monitoring data (De Backer *et al.* 2020) and fisheries-related data (De Backer *et al.* 2019, see below under socio-economics). Within this targeted PhD project (Oct 2018–Sep 2022), the effects of OWFs on **distribution and density** of plaice are being studied by looking at small-scale (turbine) and large-scale (wind farm) distribution patterns. Furthermore, the **fitness** of plaice is being investigated through a study of feeding ecology and health indices. Residency and site fidelity of plaice will also be studied through **acoustic telemetry**. Preliminary results suggest plaice are attracted to the scour protection layer because of increased food availability and high residency within the OWF, at least during the current study period (pers. comm. J. Buyse).

The above results all relate to studies looking into effects during the operational phase of the OWF, but some targeted studies have also looked at the effects of construction, more specifically at the **effect of pile driving sound** on fish species: European seabass *Dicentrarchus labrax* (Debusschere 2016), and Atlantic cod (De Backer *et al.* 2017). *In situ* exposure of **juvenile seabass** to pile driving at a distance of 45 m did not lead to increased mortality or delayed mortality (Debusschere *et al.* 2014). It did lead to physiological changes (reduced oxygen consumption rates and low whole-body lactate concentrations), but only for a short period of time. This stress period could be prolonged by repeated exposure. However, no changes in growth rate or condition were measured 30 days after exposure (Debusschere *et al.* 2016). Under experimental conditions, behavioural activities such as swimming were interrupted at the onset of impulsive sound exposure, but the **behavioural effects** showed recovery to the pre-exposure baseline within the 25-minute exposure period. Moreover, repeated exposure under experimental conditions did not appear to have a clear effect on feeding efficiency. For **Atlantic cod**, an *in situ* cage experiment was performed in which age I and II-group cod were exposed at different distances of pile driving. **No immediate mortality** was observed, but a steep increase in swim bladder barotrauma was detected with decreasing distance to the pile driving source: no swim bladders were ruptured at 1700 m nor at the control treatments; 20% were ruptured at 1400 m distance; 40% at 400 m distance; and up to 90% of the swim bladders were ruptured at 75 m distance. Although most fish in the cages in the direct vicinity of the piling source (100 m distance) did survive this short-term experiment, they all showed internal bleeding and a high degree of abnormal swimming behaviour, hinting towards a reduced survival rate in the longer term. However, these immediate detrimental effects seemed to occur only locally (without the opportunity to swim away), close to the high impulsive sound source, as **swim bladder injuries rapidly decreased with increasing distance from the pile driving source** (De Backer *et al.* 2017).

4.1.3. Management

On 20 March 2014, Belgium approved a marine spatial plan (MSP, MRP2014–2020) for the BPNS by Royal Decree. The plan lays out principles, goals, objectives and a long-term vision and spatial policy choices for the management of the Belgian territorial sea and the Exclusive Economic Zone (EEZ) (Rumes & Brabant 2019). This plan was valid for 6 years and was revised in 2020. In the revision of the MSP (MRP 2020–2026), the Belgian federal government has delineated a second zone (of 284 km²) for renewable energy, the Princess Elisabeth area, located 35–40 km offshore. Within this new area, both sustainable aquaculture and passive fishing will be allowed[2]. While, in the first Belgian OWF area (238 km² nearly fully operational), any form of fishing was and is prohibited within the concession and in the 500 m safety perimeter surrounding the concession, sustainable aquaculture was and is allowed according to the previous and revised MSP. In order for aquaculture to be able to take place, the OWF concession holder has to give his consent; a second condition is that aquaculture should reduce the level of eutrophication within the concession zone (Royal Decree 2019/13159[31]).

In the process of **revising the marine spatial plan**, proposals (from different sectors) were submitted, and data on fishing activity (including of foreign fleets) in the Belgian area were taken into account to delineate OWF areas. There was also a **first round of (bilateral) consultations** with the different sectors, including the fisheries sector (pers. comm. Jesse Verhalle FPS Environment, Marine Environment). Based on all this information, a preliminary draft was submitted to an **Advisory Committee with representatives from all authorities** (federal and regional) that have powers at sea (e.g. Energy Department and Fisheries Department). A first official draft was made taking into account the advice of the committee, and after first approval by the federal Ministerial Council. Prior to official publication of the MSP, a **second written public consultation** was held in which the (foreign) fishing sector or other sectors and the general public could sent in written remarks or objections to the OWF areas. After the public consultation process, all submissions were analysed to update and finalise the MSP.

In recent years, competition for fishing grounds between the fishing industry and other maritime sectors (e.g. wind farms) has increased due to intensifying use of space at sea. This can lead to conflicts and means that fishing is increasingly regulated in space and time. It is difficult for both fishermen and policymakers to keep an up-to-date overview of the, often rapidly, changing situation. That is why the online tool GEOFISH[32] was developed by ILVO. **GEOFISH visualizes fisheries-related data (landings and effort) in combination with marine spatial planning information** (wind farm areas, Natura

[31] http://www.ejustice.just.fgov.be/mopdf/2019/07/02_2.pdf#Page2

[32] www.geofish.be

2000). It is an **interactive tool** where data of interest (e.g. total landings, certain species, fishing hours) can be selected by the user and is projected on geographical maps; this facilitates interpretation and immediately shows spatial and temporal variation. The combination of fishery related data with spatial layers on, for example, wind farm and Natura 2000 areas, informs the fishermen of possible fishing restrictions now and in the future. Policymakers in turn can use the interactive tool during negotiations on spatial use and potential compensation, as they have direct output on the economic value (e.g. landings) of the spatial restriction areas (e.g. wind farms).

4.1.4. Legal

The legal procedure to obtain a license and permission to build and operate a wind farm in the BPNS is clearly outlined on the authority's website[33] (MUMM group of OD Nature).

Within the Environmental Impact Studies (EIS) for the different concessions, a section evaluating the potential (cumulative) effects on fish and fisheries is always included. Usually, no specific studies are undertaken for the EIS, but the results of the WinMon.BE program, complemented by international research results, are used to assess the effect on fish and fisheries.

4.1.5. Socio-economics

4.1.5.1. Fisheries

The fishery in the BPNS is dominated by Dutch and Belgian beam trawlers (including pulse trawlers since 2011) targeting sole and plaice (Depestele *et al.* 2008; Gillis *et al.* 2008; Eigaard *et al.* 2017). In the early years of OWFs in Belgium (2010–2011), a first study looking into fisheries activities was performed, based on VMS data only (with no integration with logbook and meta data on fishing vessels). At that time, a moderate increase in activity in the areas surrounding the concessions was observed. Since no major differences concerning the species of commercial interest were observed in the ecological monitoring at that time, it was assumed that the observed increase in fishing vessel presence were likely the result of redistribution of the effort (Vandendriessche *et al.* 2013). In 2019, yearly aggregated VMS data, combined with logbook data from Dutch and Belgian fishermen, was used to investigate whether beam trawl fishing activity (effort, landings and catch rate of target species sole and plaice) changed over the period 2006–2017 in relation to the presence of OWFs. This study is one of the first to look into changes in fishing activity over such a long time period. Results suggested **no negative effect for the fishing sector** (De Backer *et al.* 2019). The **Dutch and Belgian beam trawl fleet adapted to the fishing restrictions within the OWF area and relocated their activities**. A 'business as usual' scenario, comparable to the wider ICES area, was observed in the vicinity of the OWF concessions for both fishing effort and landings of the top ten species. With the current size and design of the OWF area, it was concluded that fishermen are not avoiding the areas around the operational OWFs; they even seem to be attracted to the edges (especially of the more offshore concessions). Catch rates of the target species sole in the vicinity of the operational OWFs remained comparable to catch rates in the wider ICES area, but **catch rates and landings for plaice seemed to be even higher around some operational wind farms** (De Backer *et al.* 2019). This is in line with the observed increase in plaice density in one of the two studied wind farms during the ecological monitoring (De Backer *et al.* 2020). The data also seemed to indicate that the immediate surroundings were avoided during construction. However, it remained difficult to substantiate the evidence of edge effects because of the aggregated nature of the data (grid cell level and aggregated per year). Heat maps using point data could help

[33] https://odnature.naturalsciences.be/mumm/en/windfarms/#legislation

to zoom into these edge effects, but confidentiality issues hindering the release of this type of data for foreign fleets make this type of analyses difficult.

4.1.5.2. Aquaculture

No commercial aquaculture is currently taking place in Belgian OWFs. Nevertheless, some **pilot studies** have taken place, or are planned, **to study the feasibility and economic viability of co-location**.

The first pilot was the **Edulis project**[34], which investigated **offshore mussel culture in wind farms** (C-Power and Belwind). In the pilot experiments, there were two test platforms: a biological one looking at the best set-up and rope types to optimize natural settling of mussel spat to grow into consumable mussels; and a technical one, called the 'force rope', to measure the effect of currents, waves and tides on the system. The project demonstrated that it is possible to cultivate mussels in OWFs 30 to 50 km off the Belgian coast, both on a biological and on a technical level. The experiments resulted in a well-filled and tasty, high-quality mussel that complied with all food safety regulations. The yield was equivalent to that of hanging mussel cultures in the Netherlands and Ireland, and they were market ready in 15 months, which was faster than the bottom cultured mussels. Nevertheless, the economic viability for mussel aquaculture at a commercial scale could not be validated. There is a need to further reduce technological risks and map operational costs to reliably determine the economic feasibility. Because of the rough environment and extreme conditions, investing in robust, low-maintenance and safe systems (including boats) is recommended, but this will raise overall production costs. It is therefore **important to focus on developing knowledge on the economic feasibility of mussel aquaculture in wind farms**. In addition, the Edulis project highlighted that the **size and organization of the existing Belgian wind farms is not optimal for food production**, which makes sense as they were not designed for that purpose. Furthermore, the distance from the coast also poses a challenge for the technical, practical and economic feasibility. When designing future wind farms, these issues should be taken into account in order to successfully combine offshore wind with mussel aquaculture activities[35].

Within the **Wier & Wind project** (Interreg Vlaanderen-Nederland, July 2019–June 2022), the aim is to develop a large-scale seaweed farm with automated cultivation system that can be deployed within OWFs in the North Sea. At the end of October 2020, the **seaweed farm had just been installed** in the Belgian Norther OWF, 20 km offshore. The objectives are to: i) successfully demonstrate large-scale seaweed farming in a realistic environment; ii) increase the quality and quantity of seaweeds cultivated under offshore conditions; and iii) lower the cost per kg of seaweed by fully mechanizing all process steps. Within the Wier & Wind project, information to validate the business case for commercial offshore seaweed cultivation will also be collected in order to get insights into the profitability of offshore seaweed cultivation under rough North Sea conditions[36].

A last pilot in Belgian waters is situated within the UNITED project (Horizon 2020, January 2020–July 2023), which aims to promote multi-use through installation of real-world demonstration pilots, exploring technical, regulatory, economic, social and environmental requirements and impacts[37]. Within the **Belgian pilot, the co-location of restoration and aquaculture of wild flat oyster within a wind farm will be tested** at Belwind

[34] http://bluegent.ugent.be/edulis
[35] https://ilvo.vlaanderen.be/uploads/migration/public/Mediatheek/PB/Perstekst_edulis_finaal.pdf
[36] https://www.grensregio.eu/assets/files/site/Artikel-Wier-Wind-IDON-nieuwsbrief-Okt-2020.pdf
[37] https://www.h2020united.eu/

OWF (operated by Parkwind)[38]. The production of oysters would help Belgian waters reach good environmental status (European Commission 2008b) by providing important ecosystem services, such as habitat services for epibenthic species, invertebrates and fish or water quality regulation for restoration as well as future seafood production for aquaculture (Stelzenmüller *et al.* 2020). Currently, the pilot is in a pre-operational phase in the Westdiep area, an area allocated to testing commercial and industrial activities 5 km offshore of Nieuwpoort, where substrate preferences and different set-ups are tested. The operational phase within the OWF is planned for June 2021 (pers. comm. Nancy Nevejan at Belgian Flat Oyster Day).

[38] https://www.h2020united.eu/pilots/2-uncategorised/42-offshore-wind-and-flat-oyster-aquaculture-restoration-in-belgium https://www.h2020united.eu/pilots/2-uncategorised/42-offshore-wind-and-flat-oyster-aquaculture-restoration-in-belgium

4.2. Danish Case study

4.2.1. OWF description and context

On 22 December 2016, the Kriegers Flak Concessions Agreement was signed. The licences for pre-investigations and establishment were also awarded. The Kriegers Flak Offshore Wind Farm is expected to be completed and be in operation by the end of 2021. The final project will result in 72 wind turbines installed by Vattenfall A/S (https://group.vattenfall.com) in 2021. Each monopile will be 188 metres in height and have a foundation of 800 tonnes weight. The park (132 km^2) will deliver 604.8 MW in total, which means each monopile will deliver 8.4 MW on average to supply the electrical energy demands of 600,000 Danish households.

Installed at the intersection of the Danish, German and Swedish EEZ, the Danish Kriegers Flak I OWF will be eventually connected to the existing German EnBW Baltic 2 OWF (288W) and the commissioned Swedish Kriegers Flak II OWF (640 MW), and therefore may pose challenges for cross-border coordination. The grid connection for the offshore wind turbines and electrical connection to Germany will be the first offshore grid in the world to combine the integration of renewable energy with cross-border trade in the single market. Hence, the **Kriegers Flak site** has attracted interest because of its **specificities**:

- a shallow ground (25 m) situated at the confluence of the Danish, Swedish and German economic interest zones, approximately 15 km from Danish and Swedish coasts;
- medium wind exposure, but high-quality wind energy potential;
- optimal conditions for temperate fish;
- Baltic and the North Sea water flow exchange;
- moderate exposure to waves;
- potential for combining a 600 MW offshore wind power plant with an annual production of 10,000 tonnes salmonid/trout aquaculture (salinities and temperature being close to optimal for salmonid, in contrasts to fish aquaculture in the North Sea, which is likely excluded from the design due to relatively high water temperature peaks during the summer).

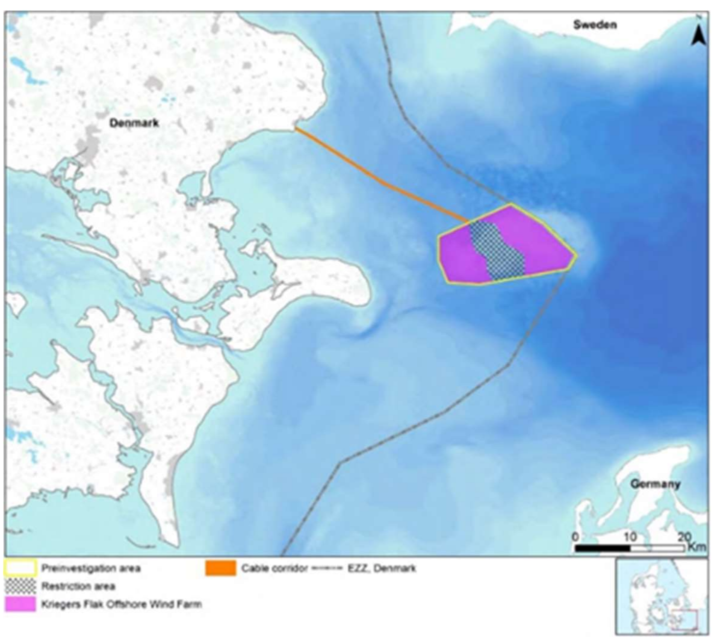

Figure 4. Location of the planned Kriegers Flak OWF (Niras, 2015). Note that the mapping does not show the other nearby concessions that will likely induce cumulated effects.

The Danish Energy Agency ordered an **environmental impact assessment** (EIA) of the Kriegers Flak I OWF concession ahead of 2016 in order to address disturbance to fisheries, ecological effects, possible non-biological related effects, including the destruction of archaeological sites, the reduction of recreational interests and property values, the change in air quality, pollution, CO2 emissions, the change in shipping, commercial fishing and sailing conditions/safety, and the alteration of existing radar installation. It also identified potential disturbances to fisheries during the construction phase and subsequent permanent losses, as well as the amount of possible compensation. The effects of the settlement on the local hydrodynamic regime and possibly related ecosystem are expected to be significant given the size of the settlement. Previous studies show that this area also constitutes a vital fishing ground. The OWF has the potential to affect pre-existing international demersal and pelagic fisheries active in the western Baltic region, the magnitude of which could apply to future OWF projects foreseen in the Baltic Sea.

The EIA was executed while there was uncertainty around the final number of monopiles. This was due to a pending decision on size of the offshore wind turbines. The environmental assessment was carried out working from a worst-case scenario (i.e. 200 monopiles) to ensure the inclusiveness of the EIA report.

4.2.2. Ecology

In general, the Environmental Impact Assessment (EIA) concludes that the construction and presence of the offshore wind farm – the transformer platforms, the cables routing onshore and the associated onshore installations –will have effects on the environment. Most of the environmental components evaluated, however, are temporary and are linked to the actual construction work.

In detail, the possible ecological effects evaluated in the EIA were:

- Change in **hydrographic conditions**. Albeit stratification is very high in the Baltic Sea, at Kriegers Flak, the water column is already mixed most of the time, and the modelling of the hydrographic regime shows that the foundations of the offshore wind turbines and transformer platforms do not affect stratification and thus salt transport into the Baltic Sea. The analysis shows that the offshore wind farm's blockage of natural water flow from the North Sea into the Baltic Sea will be minimal, as no change could be detected as a result of the establishment of the offshore wind farm.
- Change in the **seabed**, **sediment** and **coastal morphology**. A sediment concentration of 10 mg/l is used as a threshold value for disturbed sediment conditions. The modelling work found that the average sediment concentration for the water phase will exceed 10 mg/l during less than 120 hours in total for the entire phase, because the sediment on the Kriegers Flak consists mainly of sand that will quickly sink out and deposit on the seabed. The EIA considered that the seabed type bottom/rock reefs would likely not change from the establishment of turbine foundations and erosion protection, which are therefore considered to have a negligible effect on the seabed type. Finally, it is considered that the project does not affect coastal morphology.
- Change in **water quality**. The calculated concentrations of heavy metals from the modelling work on Kriegers Flak were all below the Danish minimum action levels. The release of nutrients is intended to be very small given the background concentrations of nitrogen and phosphorus.
- Change in **benthic animals and flora**. Elevated sediment concentrations in the water can overshadow vegetation and reduce plant growth. Benthic animals which live by filtering their food from seawater may be vulnerable to high sediment concentrations in the water column. However, the biological data inventory data

shows that organisms that live in the area are all common in these waters, and they are adapted to large fluctuations in the sediment content of the water and periods of high concentrations such as during stormy weather. Therefore, the degree of disturbance is considered negligible. Finally, the permanent loss of habitat for animals and plants due to foundations and erosion protection makes up only a tiny proportion of the study area total area (approx. 0.2%).

- Change in **fish populations density**. The introduction of hard substrate might create an increased biological production ('reef effect'), greater species diversity and a different species composition than before. No significant change in the fish stocks community on Kriegers Flak is expected, as the surroundings already have large areas of hard bottom structures, as shown by the seafloor survey. The one-time trawl survey has registered a total of 44 fish species in the Kriegers Flak area and includes the following species: cod, whiting, flounder, plaice, herring, sprat, sandeel and eel. Cod, flounder and plaice represent species continuously present in the area. Most benthic fish species prefer a seabed with sand, rocks, mussel banks and vegetation. It is also expected that other fish species that live in the water column, such as herring, need a solid bottom substrate (stones, plants, shells, etc.) during the spawning period, as they may put large amounts of eggs on it. Hence, the EIA concluded that the impact of the effect on the fish stocks community in the study area was assessed to be small.
- Change in **marine mammals' density**. The density of harbour porpoise in the area was estimated at less than 0.06 animals/km^2. This stock consists, according to its latest estimate from 2012, of approximately 40,475 individuals. Harbour porpoise are an internationally protected species listed in the EU Habitats Directive (Annex IV). This means that their breeding and resting areas must not be damaged or destroyed by the OWF settlement. The area impacted by noise, i.e. with >140dB created by a single stroke for installing a monopile, will be extensive. Framing of monopole foundations generates extremely loud noises that can induce permanent and temporary hearing loss in marine mammals living nearby. Besides, the noise of the OWF in operation might cause behavioural changes. The EIA argues that this impact might be limited by scaring away the marine mammals from the area before the framing starts. It is unsure, however, whether this mitigation measure is currently being applied in practice.
- Change in **migrating bats, migratory birds and seabirds**. Applying an animal movement modelling tool, it was assessed that the number of bats killed will not affect the species at the population level. The effect of the deterioration or destruction of foraging areas on seabirds will be insignificant, as the sediment spillage will not affect the mussel beds from which the birds feed. It is also expected that, if cranes fly into the offshore wind farm, two out of three cranes will flock to avoid the area where they may collide with the turbine blades. The total number of collisions per year is estimated, for Kriegers Flak alone, to be between 216 (if 8 MW monopiles) and 296 (if 4 MW monopiles). The Potential Biological Removals (PBR) value for a stable population of cranes is estimated at approx. 1,900 individuals and, for an increasing population, approx. 2,600 individuals. Based on this, the risk of collision of cranes and subsequent impact was assessed to be low.
- The EIA estimated that a surface area of approximately 3.2 ha of **protected reef habitat** (habitat code 1170 in a nearby NATURA 2000 site) could be affected directly during the construction phase with sedimentation of up to 13 mm. The EIA concluded that this poses no threat, as this would be much less than 1% of the surface area extent of this habitat in the impacted NATURA 2000 site. Besides, the EIA argues, natural sediment transport and sedimentation, especially during bad weather conditions in the winter or in stormy weather, could also lead to similar levels of sedimentation.

The EIA also considered **cumulative impacts**. The cumulative impacts from Kriegers Flak Offshore Wind Farm may occur in conditions related to hydrography, seabed, sediment and coastal morphology, fish, marine mammals, bats, birds, radar systems, commercial fishing and visual conditions. It cannot be ruled out that there may be significant effects on marine mammals in the construction and operational phases, depending on the choice of offshore wind turbine type and foundations. Besides which, the ecological effects may combine with the neighbouring German and Danish offshore wind farms. Also, combined fishing restrictions in the neighbouring German and Danish offshore wind farms, and possibly also in Swedish wind farms, will lead to a significant reduction in fishing opportunities throughout the Kriegers Flak area.

It is not clear if there is any research program is underway to assess the actual change that the OWF creates against the change anticipated in the EIA. It would however be required to ground check the anticipated effect. For example, the EIA suggests that a OWF might act as an 'artificial reef', thereby promoting local biomass enhancement by attracting fish and developing site fidelity and prolonged residence time in the area (in line with, for example, Schwartzbach *et al.* 2020). Hence, excluding fishing permanently from these sites (avoided for navigational safety reasons) could be indirectly beneficial, not only saving on fish but also possibly enhancing the benthos animals through passive habitat protection. However, the spill-over effect and the gain at the population level from local protected areas has still to be proven. The actual level of protection from OWF may be strongly linked to the configuration of the landscape mosaic as well as interacting processes operating at various spatio-temporal scales. Enhancing hard substrate fish presence also attracts predators, including marine mammals ('ecological trap', where fish are misled into staying in disadvantageous areas). Ultimately, fish aggregation, if any, might attract fishermen, which might then very quickly cancel out any possible net gain of fish production or better catch rate around the OWF. Small-scale gillnetters attracted to the site might come with more bycatching of marine mammals, etc.

4.2.3. Management & legal aspects

The Danish Nature Agency and the Danish Energy Agency are jointly the **EIA authority** for the project. The Danish Nature Agency is the authority for onshore installations; the Danish Energy Agency is the authority for offshore installations (turbines and routing onshore). Energinet[39] was tasked to prepare an environmental impact assessment (EIA) and preliminary geotechnical and geophysical surveys, and to provide DHI MetOcean data[40] etc. The results of these surveys are available online[41]. The licences and authorizations, issued according to the Danish Promotion of Renewable Energy Act (the RE Act) and the Electricity Supply Act, are as follows: i) licence to conduct pre-investigations; ii) licence to construct an electric power generating plant and establish the offshore wind turbines; iii) licence to exploit the wind power from the electric power generating plant for a certain number of years, and approval for electricity production.

An **Environmental Impact Assessment** (EIA) is required most of the time ahead of an offshore project. The Danish Energy Agency (Energistyrelsen) determines on a case-by-case basis whether a wind turbine project will be subject to an EIA. EIAs for individual projects are done following the requirements of the EU EIA Directive (Directive 2014/52/EU) as transposed into national legislation. In the Danish legislation, a project

[39] https://energinet.dk/

[40] https://www.metocean-on-demand.com

[41] The results are available from the following sources:
www.ens.dk/offshorewind
http://energinet.dk/EN/ANLAEG-OGPROJEKTER/Anlaegsprojekter-el/Kriegers-Flak-havmoellepark/Sider/data.aspx
https://ens.dk/en/our-responsibilities/wind-power/ongoing-offshore-wind-tenders/kriegers-flak

cannot begin before either i) an EIA permit has been granted, or ii) it has been decided that an EIA is not required. An EIA statement must include detailed information on the potential effects on the environment, including humans, fauna, flora, soil, water, air, climate, landscape, material assets and cultural heritage.

The EIA qualifies the **significance of the impacts**. If an impact is significant, the EIA suggests that consideration should be given to implementing remedial measures to reduce the impact. In the case of moderate influence, it is considered whether mitigation measures should be introduced. In the case of minor or insignificant impact, the impact is not further addressed. The significance of the impact is defined as the Magnitude of the effect x Probability of the impact x Duration. The statement should also include an overview of the most important alternatives examined by the developer, as well as other alternatives that have been examined, including the zero-alternative. Following the public consultation period, an EIA permit setting conditions for the project can be granted. An EIA permit can be appealed in full, i.e. both on matters of legality and discretion, to the Nature and Environment Appeals Board of the Planning Act. An appeal does not suspend the decision unless the Appeals Board decides otherwise. If the Appeals Board finds that the EIA statement or the EIA permit is invalid on matters of legality, e.g. inadequate assessment of adverse effects, such flaws can be corrected in a new process (or supplementary EIA). Appeals relating to an EIA statement are quite common[42].

4.2.3.1.Conservation areas

If there are designated **Natura 2000 sites** (an/or Annex IV species) in the vicinity of the planned OWF area, **specific assessments** need to be undertaken. Following the guidelines of the EU habitat Directive (Naturstyrelsen), the significance of the impact on the designated area is assessed as not significant if:

- The impact is estimated to involve adverse fluctuations in stock sizes that are less than the natural fluctuations considered to be expected for the applicable species or habitat type.
- The protected habitat type or species is estimated to be recovering quickly and without human help.
- No vulnerable and rare species have been recorded on the seabed in the potentially touched area.

4.2.3.2.Public consultation

According to the Danish Energy Agency (ens.dk): "After being approved by consultation by the relevant authorities, the final EIA reports are then jointly published by the Nature Agency and the Danish Energy Agency (DEA) for **public consultation**. Like for the authorities, the period of public consultation is eight weeks. Within this period, the two agencies together with Energinet conduct several public meetings, in which local citizens have the opportunity to ask questions about the environmental aspects of the project."

The complete draft EIA went through the public consultation in October–December 2015. Nevertheless, there had already been an authority consultation of a draft of the EIA in the summer of 2015. Furthermore, an ESPOO consultation (consultation with neighbouring countries) had been carried out. Objections received in connection with the public

[42] See https://curis.ku.dk/ws/files/143884872/IFRO_report_239.pdf for details

consultations are published on the Danish Nature Agency website[43] (which lists 27 entities' opinions and answers). Based on the EIA and the completion of the public consultations, together with the ESPOO consultation, the Danish Energy Agency ascertained that the EIA could be approved. For Kriegers Flak, the EIA and its consultations led to few changes or adjustments to the terms of the model licenses. A second consultation occurred in 2019 ([44]), after the project's final OWF specifications (e.g. choice of turbine type) were completed by the bid winner, as possible changes in environmental impacts could result from them.

In addition to this, local fishermen, primarily from the local fishing ports, were interviewed. Phone interviews with fishermen from 'foreign ports' fishing in the Western Baltic Sea/Kriegers Flak were also conducted. In total, 20 fishermen were interviewed as part of the EIA process (see further).

4.2.3.3.Post-ante performance evaluation

The project is in the pre-operational phase and, to our knowledge, there are **no** clear experimental **schemes** already **planned to evaluate the impact** of ongoing construction work. It is not clear whether B(efore)A(fter)C(ontrol)I(mpact) (BACI) studies (e.g. Methratta 2020) are planned to evaluate the effects of the OWF settlement on the biological and economic components that existed before the implementation of the spatial plan. It would, however, be necessary to ground-truth the initial impact assessment with field data and analysis that would relate the implementation of the OWF with environmental and socio-economics change as lessons learned for future settlements.

According to the Danish Energy Agency, Denmark has commissioned a follow-up environmental monitoring program focusing on the long-term and cumulative effects on fish, harbour porpoises, common scoters and red-throated divers. The Danish Energy Agency argues that the "new studies provide planners and developers with tools to address the cumulative effects of wind farms and to mitigate injury to harbour porpoises during construction. The Danish environmental monitoring follow-up program has led to the important conclusion that, with proper spatial planning, it is possible to construct offshore wind farms in an environmentally sustainable manner that does not lead to a significant impact on nature" (March 2019).

4.2.4. Socio-economics

4.2.4.1. Fisheries

Concerning the fisheries and socio-economics effects, fisheries data (2002–2012 logbooks) was used (BioApp & Krog Consult, 2015) to provide an insight into the **extent and nature of the impacted fisheries**. The fisheries statistical areas used are relatively large compared to the extent of offshore wind farms (ICES rectangle resolution of the fisheries catch statistics: approx. 30x30 nautical miles, 3430 km²; for the exploration area for Kriegers Flak Offshore Wind Farm: approx. 250 km²). By combining Danish, German and Swedish VMS data with ICES rectangle logbook data, the capture of the individual commercial fish species is located with VMS precision within the study area and the cable corridor. The relative importance of the study area for the different types of fisheries can be described by calculating the number of fishing VMS registration points, respectively in and outside the preliminary investigation area, in each of the ICES rectangles concerned. When using this ratio, the 'lost' quantity of fish of a given species can be calculated in case

[43] https://ens.dk/sites/ens.dk/files/Hoeringer/appendix_2_espoo_responses.pdf

[44] https://ens.dk/service/hoeringer/offentlig-hoering-af-tillaeg-til-vvm-rapport-kriegers-flak-havvindmoellepark

of exclusion from the preliminary investigation area (ca. 85 tonnes on average for the period 2002–2012). The method has the weakness that it assumes that the catches are evenly distributed across the fishing areas. The worst-case scenario is that fishing in the Kriegers study area will not be permitted (it is not yet known what fishery management will be). It might be expected that part of the loss may be recoverable from fishing in other areas, which, however, may not have conditions as favourable to fishing conditions as those found in the study area.

This coupling of VMS positions and ICES rectangle trip-based logbooks showed that different fish species were fished partly in different seasons on the planned construction site, but all in all, the displacement of fishing effort will not be large (<11% of the overall demersal trawl fishery in the concerned ICES rectangle). It has also been assessed that there will be no significant effects on fish stocks as a result of the project (i.e. no irreversible damage from increased ambient noise, no long-term effect of elevated concentration of sediment in the water column, no effect of an electromagnetic field, possible reef effect). The analyses of the effect on commercial fisheries therefore only deals with the fishing opportunities lost in the study area through fishing restrictions and with the displacement of fishing effort to the surrounding areas. In addition to this, it is emphasized that there is a risk of cumulative impacts when other pressures come into play besides the fishing that will affect fish stock fluctuations. Primarily, sand extraction will be carried out for use in connection with the establishment of a tunnel under the Fehmarnbelt. The ongoing construction of an offshore wind farm on the German part of Kriegers Flak, as well as the cabling from there, will also harm the trawl fishery immediately southeast of the Danish feasibility study area.

The EIA conducted **20 interviews** with fishermen to describe where, when and what is being fished. The fishermen naturally have a great deal of knowledge and experience, especially in commercial fishing occurrence and the pursuit of fishing activities in specific waters. This knowledge is usually not written down and can only be obtained through interviews. In the EIA project, interviews were conducted with several fishermen, primarily from the local fishing ports (Rødvig and Klintholm), and from Bornholm. Most bottom net fishermen on the east coast of Zealand (Stevns and Faxe Bay) were also consulted. One of the visits included participation in Rødvig in order to gain an insight specifically into the occurrence of non-commercial fish species. Finally, phone interviews were conducted with fishermen from 'foreign ports' who fish in the Western Baltic Sea/Kriegers Flak.

For the **small vessels** not equipped with VMS (<12 metres), electronic map plotters based on GPS systems provided by skippers of the fishing vessels (plotter data) were utilized. Plotter data information has been compared with the knowledge obtained from the 20 interviews on where, when and what is being fished, and electronic maps have been obtained from several fishermen. There remains a relatively inaccurate knowledge of the actual fishing areas used by the group of small vessels and therefore little knowledge of how this community will be affected.

The **EIA on fisheries concluded** that, overall, the significance for trawl fishery in the operational phase both in the study area and in the cable corridor would be moderate. The effect was assessed to be minor if some of the following measures were to be implemented. There are preconditions for low impact on fisheries: i) fishing over submarine cables between the transformer platforms is permitted during the operational phase; ii) fishing is allowed over the cables during the operational phase; iii) the offshore turbines are built in a set-up pattern that, to the greatest possible extent, avoids the historical trawl tracks in the study area. However, the EIA argues that these are well-known measures to minimize the effects that were applied in similar projects, but without any further justification.

In Denmark, a fisherman experiencing a loss of commercial income can apply for **compensation** from the owner; cf. the act on fishing[45]. Alternatively, the pipeline owner can consider locating the submarine cable or the pipeline deep enough into the seabed so that they are protected against damage from towed fishing gear and, thus, be granted an exemption from the 200 m buffer zone prohibition. The owner of a submarine cable or pipeline can forward an application to the Danish Maritime Authority for an exemption from the prohibition against the use of towed gear in the protective zone of submarine cables or pipelines by forwarding a declaration stating that the submarine cable or the pipeline would not be at risk of being damaged if towed gear is being used[46].

4.2.4.2. Co-location with aquaculture farms

Both aquaculture and wind energy extraction could **benefit** from sharing the seabed area, primarily in terms of cost-sharing of transportation or housing. However, **the site is likely not suitable for a possible co-location of OWF with aquaculture** as it is in the open or semi-open Baltic Sea[47]. The challenges for fish, shellfish and seaweed farming are ice and the wave and wind conditions; maintaining the competitiveness and profitability of the business requires large investment, larger volumes of harvest (for fish and blue mussels), a large surface area per site (especially for cultivating seaweeds), and many sites close together. Farming on land (for rainbow trout) and coastal areas (for mussels) is the preferred approach in Denmark, as species farmed in marine, brackish offshore water such as the central Baltic Sea may not grow large enough for human consumption or to ensure viable business up to the supermarket, or prove more profitable than the current land-based solution. Beside this, persistent opponents to marine aquaculture include: i) coastal residents, who fear impairment of waterfront views and waste accumulation on beaches; and ii) environmentalists in a broad sense, who are concerned about pollution, interbreeding between natural populations and escapees, and the impact on wild population dynamics.

[45] https://www.dma.dk/SikkerhedTilSoes/Sejladssikkerhed/EntreprenoeropgaverSoes/Sider/SoekablerRoerledningerHavbunden.aspx

[46] https://www.dma.dk/SikkerhedTilSoes/Sejladssikkerhed/EntreprenoeropgaverSoes/Sider/SoekablerRoerledningerHavbunden.aspx

[47] Aquabest report: https://www.centrumbalticum.org/uutishuone/tietopankki/tietopankki/offshore_fish_farm_investment_and_competitiveness_in_the_baltic_sea.2877.news?1771_o=165

5. SUMMARY

The global shift to **renewable energy** is well underway and includes large-scale development of OWFs within the North and Baltic Seas. Wind energy makes an essential contribution to meeting the goals of the Paris climate agreement and the European Commission's decarbonization strategy. The long-term consequences of wind turbines on marine life are still under study, as there remain several key knowledge gaps. Besides the effects on the marine ecosystems (which may have positive as well as negative aspects), the increase in OWFs could affect or provide beneficial aspects to the operations of other industries, including the fishing and aquaculture sectors. The expansion of marine renewable energy will therefore, inevitably, lead to either **increased coexistence** and the potential for multi-use of the space available for fishing and aquaculture activities, **or** a **restriction** of and potential conflict with some fishing activities.

In this context, the overall objective of this study is to provide an **up-dated understanding** of the existing and potential future effects of OWFs on fisheries and aquaculture. The study involved an in-depth literature **review** on **several aspects** (ecology, management, legislation, socio-economics, stakeholders and governance), complemented with **stakeholder interviews** and supported by **two case studies** (Belgian OWF and Danish Kriegers Flak area). Below, the output of the interviews and case studies is summarized together with the literature review output on the different aspects. The Belgian OWF case study provides 'real-life' context on all aspects through insights gained in an operational OWF area with a long history of scientific research. It illustrates the importance of a two-tiered monitoring approach (combining basic and targeted monitoring) to increase our knowledge base. The Danish Kriegers Flak case study gives a typical example of the environmental impact assessment (EIA) process required ahead of an OWF's implementation and illustrates how the knowledge gaps on anticipated OWFs effects are currently tackled in such EIAs.

5.1. Effects of offshore wind farms on ecology

The presence of offshore wind structures adds **significant pressure** to the seafloor and to the whole ecosystem. To date, most studies document the existing and expected ecological effects on single ecological receptors (benthos, fish, mammals) resulting from the different implementation stages (construction, operation and decommissioning). The observed **effects are diverse** (positive/negative, direct/indirect), occur particularly at **local** spatial scales (turbine scale and close vicinity) and alter biodiversity by modifying habitats locally. EIA evaluations (as for Kriegers Flak) tend to show that, with the current knowledge and expertise available, the environmental effects are anticipated to be temporary, minimal (on the scale of one area) and mainly linked to the actual construction work in settling the OWFs.

During the **construction** work, the seafloor ecosystem is **temporally disturbed**, due to sediment displacement or increased sediment resuspension within the OWF area. In several OWFs (e.g. Danish Krieger EIA), the organism that live in the area are adapted to large fluctuations in sediment displacement, so that the degree of disturbance can be considered negligible. Piling of the turbines also generates a high impulsive sound that has been shown to affect the behaviour of mobile marine species (e.g. juvenile seabass, Atlantic cod, marine mammals), but does not lead to immediate mortality (at least in the Belgian case study). Nevertheless, increased swim bladder injuries in Atlantic cod have been observed with decreasing distance to the pile-driving sound source. Finally, the permanent loss of habitat for animals due to foundations and erosion protection makes up only a tiny proportion of the study area total area (e.g. 0.2% for Kriegers Flak)

During the **operational** phase, introduced structures and/or turbine foundations **change the local habitat characteristics** by providing a surface for colonization of fouling species and by attracting various fish (pelagic and demersal) and crustacean species (e.g. crabs, lobster). Studies show that the turbines and scour protection act as an artificial reef (so-called '**artificial reef effect**'). Several species are clearly profiting from the shelter and increased food availability at the turbine scale, and increased local production of some species (e.g. pouting) has even been observed. Increased fish productivity at the wider scale, however, is still uncertain. At a larger OWF scale (Belgian OWF case area), nine years after construction, no drastic changes in the epibenthic and demersal fish community of the soft sediments in between the turbines have been detected. However, some increased fish densities (common dragonet, solenette, lesser weever and plaice) have been observed, hinting towards a positive secondary OWF effect. Whether this increased abundance results in an increased production at population or stock level warrants further investigation. Nevertheless, turbines serve as '**stepping stones'** for certain species (e.g., hard substrate species, invasive species, red list species), increasing as such the population connectivity. This **altered biodiversity** and **species occurrence** (structural community effects) can lead to changes in ecosystem functions and processes, which is an effect not well studied yet, and typically not addressed by EIAs. Only, a few recent studies, based on modelling or stable isotopes give some more insights into the food-web ecology. Modelling showed positive responses of higher trophic levels (e.g. piscivorous fish) to the increased biomass on turbine foundations and scour protection layer. The stable isotope study in the Belgian OWF showed that the scour protection layer plays a key role as a feeding ground for both vertebrates and invertebrates for a prolonged period of time. Moreover, an over-representation of trophic generalists and an under-representation of trophic specialists was observed, suggesting that more generalist organisms will occur in the North Sea in the future due to the development of more OWFs.

Offshore structures also induce local **changes** in **hydrodynamics** and **sediment transport**, affecting turbidity, altering fine-grained sediment dynamics and bed shear stress. Such changes influence the primary and secondary biological production within the water column up to higher trophic levels. A shift in benthic species could also occur, depending on the dominant hydrodynamic patterns within the OWF, by facilitating and determining the local organic enrichment in the wake of the turbine.

Most OWFs are '***de facto*' closed areas for fisheries**. As such, an OWF area can be seen as a passive refuge and recovery area for long-living benthic species and fish, potentially resulting in higher densities and larger animals. Nevertheless, in practice, the effect is modest in the short run. For example, in the Belgian OWF, the first signs of a refugium effect have only been reported after 9 years. Most monitoring studies are conducted over short time frames, and the current licensed OWFs are probably not yet large enough to detect these potential effects, especially since recovery time is high for certain species.

An aspect that is unknown to date is what the process of **decommissioning** will mean for the ecosystem, but lessons could be considered from the oil and gas industries and work on shipwrecks.

Stakeholder perspective on ecology

Most stakeholders refer to scientific evidence and the existing monitoring programs to identify the ecological effects. If ecological effects are mentioned, mostly the increased occurrence of certain commercial species (fish, crabs, lobster) within OWFs is noticed.

5.2. Fishery and aquaculture management

There are only **few examples** found in scientific literature of **real management** approaches to the adaptation to and/or mitigation of the effects of OWFs on fisheries and aquaculture. The OWF development process is part of the obligatory **maritime spatial planning** (MSP) process for Member States. When looking at literature on MSP processes, and specifically in cases of OWF designation and construction, it seems that consultation processes for aquaculture and fisheries and compensation measures for displaced fisheries do not always lead to satisfactory outcomes for the affected stakeholders. **Decision support tools** can aid in understanding the possible consequences of certain strategies or decisions and can therefore aid in minimizing economic and/or displacement in the case of fisheries, thereby optimizing chances for OWF–aquaculture integrations. The (further) development and improvement of decision support tools is therefore an important step in managing fisheries and aquaculture in areas with OWF construction.

Depending on the national regulations, fisheries can, cannot or can only partly access OWFs, which lead to a possible loss of fishing grounds. Where **co-location** is not prohibited, safety risks (and insurance issues) seem to make it **mostly impossible in practice**. In addition, the fishermen that currently fish in planned OWF areas are not always the same type of fishermen that will be allowed in OWFs. Loss of fishing grounds causes fishery displacement, possibly resulting in a loss of fishing opportunities and income, together with increased competition in other areas. Displacement of fishing effects depend on the fisheries behaviour, which is difficult to predict given different types of fishermen are being impacted and a lack of fishery behavioural models.

The literature review reveals **some key management strategies** that can help arrange the coexistence between fisheries and OWF. **Consultation** is key in this, and most studies advise having 'better' consultation processes. The preferred approach includes involving the fishing sector before determining the OWF sites, avoiding 'tokenism' (consultation as a mere prerequisite for OWF construction instead of a useful tool within OWF designation and management), involving local representatives, as well as arranging face-to-face meetings. Finally, allowing enough time and monetary compensation for representative participation. The case studies show that consultation took place within the MSP (Belgium) and EIA (Denmark) process, but in both cases, the fishery sector could not change any aspect of the OWF planning or receive any compensation. **Compensation of the fishery sector** is another strategy, but is not a simple matter, as there are different opinions on who is eligible for compensation and what kind of compensation is appropriate. Some literature indicates that community-based compensation might be more effective than compensation at the fishermen level in stimulating alternative livelihoods for fisheries communities.

For **offshore aquaculture**, which has **clear co-location potential** within some OWFs, the current lack of experimental pilots to test technical and economic feasibility, in combination with the lack of clear licensing procedures and regulations, is inhibiting the development of aquaculture in OWFs. Several studies show that OWF developers are not intrinsically motivated to engage in multi-use, as this might increase their costs of operation and is not related to their core business of energy production. Therefore, when economically viable aquaculture systems within OWFs have been developed, Member States could stimulate and enhance opportunities for aquaculture co-location with incentives (e.g. criteria in tender procedures, area passports, clearer licensing procedures).

Stakeholder perspective on management

The fishing sector indicates that, while it is always being consulted, consultations are limited and occur at a late stage, when the OWF area is already designated. Therefore, its input and influence are minimal. This leads to a pessimistic view on solving the spatial battle between fishery and OWFs. In areas (UK) where fishing is allowed inside the OWFs area, fishermen indicate that the fishing is compromised due to impaired safety, maintenance zones and gear type conflicts. Nevertheless, fishermen indicated that fishing is done in the vicinity of OWFs. Compensation for loss of fishing grounds has not yet happened, as there is no legal requirement or the effect on fishery is estimated to be minor within the EIA process. In some cases (UK), donations are made to fisheries science or a good-will fund for the communities.

The OWF developers stress the multi-use potential for aquaculture, nature-based initiatives, solar energy and fishery. They indicate that such types of activity are possible, except when they impact the seafloor (e.g. regular anchors, bottom trawling), mostly in relation to not damaging the cable grid. In relation to aquaculture, good collaboration between both sectors is essential, which is demonstrated by the Wier & Wind project (Belgium).

The interviews with the government representatives revealed that most of them found the following aspects important: that a broad consultation process is necessary; that spatial planning tools (decision support tools) enable the minimization of conflicts; that multi-use should be the intention; and that wind farm developers should design their farms so multi-use is possible (e.g. ensuring more turbine spacing, appropriate cable grid and alignments). Compensation measures have to be put in place, but this is, for now, something between the developer and fishing industry.

5.3. Legal

The right of Member States to regulate fisheries and aquaculture activities in and around OWFs derives from the **United Nations Convention on the Law of the Sea** (UNCLOS), which confers upon them a right to claim a 12 nautical mile (nm) territorial sea and a 200 nm Exclusive Economic Zone. A coastal state has **full sovereignty** over its **territorial sea** and may adopt laws and regulations on activities that are undertaken there, including fishing, aquaculture, windfarms, navigation and safety zones around OWFs and other offshore structures, subject only to the right of innocent passage of foreign ships. Within its **EEZ** a coastal state has '**sovereign rights**', meaning that it can adopt similar laws and regulations to ensure that the maximum breadth of safety zones around OWFs and other offshore structures may not exceed 500 metres. Fishing activities in the EU waters of the North Sea and the Baltic Sea, including in areas around windfarms, are of course, in general terms, subject to the rules of the Common Fisheries Policy, EU environmental legislation and the overall framework for maritime spatial planning (MSP). But **EU legislation does not** specifically **address fishing and aquaculture in and around OWFs**. Consequently, each Member State is free to adopt its own specific legislation on safety zones around OWFs. There has **not been a common approach to this matter**. In some Member States, the legislation provides for the creation of 500 m safety zones around OWFs in which all navigation is prohibited. Elsewhere the legislation permits navigation through OWFs but prohibits fishing either altogether or using active gear. In some Member States, safety zones are applied only during construction, maintenance and removal. As regards aquaculture in OWFs the only explicit reference is contained in the Belgian MSP decree and there are also, in some cases, questions as to the extent of the spatial scope of aquaculture legislation.

5.4. Socio-economic effects of OWFs on fishery and aquaculture

Most studies on economic effects were conducted in a qualitative manner. The major economic effects are the **loss of fishing grounds** (economic value, but also emotional value), the possible **effect on catch volume**, **gear conflict issues** and **changes in travel time**. Some studies show that OWFs overlap with existing fishing grounds, resulting in large losses in fishing opportunities (e.g. 90% Danish and 40% German annual plaice landings for German EEZ). On the other hand, analyses of fishing activities in relation to the Belgian OWF area revealed that fishermen adapt and relocate activities, with indications of reaching even higher plaice landings around the wind farm. This shows that fishermen displace their effort in an attempt to compensate by fishing elsewhere, and possibly on other target species, and switching to another fishing type (e.g. mobile gear to crab or lobster potting). Studies show that only a part of the fleet can and will change. Fishing with static gear is suggested as a management strategy for fishing within OWFs, but this can lead to gear conflict issues. A natural compensatory effect could also occur in cases where exploited fish spill over from the OWFs area, with more lucrative fishing at the edges of OWFs. There are some signs in the Belgian case study of such an effect benefitting the Belgian and Dutch trawlers targeting plaice.

The main fishery concerns on this are the **safety implications** of potential collisions of their gear with wind turbines, especially during bad weather and strong tides. Operating within a windfarm can be done in a **less flexible way**, as the fishermen are subject to the operational activities of the wind farm owners, which have first priority. Fishermen fear losing traditional fishing grounds, and that full development of the OWF plans in Europe will lead to a loss of business, jobs and income for the current fishery sector. A (partial) **switch to other activities**, including new fishing methods, is **not** considered to **fully compensate** for the loss. Therefore, there is increasing opposition within the fishery sector to OWF developments. It should be said that no study exists that provides complete quantitative data on the economic effects, especially not covering the entire value chain (fishing, processing, transport, marketing). Positive or negative claims on eventual effects cannot be validated at this time.

It was not possible to identify socio-economic effects of **OWFs** on **aquaculture**, mainly because offshore aquaculture is in its infancy (there are no real business cases and, as yet, no spatial conflict) and **still needs to be proven a viable business**. In Belgium, several pilots (Edulis project, Wier & Wind project, United project) have taken place, or are planned, to study the feasibility and economic viability of aquaculture. An important conclusion was that, in order to have a chance of being economically viable, the OWF should be designed from the beginning for co-location with aquaculture activities, and that much more mechanization will be needed to sort out the fouling issues in the North Sea. The Danish Krieger's Flak area is not likely to be economically viable for aquaculture, as it is economically worth more to continue fish farming on land and in coastal areas. Nevertheless, aquaculture within OWFs is identified as the major co-use concept, with several advantages. Aquaculture could create jobs directly, but also indirectly (new skilled labour, specialized suppliers, education programs, innovation jobs) and therefore enhance and transform local (fishery) communities.

Stakeholder perspective on socio-economics

The fishing industry clearly expressed their concerns, as their fishing grounds are changing and lost, travel times become longer, flexibility is reduced and higher competition means more stress. Thus, OWFs have become an emotional topic and the sector more resistant as more OWFs are constructed. The industry also stated that there has not been enough research done to provide concrete evidence on, for example, increased production (or changes in species/size composition). Where fishermen can often return to an OWF area after construction, they noted that it cannot always be fished as efficiently or effectively as before construction. Coexistence seems very difficult because of safety concerns (e.g.

not enough distance) and insurance reasons. In terms of insurance, fishing in OWFs is risky, and it is very difficult to insure against the risks (collision, cable damage); this is also mentioned by the wind farm sector. Nevertheless, the fishing industry indicates that the socio-economic effects of OWFs are still unknown, especially when it comes to the causes of changes in fishing grounds, which also include climate change-driven changes in target species distribution.

The aquaculture sector confirms the multi-use potential of OWFs, but the economic return that can be gained from the coexistence is currently not known or estimated to be low, as many aspects (longer travel time, reduces working days at sea, safety risks, extra training courses, fouling) influence the operability.

The policy stakeholders confirm that insurance of non-OWFs activities inside OWF areas and liability for damage is an issue and requires further investigation. Therefore, the UK is developing a best practice guidance document on mitigation management and assessing fisheries displacement.

5.5. Stakeholders and governance

Key stakeholders at the regional, national and international level who have responsibility for the planning, implementation and operation of OWFs in the North and Baltic Seas are listed. The **stakeholder landscape is quite complex**, as illustrated by three examples. The first example shows that the Belgian fishery sector is not consequently consulted. In Belgium, consultation takes place through the marine spatial planning process, whereas in the UK, the fishery sector is consulted for each OWF ('statement of common ground'); it is not yet consulted for OWFs in France or the Netherlands. This illustrates that there is **no common** EU **approach**. The second example is from Scotland, where the Fishing Liaison with Offshore Wind and Wet Renewables (FLOWW) is a national initiative set up to foster good relations between the fishing and offshore renewable energy sectors and to encourage coexistence between both industries. Stakeholders meet regularly, common issues are proposed and discussed, and specific working groups can be established and have to lead to advice and information exchange among stakeholders. The third example indicates that involving regional organizations in OWF development plans is not done (e.g. Baltic Sea Advisory Council for Danish case study). The BSAC perceives that there is a considerable lack of transparency on how settlements for marine infrastructure are put in place in the maritime space.

Stakeholder perspective on best practice in stakeholder governance

The fishery and aquaculture sector demands clearer guidelines from government, with similar standards for OWF developers across the EU (also stressed by the wind farm sector), early engagement, a focus on solving problems and shared understanding and established lines of communication. Important problems to solve for them are distance between turbines (real multi-use possibility) and shipping routes to maintain access to fishing grounds. They all stated that the MSP system needs improving and is too weighted towards OWFs. The aquaculture sector also noted that the wind farm sector should consult it before construction, to optimize the wind farm design to allow multi-use. The same barriers (space between turbines, cables, anchoring places) as for fishery were encountered.

The wind farm sector stresses the importance of cooperation and communication at all levels, which is in the UK implanted through the FLOWW.

6. GAPS AND RECOMMENDATIONS

Activities addressing global warming and ensuring security of energy supply, alongside food security challenges, have become top of the agenda for governments, industries and regulators (Birchenough and Degraer, 2020; Degraer *et al.* 2019). Governments have committed to investing in renewable energy to reduce dependency on fossil fuels and carbon emissions. Alongside this, fishery and aquaculture production are needed to ensure the food supply requirements of an increasing human population can be met.

The research consortium held a virtual workshop to capture all relevant gaps and recommendations from this study. In chapter 6.1, a short summary on the gaps per aspect is provided; these are transformed into recommendations through the 'bridging table' concept (Figure 5) in chapter 6.2. In the gaps section, a link with some specific recommendations is made.

Figure 5. Example of summary schematics used to determine recommendations as a 'bridge table', covering aspects of: i) current state of knowledge; ii) how to address this research gap; and iii) the desired knowledge base.

6.1. Gaps

Ecology

The literature review demonstrated that the presence of offshore wind structures creates pressures of varying degrees on the seafloor components (highlighted by several site-specific studies) and potentially on the wider ecosystem. This is highlighted by several site-specific studies, but not considered at wider scales (see recommendation 1). An important distinction is that a number of effects of OWF on ecological components are evident; some are considered as positive, some negative and some mixed or neutral. Whether these demonstrated effects translate into meaningful impacts (*sensu* Boehlert and Gill 2010; Wilding *et al.* 2017) on the ecological receptors (see recommendation 2) or cause change of significance at the ecosystem scale (see recommendation 3) remains unknown. There are therefore key gaps in ecological knowledge. In relation to fishery, it is unknown what those observed changes mean at population level or wider regional scale for fish stocks (see recommendation 4). Therefore, it remains unclear what the benefits for fisheries in relation to OWFs are, and more dedicated research is needed.

Management

To date, there is not much literature available that has reviewed or studied the current effect of OWF on fisheries and aquaculture or possible management strategies (see recom. 5). However, some information on consultation and compensation of (displaced) fishermen resulting from the placement of the turbines is available. There is also some general information available on how the inability of fishermen to utilize OWF areas affects their normal fisheries practices. Consultation (see recommendation 8) and compensation (see recommendation 6) are different across Member States and sometimes even between projects/OWFs, which requires practices among Member States to be aligned. Consultation processes should start before OWFs are located, so that, with the input of fishermen and the help of decision support tools, the impact on fisheries can be kept to a minimum (see recommendation 9). Compensation can be done in a variety of ways, from individual-based compensation to community-based compensation (which fishermen seem to prefer). It is recommended that the effect of different types of compensation is studied in more detail.

The current information available on aquaculture management practices was primarily documented by exploratory or research studies, with no clear development of pilot practices. Based on case studies, it seems that currently the OWF industry is not (yet) keen on developing these types of joint activities. Therefore, co-location of OWFs and aquaculture needs to be stimulated and facilitated by new policies and regulations (see recommendation 7), for instance, through the development of (financial) incentives or specific multi-use requirements in the licences.

Legal

The current rights of Member States to legislate and adhere to this issue are directly from the Law of the Sea Convention (LOSC) and the rights coastal States have in their territorial seas and EEZs. But EU legislation does not specifically address fishing and aquaculture in and around OWFs. Consequently, each Member State is free to adopt its own specific legislation on safety zones around OWFs. Specific to fisheries, there are restrictions on navigation and fishing practices (see recommendation 10) for which no legal framework is available. There is very little information available in relation to the legal aspects associated with aquaculture practices (see recommendation 7 and 10). There is a need to distinguish between: i) leasing the sea bed for current structures; and ii) the type of regulation based on the development of aquaculture legal requirements (see recommendation 10), as these vary across different territorial seas and EEZs.

Socio-economics

The main socio-economic effects associated with OWFs in relation to fisheries is the loss of fishing grounds, about which no quantitative assessment is available. Part of the loss can be compensated by fishery displacement, increased fishing near the OWF edges ('spill-over effect' or MPA effect of OWFs) or changes to fishing gear. The latter is not straightforward, as only a part of the fleet can switch, and the fisheries practices within OWFs encounter several hurdles (gear entanglement, safety implications, insurance risks, reduced flexibility). Therefore, a targeted socio-economic assessment on an EU scale that takes into account the entire value chain (landings, jobs, market, etc.) and loss & benefits balance (see recommendation 11) needs to be conducted. An uncertain factor in this process is predicting fishing behaviour (displacement).

For aquaculture, there is currently no spatial conflict (no spatial overlap between OWF and aquaculture) leading to economic loss. The potential socio-economic benefits are known, but co-use of OWFs and aquaculture is in its infancy. Business cases need to be further developed by bringing relevant parties to a joint forum to discuss and plan common issues of concern (see recommendation 7).

Stakeholders and governance

Stakeholders provided their different perceptions (often polarized) depending on their background and their direct interactions and collaborative opportunities. For example, the fisheries sector indicated that it has almost no influence on OWF area planning (through MRP) or OWF design (corridors, cable issues). For aquaculture, it is important that the OWF design is fit for multi-use, which is currently not the case. The OWF plans must be adapted accordingly or jointly planned. The major gap is the lack of effective implementation early on in the planning process, and more transparent involvement to avoid, for example, the 'pick and choose' that the fishing industry stakeholders mention (see recommendation 12). Therefore, best practices in stakeholder governance including early engagement in discussions and planning will be beneficial for future multi-use and co-location of activities.

Case studies

Two case studies were presented, for Belgium and Denmark, which largely confirm the above-mentioned gaps. The results pointed out that there are still uncertain levels of understanding with regards to localized changes and their ramifications for wider population level and ecosystem level effects. Similarly, these localized changes might not be observed at the same level at other offshore wind farms, as some of these changes will be also be determined by the hydrodynamics and the morphology of specific areas. Further research and guidance documents on the benefits of OWFs for fishery and aquaculture is needed. The Belgian OWF case study illustrates the importance of a two-tiered monitoring approach (combining basic and targeted monitoring) to increase our knowledge base for this.

6.2. Recommendations

The current knowledge (see summary, chapter 5), together with the knowledge needed (see gaps, section 6.1) allowed us to formulate a series of recommendations (Table 4). The recommendations are tabulated, following the 'bridging table' concept: in this table the current and desired situations are presented and a description is given of the needed information to get to the desired situation. They are ordered by the tasks carried out within this contract. In addition, two recommendations on general aspects have been added: "other OWF devices" (recommendation 13) and "decommissioning" (recommendation 14). All recommendations together will help advancing and/or improving the ongoing pivotal practices at a national, North Sea and Baltic sea level.

The **ecological** work suggests that site-specific studies, on single OWFs, provided relevant evidence of localized effects. Most studies focused on specific structural attributes (e.g. presence/absence, abundance of the fauna) during a short time-span. This results in knowledge on effects on a species level. Also, based on current knowledge it is difficult to fully quantify the level of effects and their significance. The level of the effects will vary across areas, as it depends on the conditions of the site (e.g. hydrodynamics, sediment, fauna colonization, etc.). The spill-over effect of OWFs is unclear: conclusions cannot be drawn on what observed ecological changes mean at population level or wider regional scale for the stock of commercial fish and crustaceans. Several activities can improve the ecological knowledge on the impacts of OWF: a decision is needed on which are the relevant ecological receptors (e.g. benthos, fish, mammals, birds) to be monitored. Monitoring in itself needs a two-tiered approach, combining basic (observing) and targeted (explanatory) components. Comparative studies across regions and sub-regions can be used to integrate and complement the current ecological knowledge gained from OWFs. Integration of data within and across regions is needed to **quantify the 'spill-over' effect**: e.g. the effect on population level. Monitoring studies on the regional scale over longer periods of time can improve the knowledge on trends in the region. Such comparative and monitoring studies will help us to continue documenting changes and providing data to answer new questions. In order to draw conclusions on **whether OWFs** are **creating benefits for ecosystems** to be used for fisheries and aquaculture, more ecosystem-based oriented research is required (recommendation 3). The extent to which OFW development leads to changes in biodiversity, species composition, spill-over effects and habitat characteristics in the short-, medium- and long-term have to be explored on a wider scale (i.e. marine resource management scale) (recommendation 1, 2 and 4).

In relation to **managing the fishery and aquaculture sector activities** in and around OWFs within a region, the **consultation process** with the stakeholders should start in an early stage and should be maintained on a continuous basis (e.g. Scottish Fishing Liaison with Offshore Wind and Wet Renewables group). Engaging stakeholders and discussing ongoing issues and lessons learned on national level will be beneficial for future multi-use and co-location of activities. The **compilation of guidance and 'best practice' documents** (with emphasis on co-location opportunities, co-existence of activities, potential conflicting issues and wider cooperation) will help to improve multi-use implementations. They could include a description of the benefits of good management practices on the business model, livelihoods and social well-being of fishery and aquaculture sector (see recommendation 5, 8 and 9). Besides, adequate compensation initiatives need to be outlined in the document when the activities will be limited/and or restricted (e.g. fisheries). For this, an analysis of the **short- and medium-term losses in monetary units for the fishing sector** due to OWF development is required, while considering the resilience of the sector in the short- and medium-term by taking into account their potential to relocate effort or change occupation (see recommendation 6).

The **legal settings** will need to consider opportunities and restrictions for multi-use OWFs by other activities (e.g. aquaculture and fisheries). Legal frameworks should be clear across sectors: this can be achieved by creating a coordinated legal planning (in support of Marine Spatial Plans-MSP) through collective discussions between operators, regulators and stakeholders (see recommendation 7). The **management and legal framework** for offshore aquaculture activities **need clarification**. This can be achieved by analysis of possible incentives for multi-use and of how to better imbed multi-use in legislations (e.g. license process) (see recommendation 7). In addition, it would help to create an overview of national legislations on the operability (possibilities and restrictions) of fishing and aquaculture in and around OWF. The overview should contain information on the **required modifications to these legislations** for fishery and aquaculture stakeholders to be able to start an activity within OWFs (see recommendation 10).

In relation to the **socio-economic** aspects, there is a need to conduct a balanced assessment of restrictions and/or opportunities across sectors (e.g. aquaculture development, fisheries) in relation to OWFs development. **Accurate plans** to support multiple users (e.g. with incentives and/or compensations measures) of a given area should be provided (see recommendation 11). This would result in a better view on **possible compensation needs** for fisheries and wins for offshore aquaculture.

The **stakeholder** interviews revealed that the OWF sector wants to work effectively with other sectors, to support planning, data sharing, future exploration of multi-use of platforms and co-location of activities if this is agreed and planned accurately. Nevertheless, the fishery sector is skeptical and see it currently more as a threat. Only, **early engagement** in discussions and planning, on a **continuous basis** and by taking **into account the fishery and aquaculture concerns** from **the start of the OWF design** can create beneficial conditions for future multi-use and co-location of fishery and offshore aquaculture activities with OWFs (see recommendation 12).

The compilation of this report has also demonstrated **the strong progress in knowledge** that OWFs companies, regulators, conservationists, fishery, aquaculture sector and scientists have undergone in this matter. However, it is also clear that in some instances some projects are done in isolation: a **further integration** of lessons learned in Europe would help to facility for instance the knowledge transfer in relation to facing new challenges, as implementation of new technologies (e.g. floating devices; see recommendation 13) or dealing with decommissioning (see recommendation 14). This opportunity to take stock across OWFs developments, over multiple disciplines (i.e. ecological, management, socio-economics, legal and across stakeholder) has helped to document the currently knowledge and support our informed decisions to set and guide priorities for further research.

Table 4. Knowledge bridge gap analysis based on the evidence synthesized from the workshop and the desired knowledge base. Following the process in Figure 5, each task is represented in the rows along with a summary of the current knowledge; a link to the appropriate report section or scientific literature; the information needed in order to reach the desired knowledge. The final column summarizes the overall recommendations. ** behind a recommendation number indicates that it is similar or related to recommendations in the Stelzenmüller et al. (2020) study.*

Task		Current knowledge base	Link to report section	Information needed	Desired knowledge (recommendation)
Ecology	1	The current ecological understanding arises from **site-specific** areas of offshore windfarms sites.	Section 3.1.5; 5.1.2 and Dannheim *et al.*, 2020	Some evidence is based on monitoring, research and advice. There is a need to test if responses observed are **common and consistent across OWF developments** (site-specific vs wider responses).	**Comparable** and documented ecological knowledge which assesses individual, localized and **wider effects** and **responses**. This information is important to assess the level of impact of similar structures or site-specific effects.
	2*	Our ability to fully quantify the current level of **positive and/or negative effects remains difficult** (significance level). As there is a difference between an effect or response and an actual significant impact. Scientists, advisors and regulators still have knowledge gaps and a different perspective in understanding those effects. .	Table 1 & section 3.1.7	There is a need to contextualize observed effects and define the parameters (statistically) of positive and negative effects and how they relate to impacts at levels such as population, community and/or ecosystem.	A targeted, integrated analysis aimed at defining **what the level of effects (significance) are** across sites, responses and scales (e.g. meta-analysis) is needed. Proper communication among stakeholders is key to ensuring a **similar level of understanding of the effects**.
	3	Some of the current ecological effects are for **individual receptors** (e.g. benthos, fish, birds, mammals, etc.) and based on EIA studies operating over a short-term period.	Section 3.1.3; 5.1.2 and 5.2.2	Ecosystem-level work (samples covering benthos to birds) over the long term. A **two-tiered monitoring approac**h (combining basic and targeted monitoring) is the way forward to increase our knowledge base for this.	**Ecosystem-level research** to place into context if OWFS are **benefiting** ecosystems for **fisheries** and **aquaculture**.
	4	It is unclear what the observed ecological changes (‘**spill-over' effect**) mean at population level or wider regional scale for the stock of commercial fish and crustaceans.	Section 3.1.5	To undertake dedicated sampling and comparative studies and/or modelling case studies to provide data on the ‘spill-over' effect.	Determination of **ecological pathways** and collection of **appropriate data**, and include commercial fish and crustacean population data of OWF areas within the **stock assessment**

Task		Current knowledge base	Link to report section	Information needed	Desired knowledge (recommendation)
					frameworks. A point of attention for the CFP.
Management	5*	There are **no tailored management approaches** for fishery and aquaculture management in the OWF development process.	Section 3.2	A management guidance document and joint events across multi-sectors should facilitate the development of multi-use implementations.	When can we speak of coexistence, co-location or cooperation between the different sectors? **What are good practices** in management of aquaculture and fisheries affected by OWF development?
	6*	A standard procedure **to compensate** the fishery sector for **socio-economic loss** is lacking.	Section 3.2.3; Alexander *et al.*, 2013	A systematic EU-wide approach for fishery compensations needs to be explored (Who?, When?, What?, Which type?). This to ensure that fishery is treated in the same manner throughout the EU.	Some guidance and best practice **on compensation strategies** for the fishery sector should be developed.
	7	Different studies and stakeholder views indicated that developing **aquaculture** activities within **OWFs** is **difficult in practice**.	Section 3.2.4	Co-location of OWFs and aquaculture can be stimulated and facilitated by new policies and regulations, for instance, through the development of (financial) incentives or specific multi-use requirements in the licences.	The **management and legal framework** for aquaculture activities in OWFs need to be **further clarified** and developed.
	8	**Consultation is key** when developing management strategies or mitigating the effects. The practices are **variable** among **Member States and OWF areas**.	Section 3.2.3; 3.5.2 and 4.1.4; De Groot *et al.*,2014	A better consultation process needs to include involving the fishing sector before determining the OWF sites, avoiding 'tokenism', involving local representatives, arranging face-to-face meetings, allowing enough time and monetary compensation for a representative participation.	A **more uniform application** of **best practices in stakeholder governance**, and early engagement in discussions and planning will be beneficial for future multi-use and co-location of activities.
	9*	Discussion and planning of how **Maritime Spatial Plans** can support	Section 3.2.3	An overview of current activities across Member States (e.g.	A document with the current details on co-location in MSP would

Task		Current knowledge base	Link to report section	Information needed	Desired knowledge (recommendation)
		the development of co-location of activities needs to be included in country specific activities and management.		sectoral approaches) could be mapped with the assistance of decision support tools to assess the current 'state of play' and future benefits of jointly planning MSPs across North and Baltic Sea Regions.	help as a **'best practice' document** to inform industries and Member States of current practices, to help counter bias and 'polarization' of current approaches.
Legal	10	**Several types** of **restrictions** in relation to navigation and operability of other activities are present across offshore wind farms. During construction, navigation is in general forbidden, but once the OWF is in operation variable rules exist.	Section 3.3.2 and table 2	Building a tool on navigation possibilities and restrictions within EU offshore OWFs. What about different safety zones (50 m, 200 m or 500 m). What is an optimal distance between the pylons to execute certain activities? And this in relation to type/size of vessels (trawl, static, recreational)?	There is a need **to study** the **possibilities** and **restrictions on operability** (including opportunities and risks) of other activities (e.g. fishery and aquaculture) in and around OWFs in Europe within the legal frameworks.
Socio-economics	11*	Quantitative studies to assess the **monetary value of the loss of fishing** and aquaculture grounds due to the presence of OWFs are **missing**.	Sections 3.4.2; 5.1.5 and 5.2.4	An EU-wide, targeted economic assessment along the entire value chain (landings, jobs, market, etc.) needs to be conducted across OWFs on fisheries and aquaculture, also considering the benefits (e.g. recom. 4).	An **estimation** of the **possible socio-economic loss** due to OWFs for the EU fishery fleet and aquaculture sector is needed to have a better view on possible **compensation and mitigation needs**.
Stakeholders and governance	12	**Stakeholders** have **different views**, which are often **polarized**. Fishery sector indicates that it has almost no influence on OWF area planning (through MRP) or OWF design (corridors, cable issues).	Section 4	The consultation guidelines need to be more effectively implemented and in a more transparent way to avoid the 'pick and choose' that the fishing industry stakeholders mention.	The existing **'stakeholder guidelines on 'best practice'** should be **more effectively implemented** and in a more **transparent way**.

Task		Current knowledge base	Link to report section	Information needed	Desired knowledge (recommendation)
General aspects	13	The current study reviewed the effects of bottom-fixed structures in OWFs. The **new OWF devices** (e.g. floating) will probably change the view on multi-use and operability of fishery and aquaculture within those areas.		A review to evaluate if the same effects, restrictions, multi-use possibilities are in place when other wind farm concepts are installed?	It is recommended **to take the lessons learned** from **current OWF planning** and developments in relation to fishery and aquaculture and consider the **synergies** and/or differences between **floating** and **fixed OWF** from the early planning stages onwards.
	14	**Decommissioning** processes of OWFs shall start soon, but **no strategy** is defined yet.	Birchenough and Degraer 2020	The gaps in terms of ecology, engineering and socio-economic aspects of removing a structure need to be defined and studied, these can be supported by the improved knowledge specified in the rows above.	**Information** on **ecological** changes (e.g. some ecological benefits shall change), **engineering possibilities** (e.g. not increasing the OWF foot print in an area) and **socio-economic** aspects (e.g. OWF area back as fishing ground?) of **removing a structure** need to be **collected**.

7. REFERENCES

All the scientific references (A1 scientific literature, reports), where this study is based on, are grouped in an excel document. The structure of the excel is as follows:

- Longlist task 1.1: Containing an overview of the ecological literature survey used as input for the ecology chapter.
- Shortlist task 1.1: Overview of the in detail reviewed literature for the ecology chapter, accompanied with the meta-analyses info.
- Longlist task 1.2: Containing an overview of the management literature survey used as input for the management chapter.
- Shortlist task 1.3: Overview of the in detail reviewed literature for the management chapter, accompanied with the meta-analyses info.
- Longlist task 1.4: Containing an overview of the socio-economic literature survey used as input for the socio-economic chapter.
- Shortlist task 1.4: Overview of the in detail reviewed literature for the socio-economic chapter, accompanied with the meta-analyses info.
- Literature case studies: References of the used literature in the case study chapter.

8. ANNEXES

8.1. Overview of information sources of case studies

Table 5. Overview on a selection of available sources for Belgian OWF case study linked to the five dimensions of Task 1.

Task 1 Aspects	Sources
Ecology	• There is an extensive program on the study of the effects of the installation of wind turbines on the marine ecosystems in Belgium. Results are published yearly on different ecosystem components i.e. birds, bats, harbour porpoises, fish, epibenthos and macrobenthos. • Within this case study summary, the focus will be on the results of the ecological aspects related to fisheries and aquaculture obtained in this program and in related targeted PhD studies. Some of the literature sources that will be included are: Reubens 2013, Rumes *et al.* 2013, Vandendriessche *et al.* 2015, Derweduwen *et al.* 2016 a, Derweduwen *et al.* 2016b, Debusschere 2016, De Backer *et al.* 2017a, De Backer *et al.* 2017b, Kerckhof *et al.* 2018, De Backer *et al.* 2018; De Backer *et al.* 2020 (new chapter in Winmon.BE report in press); Mavraki *et al.* 2020; Mavraki 2020 (PhD thesis); Coates *et al.* 2016
Management	• Since March 2020, a new marine spatial plan has come into force: Marine Spatial Plan 2020–2026 • EIAs and other related management documentation for the different OWFs in Belgium: https://odnature.naturalsciences.be/mumm/en/windfarms/list?type=1&sorts[projectLastUpdate]=0 • Rumes & Brabant 2019, most recent update on OWF developments in Belgium
Legal	• Overview and links to legal sources for building and operating a wind farm in Belgium: https://odnature.naturalsciences.be/mumm/en/windfarms/#legislation
Socio-economics	• Studies on fisheries activities in the vicinity of OWFs: Vandendriessche et al . 2013, Vandendriessche *et al.* 2016, De Backer *et al.* 2019 • Online interactive geographic information platform visualizing fishing activity and other spatial use: http://geofish.be/ • Projects combining aquaculture and OWFs: Edulis project – mussel aquaculture in windfarms; H2020 United project – Belgian pilot on oyster aquaculture in a wind farm; Wier en wind project (Interreg Vlaanderen Nederland) – project aim is to develop a large-scale seaweed farm with automated cultivation system that can be deployed within the wind turbine park, pilot study in Belgian OWF Norther, MARCOS- Blue Cluster project looking in the possibilities of offshore aquaculture in the Belgian North Sea
Stakeholders and governance	Annex 9.2, list of the stakeholders for Belgium

Table 6. Source of reports and links partly used by the EIA of the Danish Kriegers Flaks OWF project

Subject	Source
Ecology	• Sea-bottom biotopes - HELCOM Underwater biotope and classification system (HELCOM, 2013). HELCOM, 2013. HELCOM HUB – Technical report on the HELCOM Underwater Biotope and habitat classification. Baltic Sea Environment Proceedings No. 139. - MariLim, 2015. Kriegers Flak Offshore Wind Farm and Grid Connection: Baseline and EIA report on benthic flora, fauna and habitats. June 2015 • Fish - BioApp & Krog Consult, 2015. Fisk og Fiskeri: Forundersøgelse og udarbejdelse af VVM-redegørelse for Kriegers Flak Havmøllepark. Juni 2015. (BioApp & Krog Consult, 2015) • Marine sea birds - Skov *et al.* 2011. Waterbird Populations and Pressures in the Baltic Sea. TemaNord 2011: 550. 229 pp. Nordic Council of Ministers. • Marine mammals - the SAMBAH project https://www.sambah.org/, mapping the presence of marine mammals in the Baltic using a dense network of GPS detection facilities, especially *Phocoena phocoena* and *Phocea vitulina* - DCE, DHI, NIRAS, 2015. Underwater noise and marine mammals. Energinet.dk. (DCE, DHI, NIRAS, 2015)
Management	- EU Habitat & Birds Directives. Large areas are designated Natura 2000 areas protecting birds, marine mammals or habitats. - CFP EU Regulation 2013/1380 - MSFD EU Regulation 2017/848 - Danish national MSP plan - EIA Directive 2011/92/EU (Environmental Impact Assessment Directive)
Legal	The Danish Energy Agency (https://ens.dk) is responsible for approving EIA for any OWF project. The conditions for offshore wind farms are defined in the Danish Promotion of Renewable Energy Act. Three licences are required (Licence to carry out preliminary investigations; Licence to establish the offshore wind turbines; Licence to exploit wind power for a certain number of years, and an approval for electricity production)
Socioeconomics	• Fisheries - VMS-logbooks-sales slips coupling held by DTU-Aqua www.aqua.dtu.dk - BioApp & Krog Consult (2015) • Shipping, cable, pipe etc. • Coexistence of uses - Christensen, E. D. *et al.* Go offshore – Combining food and energy production, DTU Mechanical Engineering - PanBalticScope project http://www.panbalticscope.eu/ - EU-FP7 MERMAID project http://www.vliz.be/projects/mermaidproject/
Stakeholders and governance	• Annex 9.2 lists the stakeholders for Denmark and those that are involved in Public society - public hearing, e.g. https://energinet.dk/kriegers-flak#Anlag

8.2. Overview of the stakeholder involvement

Table 7. List of respondents contacted for Tasks 1.5 and 2.

Type of stakeholder	Name of stakeholder	Website	Contact persons
EU agency	European Fisheries Control Agency	https://www.efca.europa.eu/	Pascal Savouret, executive director
Advisory Council	North Sea Advisory Council	http://nsrac.org/	Tamara Talevska, Executive Secretary
Advisory Council	Baltic Sea Advisory Council	http://www.bsac.dk/	Sally Clink (Executive Secretary)
MS administrations NS	Ministries and control agencies North Sea	BEL: FOD Environment / BEL: BMM (KBIN) NLD: Ministry of Agriculture, Nature and Food Safety DEN: The Danish Ministry of Climate, Energy and Building DEN: Danish Energy Agency DEN: Danish Ministry of Environment & Food https://en.mfvm.dk/ UK: The Crown Estate UK: Marine Management Organisation	Steven van den Borre Brigitte Lauwaert Nathalie Scheidegger Kim Rægaard Maria Louise Flachs Olivia Thomas

			Richard Green
MS administrations Baltic	Ministries and control agencies Baltic	DEN: The Danish Ministry of Climate, Energy and Building	Kim Rægaard
National and international Federations and Producer Organizations	e.g. NFFO, VisNed, ANOP, EAPO	BEL: Redercentrale NLD: VisNed, Netviswerk DEN: Danish Fishermen Producer Organisation DFPO UK: National Federation of Fishermen's Organisations (NFFO) Inshore Fisheries Conservation Agencies (IFCAs)	Sander Meyns Pim Visser Mikael Andersen Dale Rodmell Stephen Bolt
National and International NGO’s	Marine environmental related NGO’s	BEL: Natuurpunt NLD: Stichting de Noordzee DEN: Not yet defined UK: Kingfisher Division of Seafish Maritime and Coastguard Agency	Krien Hansen Floris van Hest Matthew Frow Steve Nesbitt
Research Institutes (others from project partners)	e.g. IFREMER, RKTL,	DE: Thünen Institute Fr: IFREMER	Antje Gimpel Vanessa Stelzenmueller Nicolas Desroy or Jean-Claude Dauvin or Aurore Raoux

		UK: Offshore Renewables Joint Industry Programme (ORJIP)	ORJIP@carbontrust.com
Wind farm industry	e.g. Wind Europe, Belgian Offshore Platform, Offshore Renewable Joint Industry Programme (ORJIP)	BEL: Belgian Offshore platform NLD: NWEA NLD: Eneco (involved in project Vis-Wind) DEN: Energinet.dk DEN: Vattenfall DEN: NIRAS consulting UK: RenewableUK UK: European Subsea Cables Association DONG UK: Vattenfall UK: E-ON EU: Wind Europe	Annemie Vermeylen Hans Timmers Gerard Harder Betina Haugaard Heron, Robert Norris Steve Dawe Christina Sobfeldt Jahn Chris Jackson Mrs Eleri Wilce
Aquaculture industry	Sector representative	BEL: Brevisco NLD: PO Mosselcultuur, NLD: Stichting Noordzeeboerderij	Willy Versluys Wouter van Zandbrink

		DEN: Not yet defined UK: Scottish acquaculture EU: EABA: European Algae Biomass Association	 info@eaba-association.org

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