STUDY

Requested by the PECH committee

European Parliament

Impact of the use of offshore wind and other marine renewables on European fisheries

Fisheries

Policy Department for Structural and Cohesion Policies
Directorate-General for Internal Policies
PE 652.212 - November 2020

EN

RESEARCH FOR PECH COMMITTEE

Impact of the use of offshore wind and other marine renewables on European fisheries

Abstract

The study provides an overview of general impacts of the development of offshore wind farms and other marine renewables on the European fishing sector. It further highlights pathways for possible co-existence solutions of both sectors, a description of best practice examples and lessons learnt, the identification of research gaps and last but not least the presentation of policy recommendations.

This document was requested by the European Parliament's Committee on Fisheries.

AUTHORS

Thünen Institute of Sea Fisheries:
Vanessa STELZENMÜLLER, Antje GIMPEL, Jonas LETSCHERT, Casper KRAAN, Ralf DÖRING

Research administrator: Marcus BREUER
Project and publication assistance: Mariana VÁCLAVOVÁ
Policy Department for Structural and Cohesion Policies, European Parliament

LINGUISTIC VERSIONS

Original: EN

ABOUT THE PUBLISHER

To contact the Policy Department or to subscribe to updates on our work for the PECH Committee please write to: poldep-cohesion@europarl.europa.eu

Manuscript completed in October 2020; revised 2nd edition published in November 2020

This document is available on the internet in summary with option to download the full text at: https://bit.ly/33OC3nl

This document is available on the internet at:
https://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL_STU(2020)652212

Further information on research for PECH by the Policy Department is available at:
https://research4committees.blog/pech/
Follow us on Twitter: @PolicyPECH

Please use the following reference to cite this study:
Stelzenmüller, V. *et al.*, 2020, Research for PECH Committee – Impact of the use of offshore wind and other marine renewables on European fisheries. European Parliament, Policy Department for Structural and Cohesion Policies, Brussels
Please use the following reference for in-text citations:
Stelzenmüller *et al.* (2020)

DISCLAIMER

CONTENTS

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
CFP	Common Fisheries Policy
DCF	Data Collection Framework
EEZ	Exclusive Economic Zone
GFW	Global Fishing Watch
GW	Capacities of offshore renewables in gigawatts
HELCOM	Helsinki Commission for the protection of the Baltic Sea
ICES	International Council for the Exploration of the Sea
JRC	Joint Research Centre
KW	Capacity of a fishing vessel, i.e. the installed power expressed in kilowatts in the case of vessels using towed gear; and kilowatts and tonnage in the case of vessels using fixed gears
MSFD	Marine Strategy Framework Directive
MPA	Marine Protected Area
MSP	Marine (or maritime) Spatial Planning
MW	Capacities of offshore renewables in megawatts
OR	Offshore Renewables
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
OWF	Offshore Wind Farms
SEA	Strategic Environmental Assessment, i.e. a systematic process for evaluating the environmental implications of a proposed policy, plan or programme. Provides means for looking at cumulative effects and appropriately addresses them at the earliest stage of decision making alongside economic and social considerations
STECF	Scientific, Technical and Economic Committee for Fisheries
VMS	Vessel Monitoring System

TECHNICAL TERMS

Active fisheries	Any form of fishing gear that is towed or moved through the water, e.g. beam or otter trawls, purse seines, dredges, etc.
Benthic fisheries	Fishing targeting species living primarily on the seabed or are burrowed in the upper sediment layer, e.g. scallop dredging
Beam trawl	Active fishing gear type. Target species: Crustaceans, demersal fish, molluscs[1]
Danish seine	Active fishing gear type. Target species: Demersal fish, mainly European plaice (*Pleuronectes platessa*) and Atlantic cod (*Gadus morhua*)[2]
Demersal fisheries	Fishing occurring on or near the seabed, e.g. beam trawling and seines
Dredge	Active fishing gear type. Target species: Scallops and mussels[3]
Metier	Group of fishing operations targeting a specific assemblage of species, using a specific gear, during a precise period of the year and/or within the specific area
Midwater otter trawl	Active fishing gear type. Target species: Small pelagic fish[4]
Otter trawl	Active fishing gear type. Target species: Crustaceans, mainly Norway lobster (*Nephrops norvegicus*), demersal fish, and small pelagic fish, mainly European sprat (*Sprattus sprattus*) or sandeel (*Ammodytes*)[5]
Pair trawl	Active fishing gear type. Target species: Demersal fish[6]
Passive fisheries	Any form of fishing gear that operates without being towed or moved through the water (static), e.g. longlines, gillnets, pots, traps, etc.
Pelagic fisheries	Fishing occurring from midwater to the surface of the sea, e.g. herring trawlers
Pelagic pair trawl	Active fishing gear type. Target species: Small pelagic fish[7]

1 http://www.fao.org/fishery/geartype/305/en
2 http://www.fao.org/fishery/fishtech/1003/en
3 http://www.fao.org/fishery/geartype/104/en
4 http://www.fao.org/fishery/geartype/400/en
5 http://www.fao.org/fishery/geartype/306/en
6 http://www.fao.org/fishery/geartype/208/en
7 http://www.fao.org/fishery/geartype/310/en

Scottish seine	Active fishing gear type. Target species: Demersal fish, mainly Atlantic cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*), and flatfish species[8]
Set gillnet	Passive fishing gear type. Target species: Demersal fish[9]
Target assemblage	The assemblage of target species

8 http://www.fao.org/fishery/fishtech/1008/en
9 http://www.fao.org/fishery/geartype/219/en

LIST OF FIGURES

LIST OF MAPS

LIST OF TABLES

EXECUTIVE SUMMARY

KEY FINDINGS

- The **exploitation of offshore renewable (OR) resources varies greatly** in size and capacity across the different European sea basins, whereby the spatial expansion until 2025 will be greatest in the **North Sea** and **Baltic Sea**.
- An overlap analysis of OR and fisheries suggests a **sharp increase of spatial conflict potential** in the North Sea, Baltic Sea, and Mediterranean over the next five years.
- The current and future cumulative OR development 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** of the OR effects on fisheries need to address the direct and indirect **costs of lost fishing opportunities**.
- European-wide **standardised monitoring programmes** would provide currently unavailable ecological and socio-economic data, which are needed to assess the general cumulative **ecological and socio-economic effects** of OR expansions.
- A **review of case studies** suggested that **early stakeholder consultation**, the involvement of **independent third parties**, the creation of **transparent guidelines**, and **compensation payments** could **alleviate the conflict potential** between fisheries and OR.
- **An integrative framework** is proposed to **clarify** and **mitigate** the **effects of OR on fisheries**, and to facilitate **best practice guidance for marine spatial planning** and the co-operation among marine users.

Background

This study aims to **provide an overview of the general impacts** of the **development** of **offshore renewables** (OR) **on fisheries** in European sea basins. Furthermore, it highlights **pathways for possible co-existence solutions** for both sectors, a description of **good practice examples** and lessons learnt, **research gaps**, and **policy recommendations**.

The research focusses on an **in-depth spatial overlap analysis** between the present-day **fishing effort by fleet and the current and future spatial expansion of OR** in European seas based on Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data. Further, we **defined the concepts of co-existence, co-location and co-operation,** and subsequently synthesised the lessons learnt from representative cases from the UK, Denmark, Belgium, Germany, and the Netherlands. A standardised literature review allowed us to **summarise the current knowledge on the impacts of OR on fisheries** and to **identify respective knowledge gaps**.

This study has been prepared during the period June to August 2020 by the Thünen Institute of Sea Fisheries, Germany, on the basis of desk research consisting of a compilation and analysis of existing data, and a literature review.

Impact of offshore renewables on European fisheries

The **proliferation of OR**, such as offshore wind farms (OWF), is a key pillar in the global transition to a **carbon-free power sector**. The expansion of OR varies greatly across the European seas, whereby Northern European countries such as the UK, Germany, Denmark, Belgium, the Netherlands, and Sweden currently have the highest numbers of installed OWF. This **spatial expansion** is accompanied by an **increasing conflict potential** with other marine sectors, such as fisheries. In Europe, **marine spatial planning** (MSP) **allocates multiple human activities** at sea, such as OR development or shipping, but often falls short in contributing to the adaptive capacity of fisheries.

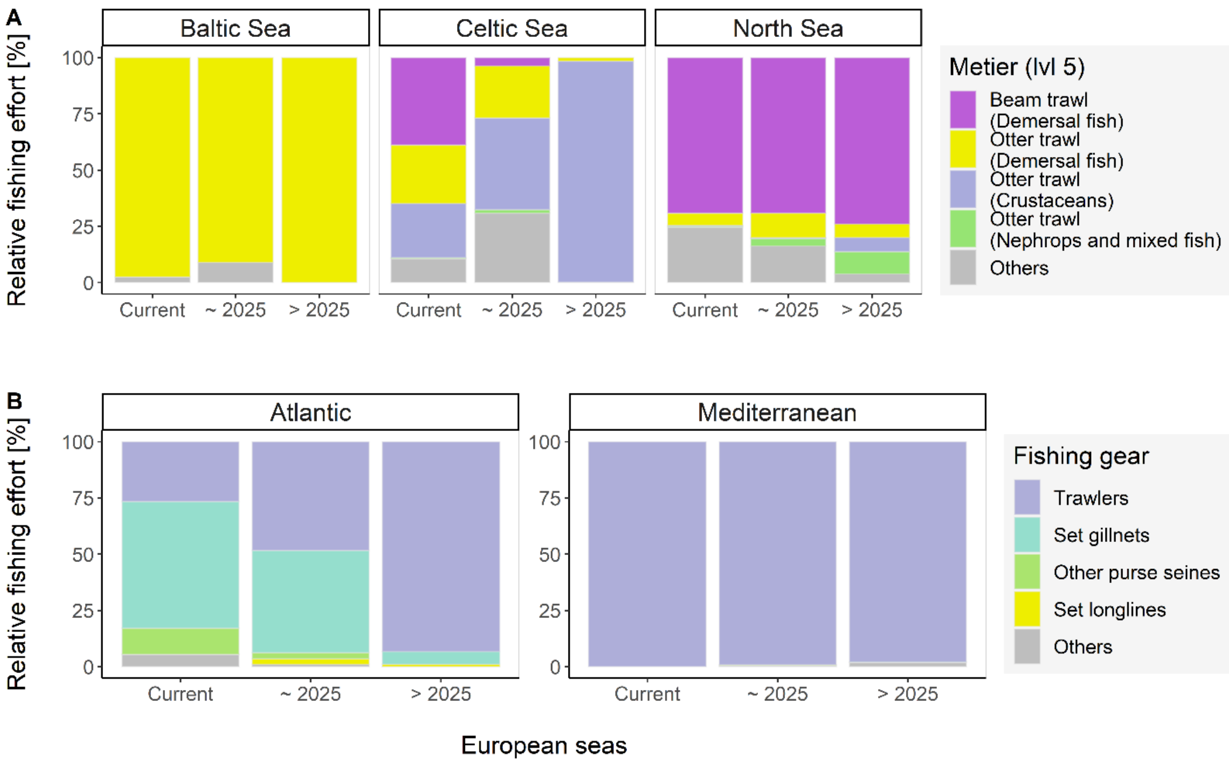
A spatio-temporal overlap analysis of OR development and fishing activities of European fleets suggests a **sharp increase of spatial conflict potential** in the North Sea, Baltic Sea, and Mediterranean on a mid-term perspective (until 2025). For instance, in the North Sea, the spatial overlap in terms of absolute hours fished could more than double by 2025 (**Figure 4**). In contrast, the conflict potential due to OR expansions in the Atlantic and Celtic Sea regions will remain low at mid-term, but is expected to **increase substantially** at the long-term (after 2025). In the Baltic, Celtic, and North Sea, OR expansion will affect mostly fishing fleets that deploy trawl gears and target crustaceans (**Figures 1** and **4**). Furthermore, the results show a **great variation of fishing effort per fleet** and OR **across years**, hence highlighting the need for **local and regional assessments** based on standardised data.

Restricting fishing activities in a larger area will likely lead to the **reallocation of fishing activities** including associated industries and logistics. **Economic impact assessments** for the effects of OR on fisheries need to address **direct and indirect costs** of the loss of fishing opportunities as well as the **effects on the local communities and economic activities onshore**, but these are hampered by the **lack of available and harmonised socio-economic data**. While spatial data on fishing activities become increasingly available, a **European-wide standardised research** and **monitoring strategy** with respect to OR expansion and its socio-ecological effects is missing.

Good practice in co-existence solutions

The concept of **co-existence** refers to two or more activities (e.g. fishing activities and OR) **existing at the same time and/or in the same place**, while **co-location** describes the fact that at least two activities are **actively managed together** while sharing space at sea. **Co-operation** reflects an interaction between two or more activities, each **benefitting from that relationship**, and leading to a growth for both. The implementation of co-location or co-existence solutions depends on site-specific characteristics and prevailing **integrated management approaches, such as MSP**. From existing case studies in the UK, Denmark, Belgium, the Netherlands, and Germany a few measures emerged that may support the **mitigation of spatial use conflicts**. Those comprised 1) early **stakeholder consultation** to detect conflict potential at an early stage and acknowledge the importance of all actors; 2) facilitation of negotiation processes by **independent third parties** and the **creation of guidelines for the expansion of OR**; 3) **compensation payments** for the disturbance and the associated loss of income or additional expenditures: all three aiming at contributing to **a reduction of the impact**. Co-design approaches for the co-location of OR with other uses can reduce the impact potential on fisheries, strengthen the relationship of the sectors of concern, and even enable beneficial co-operation between them.

Figure 1: Relative proportions of total fishing effort of the main fishing fleets overlapping with the areas of the current, mid-term (~ 2025), and long-term (> 2025) scenarios of offshore renewable installations across European sea basins



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by (A) OSPAR (the Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (Helsinki Commission for the protection of the Baltic Sea), and the German Federal Office for Agriculture and Food (BLE) and (B) Global Fishing Watch (GFW) for fisheries; the metier levels (lvl) are provided by European Commission 2008a

Note: The metier level represents a group of fishing operations targeting a specific assemblage of species, using a specific gear, during a precise period of the year and/or within the specific area

Key knowledge gaps to inform integrated management

Existing knowledge on the impact of OR on fisheries is focused mainly on **ecological and environmental impacts**. Current case studies often neglected the assessment of future expansions of OR sectors. We identified a **clear gap of economic and socio-cultural impact assessments** for the impact of OR expansion on fisheries. Overall, **more research is needed** to assess potential impacts of the development of OR, especially OWF, on the fishing sector, local communities and economic activities onshore.

Recommendations

Based on our analyses we recommend:

- To **promote standardised monitoring programmes** and the **harmonisation of fishing data, needed** to perform cumulative ecological and socio-economic environmental impact assessment of the expansion of marine energy;
- To **enable more research to understand the effects of offshore renewable** (OR) **installations** on the fishing sector, local communities and onshore economic activities to

provide guidance for marine spatial planning (MSP) to plan with fisheries and support their adaptive capacities;

- To **develop best practice guidance for MSP on the implementation of mitigation measures** to lower the conflict potential between fisheries and OR development and to promote co-operation between marine uses.

1. CONTEXTUALISING THE CONFLICT POTENTIAL BETWEEN THE FISHING SECTOR AND THE EMERGING MARINE ENERGY SECTOR IN EUROPEAN SEA BASINS

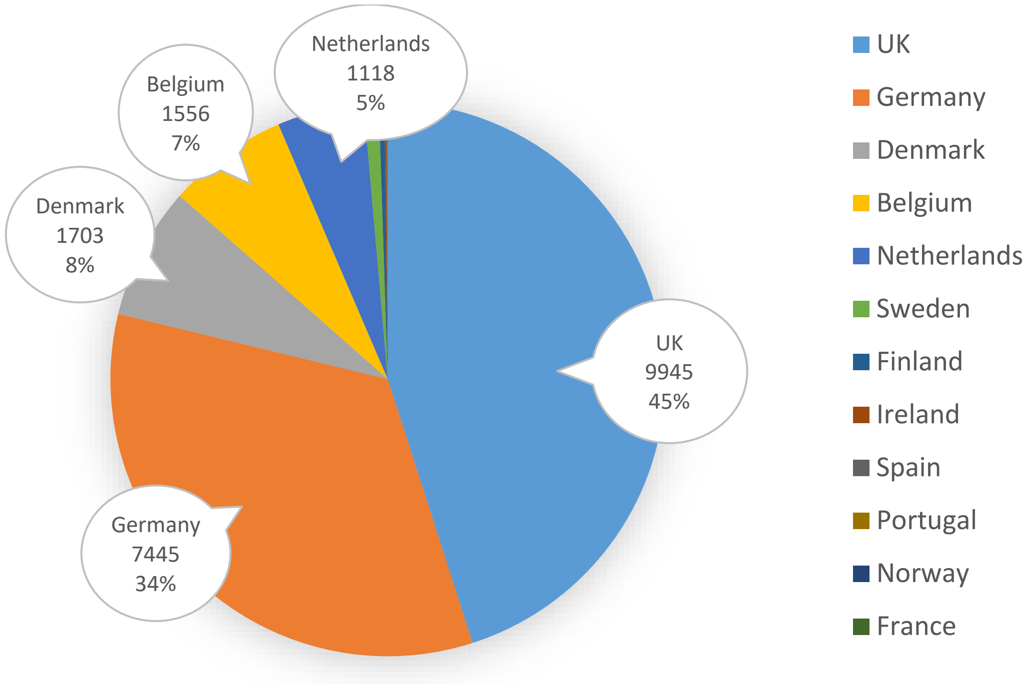
KEY FINDINGS

- The **development of offshore renewables (OR) varies greatly** in size and capacity across the different European sea basins (Baltic Sea, North Sea, Atlantic, Mediterranean Sea and Black Sea).
- In particular, the **spatial expansion** of offshore wind farms (**OWF**) in the **North Sea** and **Baltic Sea** will speed up the race for space in the already heavily used offshore and coastal waters.
- **Marine spatial planning** (MSP) should create opportunities and synergies of human activities across various temporal and spatial scales. Therefore, concepts such as **co-locating human activities** are progressively explored.
- **Evaluating** co-location options or spatial use conflicts requires **transparent frameworks** and **spatio-temporal analysis** of overlapping human activities such as fisheries and OWF.
- The quantification of general **effects for fishing fleets** is hampered by the **lack of** available and harmonised socio-economic **data**.
- **Potential fisheries benefits** as a consequence of OR installations are **not well understood** and empirical evidence is pending.

The advancement of **offshore renewables** (OR), such as **offshore wind farms** (OWF) or wave and tidal energy devices, is a response to increasing energy demands and a key pillar in the global transition to a carbon-free power sector (GWEC 2019). In 2018, the worldwide installed capacity of offshore wind summed up to 23.1 GW with a European contribution of roughly 79%. This corresponds to **5,047 grid-connected wind turbines** across 12 countries[10] with a current average **distance to shore** of **59 kilometres** and an average **water depth** of **33 metres**. In Europe, the development of OR varies greatly among the different European sea basins (Baltic Sea, North Sea, Atlantic, Mediterranean Sea and Black Sea). **Northern European countries** such as UK, Germany, Denmark, Belgium, the Netherlands, and Sweden currently have the **highest numbers** of installed **OWF** and **turbines** (**Figure 2**). **Europe** is still world leading in **tidal energy** installations (27.7 MW), with new installations in France, the UK, and an overall **50% increase** of energy production in 2019. In contrast, the European **wave energy** production cumulated to **11.8 MW** in 2019 when new wave devices were installed in Belgium, France, Italy, Portugal and the UK[11].

10 www.windeurope.org
11 www.oceanenergy-europe.eu

Figure 2: Cumulative capacity (total numbers) and relative proportion of installed offshore wind power [%] in European countries in 2019



Source: Author based on data derived from WindEurope[12]
Note: Numbers refer to the proportion per country

Further, a reduction of **greenhouse gas emissions by at least 55% by 2030** (compared to 1990)[13], a target adopted under the global Paris Agreement in 2015 and its wider 2030 climate energy framework, is to be implemented via **national climate action plans** (European Commission 2015, 2018, Europêche 2020). A large share of this (at least 32%) will be achieved by the EU Member States through OR (European Commission 2018, Europêche 2020, Gimpel 2015, Leonhard *et al.* 2013, Lindeboom *et al.* 2015, Methratta and Secor 2020, Pezy *et al.* 2018, Raoux *et al.* 2017). As a result, the OR implementation will **speed up the race for space** in the **already heavily used offshore and coastal waters** (Halpern *et al.* 2019). In most cases, newly licensed **OWF reduce** the **access to traditional fishing grounds** by restricting available space for fishery due to **safety requirements** imposed by OWF development (Gimpel 2015).

Over the last decade **marine spatial planning** (MSP) has become the most widely used integrated, **place-based management approach** in the marine environment (Frazão Santos *et al.* 2020). MSP aims to **mitigate spatial use conflicts** at sea, create legal foundations for maritime investments, and implement an ecosystem-based approach to marine governance (Ehler *et al.* 2019). Europe was at the forefront of putting MSP into practice (Ehler and Douvere 2009), and in the early 2000s the first spatial plans were implemented in the southern North Sea (Belgium and Germany) triggered by Blue growth initiatives (European Commission 2012). **MSP processes should create opportunities and synergies** of human activities across various temporal and spatial scales, therefore concepts such as **co-locating human activities** in a given marine space are progressively explored (Jentoft and Knol 2014, Kyvelou and Ierapetritis 2019). The terms "co-location", "co-use" or "multi-use" are often used synonymously,

[12] www.windeurope.org
[13] https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en

but require a careful consideration of the spatial, temporal, provisional, and functional dimensions of the connectivity of uses (Schupp *et al.* 2019). As to date, **most debated** co-locations are the ones of **OWF and aquaculture systems** (Buck and Langan 2017), and OWF and fisheries (Stelzenmüller *et al.* 2016). The identification of areas with conflict potential or the assessment of transparent and integrated spatial management options, is increasingly addressed through the use of spatially explicit decision support tools and frameworks (Gimpel *et al.* 2018, Gusatu *et al.* 2020, Pınarbaşı *et al.* 2017, Stelzenmüller *et al.* 2013).

Since numerous **European MSP processes** have been or are currently revised, the socio-ecological effects of the plans are progressively debated. In Europe, an assessment of the **socio-economic effects of a plan** relate mostly to **spatial use conflicts** between the renewable sector and other sectors, such as shipping or fisheries. Often a spatial overlap or intersection analysis is conducted to identify areas with the highest conflict potential (Coccoli *et al.* 2018, Gimpel *et al.* 2013). Other studies **assessed conflicts,** e.g. with the help of a stakeholder consultation process (Noble *et al.* 2019). However, the first requirement to conclude on the actual **economic impacts of future OR on fisheries** is to link the location to spatially resolved data on catches of a given target species and market prices. This enables an estimation of **spatially resolved revenues for the respective fishing fleet** (Pascual *et al.* 2013, Stelzenmüller *et al.* 2011). Nevertheless, an economic impact analysis also requires the consideration of the costs and resource availability at new fishing grounds. Bio-economic fisheries models are common tools to link total costs of the fishing activities with population dynamics of the respective resources (Nielsen *et al.* 2018).

Thus, **categorizing data on fishing effort by fleets**, which are differentiated by **fishing gear and target species or assemblage** is a key requirement. Fishing fleets comprise passive and active gears, as well as pelagic, demersal, and benthic fishing gears. For instance, dredging for scallops (various bivalve species) are examples of active benthic fisheries, whereas pot fisheries, for brown crab (*Cancer pagurus*), European lobster (*Homarus gammarus*), or whelk (*Buccinidae*), are examples of passive benthic fisheries. Demersal fisheries encompass beam trawls, bottom otter trawls and seine fisheries (actively) targeting groundfish, flatfish, and crustaceans such as Norway lobster (*Nephrops norvegicus*) or common shrimp (*Crangon crangon*). Gillnets and longlines are examples of passive demersal fisheries targeting groundfish and flatfish. Active pelagic trawl and sein fisheries target for instance sandeel (*Ammodytes*), herring (*Clupea harengus*), horse mackerel (*Trachurus trachurus*) and mackerel (*Scomber scombrus*) (Jennings and Kaiser 1998).

There is also an increasing debate about the **potential ecological benefits of OR**. Artificial hard substrates of OR, as well as sediment and topographical diversity in their vicinity provide ideal conditions for certain benthic and fish species, suggesting that OR sites can provide **high-quality spawning, nursery and feeding grounds**. Various hard structures have been shown to attract different life stages of fish for foraging, shelter and reproduction (Bergström *et al.* 2013, Cote *et al.* 2003, Gregory and Anderson 1997, Hooper *et al.* 2017, Lindeboom *et al.* 2015, Lindholm and Auster 2003, Lough *et al.* 1989, Reubens *et al.* 2013, Stenberg *et al.* 2015, Wieland *et al.* 2009). As fishing activity might be able to temporally interrupt (Morgan *et al.* 1997) or even disrupt (Dean *et al.* 2012) spawning aggregations, the creation of a de-facto marine protected area (MPA) by the construction and operation of OR might have beneficial impact on the reproductive output of fish spawning in this area (Armstrong *et al.* 2013, Leonhard *et al.* 2013). OR infrastructure might thereby lead to an **increased opportunity for fisheries benefits** due to the introduction of new hard substrate. Fisheries may benefit from the **spill-over of biomass, greater size of fish individuals, and the availability of new fishing resources** (Roberts *et al.* 2001, Russ and Alcala 1996).

In the following Chapters we will analyse and describe the current and future conflict potential between the main fishing fleets and the implementation of OR for each European sea basin by the means of their spatial overlap (**Chapter 2** and **3**). We describe the relative impacts of this overlap for the main fishing fleets (**Chapter 4**), highlight lessons learnt from co-existence and co-location examples (**Chapter 5**), identify research gaps (**Chapter 6**), and derive policy recommendations (**Chapter 7**).

2. DESCRIBING SPATIO-TEMPORAL AQUACULTURE AND FISHING ACTIVITIES IN EUROPEAN SEAS

KEY FINDINGS

- **Fisheries data** from Automatic Identification System (AIS) and Vessel Monitoring System (VMS) **varied in spatial and temporal resolution** across the European seas.
- Global Fishing Watch (GFW) **data** used for spatial overlap analysis in **Atlantic and Mediterranean lack information on target assemblages**.
- Standardised VMS data used for spatial overlap analyses in the **Baltic Sea, Celtic Sea** and **North Sea** comprise **only bottom contacting gears**.

In this Chapter we provide an **overview of the aquaculture and fisheries data** used **(Annex 1**) and how they were processed to **estimate and quantify fishing effort within OR installation sites** (**Annex 2**). In general, data products describing aquaculture activities refer to commercial activities related to finfish or shellfish products. Data products related to various fisheries activities are based on geographic ship position information, i.e. Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data.

2.1. Past and present commercial fishing activities

There are no aggregated and standardised data on fishing effort covering all European sea basins. Consequently, we integrated four fishing effort data sources with varying spatial and temporal resolutions, to analyse spatial pattern of **fishing activities** (**Table 1**).

Fishing effort data for the **OSPAR** (the *Convention for the Protection of the Marine Environment of the North-East Atlantic*) and **HELCOM** (*Helsinki Commission for the protection of the Baltic Sea*) regions are publicly available[14]. They include annual fishing efforts and catches by metier (fishing gear and target assemblage) of all bottom-contacting gears, excluding those that are used to catch pelagic species, i.e. herring and mackerel. The geographic scope of the OSPAR data encompasses the North, and Celtic Sea, while HELCOM data cover the Baltic Sea. ***Global Fishing Watch*** (GFW) data have a world-wide coverage and are publicly available until 2016[15], whereas data for the years up to 2018 are available on request. They include fishing effort data by gear group and do not contain information about the target assemblages or catch volumes. **Fishing effort data for the OSPAR and HELCOM regions are based on VMS data** of Member States that are regularly collected by the *International Council for the Exploration of the Sea* (ICES). In contrast, **GFW fishing effort data are based on AIS data**.

As a fine scale example, we extracted raw VMS pings provided by the German Federal Office for Agriculture and Food (BLE). These are broadcasted by German vessels and can be linked to logbook data, which provided information on the fishing metier, catch volumes, and species caught. We calculated the temporal distances between each VMS ping affiliated to a fishing activity to represent fishing effort. **Annex 2** contains more details on data processing, as well as qualitative and quantitative differences between the four fisheries data sources.

14 https://doi.org/10.17895/ices.data.4686 and https://doi.org/10.17895/ices.data.4684
15 https://globalfishingwatch.org/

Table 1: Spatial and temporal coverage of data on fisheries activities used to analyse the conflict and impact potential of marine energy development

Data source	Type of data	Grouping variables	Temporal scale	Spatial scale	Resolution
Global Fishing Watch (GFW)	Fishing effort [h]	Fishing gear	2012-18	Global	Daily; 0.01° × 0.01°
OSPAR	Fishing effort of mobile bottom contacting gears [h]	Fishing metier level 5 (DCF)	2009-17	OSPAR region	Yearly; 0.05° × 0.05°
HELCOM	Fishing effort of mobile bottom contacting gears [h]	Fishing metier level 5 (DCF)	2009-16	HELCOM region	Yearly; 0.05° × 0.05°
Vessel monitoring system (VMS)	Fishing effort of German vessels [h]	Fishing metier level 5 (DCF)	2012- 19	German exclusive economic zone (EEZ) of the North Sea and Baltic Sea	Pings; 2 hrs frequency

Source: Author based on European Commission 2008a

Note: Details are given in Chapter 4. DCF = Data collection framework, HELCOM = Helsinki Commission for the protection of the Baltic Sea, OSPAR = Convention for the Protection of the Marine Environment of the North-East Atlantic

To **accommodate quantitative and qualitative differences** between the used fisheries data sources (Hinz *et al.* 2013), we decided to use **the best available data** to cover a certain geographical area. For example, GFW data could not directly be linked to data on landings or main target species. Zooming in on the wider North Sea, Celtic Sea and Baltic Sea regions, we used standardised VMS data (OSPAR and HELCOM regions). That allowed us to identify fishing hours per unit area and main metier. Within the German exclusive economic zone (EEZ), we zoom in further and make use of the high-resolution VMS data. Depending on the data source, we were able to either **group fishing effort into gear types** (GFW), **or metiers** using additional vessel and target species information (OSPAR, HELCOM, and VMS) (**Table 2**).

We identified **intersecting grid cells** (GFW, OSPAR & HELCOM) and **VMS signals**, so-called pings (VMS German EEZ), of fishing data with polygons of OR. In a next step we aggregated the annual fishing effort per OR installation. In order to allow for a spatial overlap analysis of fisheries with current and future **OR** installations, we used the average annual fishing effort.

Table 2: Overview of the metiers distinguished in the subsequent analysis of the OSPAR/HELCOM and VMS data

Gear type	Target assemblage/species	Metier (level 5)
Beam trawl	Crustaceans, mainly common shrimp (*Crangon crangon*)	TBB_CRU
Beam trawl	Demersal fish	TBB_DEF
Beam trawl	Molluscs	TBB_MOL
Danish seine	Demersal fish, mainly European plaice (*Pleuronectes platessa*) and Atlantic cod (*Gadus morhua*)	SDN_DEF
Dredge	Scallops and mussels	DRB_MOL
Midwater otter trawl	Small pelagic fish	OTM_SPF
Otter trawl	Crustaceans, mainly Norway lobster (*Nephrops norvegicus*) and common shrimp (*Crangon crangon*)	OTB_CRU
Otter trawl	Demersal fish	OTB_DEF
Otter trawl	Crustaceans, mainly Norway lobster (*Nephrops norvegicus*) and demersal fish	OTB_MIX_CRU_DEF
Otter trawl	Small pelagic fish, mainly European sprat (*Sprattus sprattus*) or sandeel (*Ammodytes*)	OTB_SPF
Pair trawl	Demersal fish	PTB_DEF
Pelagic pair trawl	Small pelagic fish	PTM_SPF
Scottish seine	Demersal fisheries, mainly Atlantic cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*) and flatfish species	SSC_DEF
Set gillnet	Demersal fish	GNS_DEF

Source: Author based on data provided by European Commission 2008a

Note: Metiers are limited to the metier level 5, comprising of the gear type and target assemblage (European Commission 2008a). Further information are given in Chapter 4. HELCOM = Helsinki Commission for the protection of the Baltic Sea, OSPAR = Convention for the Protection of the Marine Environment of the North-East Atlantic, VMS = Vessel monitoring system

2.2. Past and present commercial aquaculture activities

Information on shellfish and finfish aquaculture facilities are available at *EMODnet Human Activities portal*[16] as centroids of aquaculture facilities (point data). Nevertheless, they allowed for a coarse spatial overlap analysis of current and future **OR** installations.

16 http://emodnet-humanactivities.eu

3. CURRENT AND FUTURE SPATIAL EXPANSION OF THE MARINE ENERGY SECTOR IN EUROPEAN SEAS

KEY FINDINGS

- **Current spatial expansion** of marine energy sectors is the greatest in the **North Sea** and **Baltic Sea** with the UK having the **largest major surface area** allocated to offshore renewable (**OR**) development, followed by Germany, Denmark, and the Netherlands.
- In the **mid-term scenario** (~ 2025) **most OR installations** comprise offshore wind farms (**OWF**) with the **North Sea** remaining as the centre of the development.
- Installations of **OWF** will advance in the **mid-term** scenario in the **Atlantic** (Spain and Portugal), and in the **Mediterranean** (France, Italy and Greece).
- **Norway**, followed by the **Netherlands, France**, and **Germany**, has allocated **the largest area for OR installations in the long-term** view (> 2025).

This Chapter gives a condensed overview of the 'current' and 'mid-term' and 'long-term' distribution of 314 OR installations (**Figure 2, Map 1**, **Annex 3**) within the European seas (**Figure 4** and **Annex 5**).

Data on **wave** and **tidal energy plants** are available at the EMODnet Human Activities portal including information about their starting and, if applicable, ending year. Here we used all active and decommissioned farms. Reliable **data on current and future OWF** were not publicly available, therefore we purchased a global data licence on offshore wind energy development, updated monthly, from *4C Offshore Ltd*.[17] including detailed information about the capacity and starting dates. We restricted the *4C Offshore* data to OWF with available information about the **starting date** (i.e. the date at which an OR is actively being developed on site) and used **all active, decommissioned and planned farms** (the latter were used for future scenario analyses). Both data sources provided spatial polygons of OR sites and combined they allowed for a precise spatial overlap analysis of current and future OR with aquaculture and fishing effort data. We distinguished **three time periods**:

(i) 'current',

(ii) 'mid-term' (~ 2025), and

(iii) 'long-term' (> 2025).

Current OR were defined as those with a starting date (i.e. start of construction) matching the temporal coverage of the respective fisheries data. In order to define the future OR, we distinguished in between those with a starting date before the end of 2025 (i.e. mid-term scenario) and those with a starting date after 2025 (i.e. long-term scenario). Since the temporal coverage differed among the fishing effort data sets (**Table 1**), the definition of current OR varies depending on the fishing effort used.

Moreover, we separated **four types of OR**:

(a) offshore wind,

(b) tidal,

17 https://www.4coffshore.com/

(c) wave, and

(d) combined wind and wave installations.

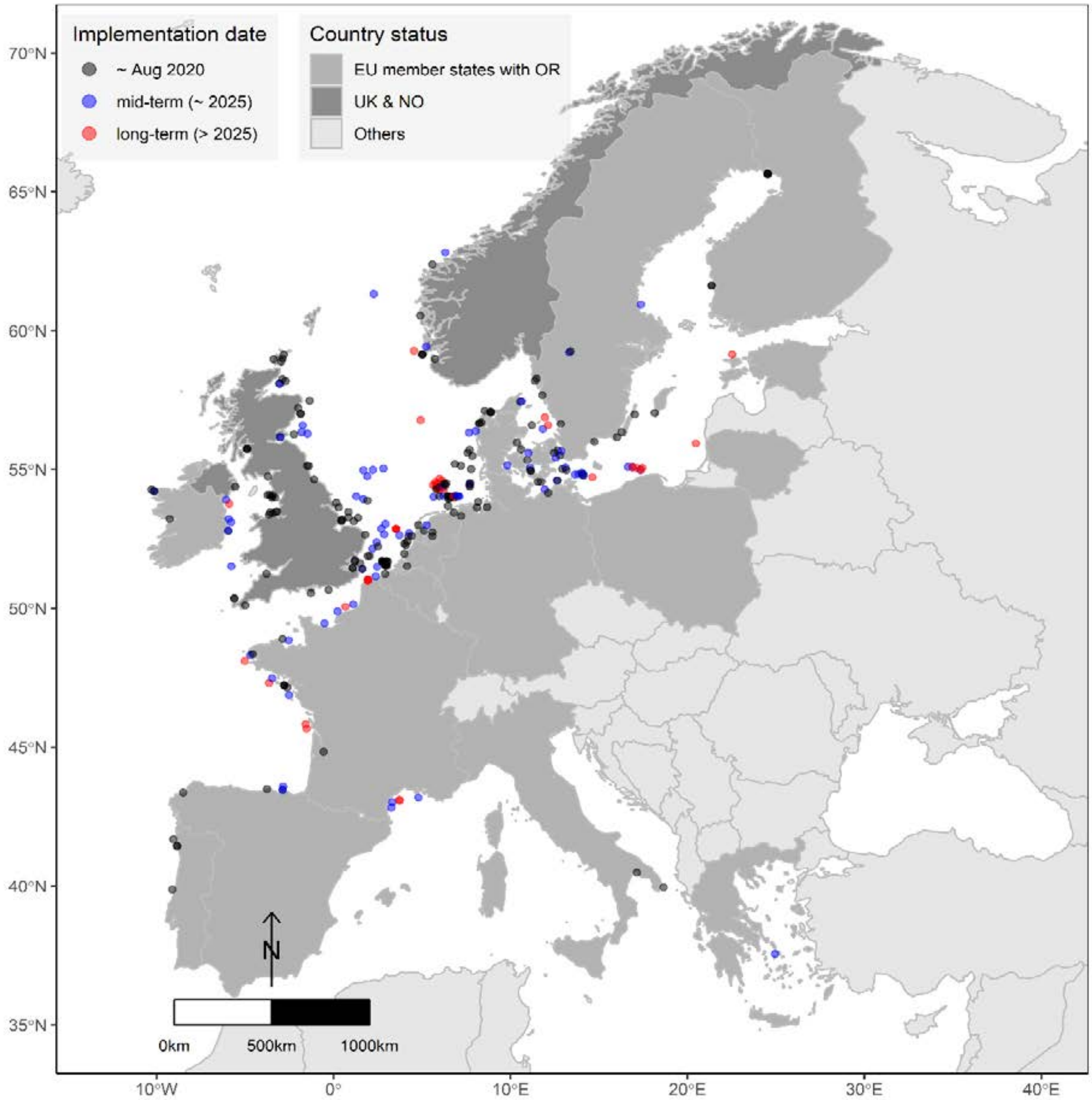
For each period and OR type combination we described in **Chapter 4** the overlap between OR and the respective fishing activities based on **three data-sources**:

(1) **GFW** for the Mediterranean, Black Sea and central-eastern Atlantic,

(2) **VMS** covering the German EEZ, and

(3) **OSPAR-HELCOM** for the Baltic and North Sea areas (**Chapter 2**, **Annexes 1, 2** and **3** for methodological details).

Map 1: Spatial location of all 314 offshore renewable installations within European seas showing a spatial expansion of the marine energy sectors (status August 2020)

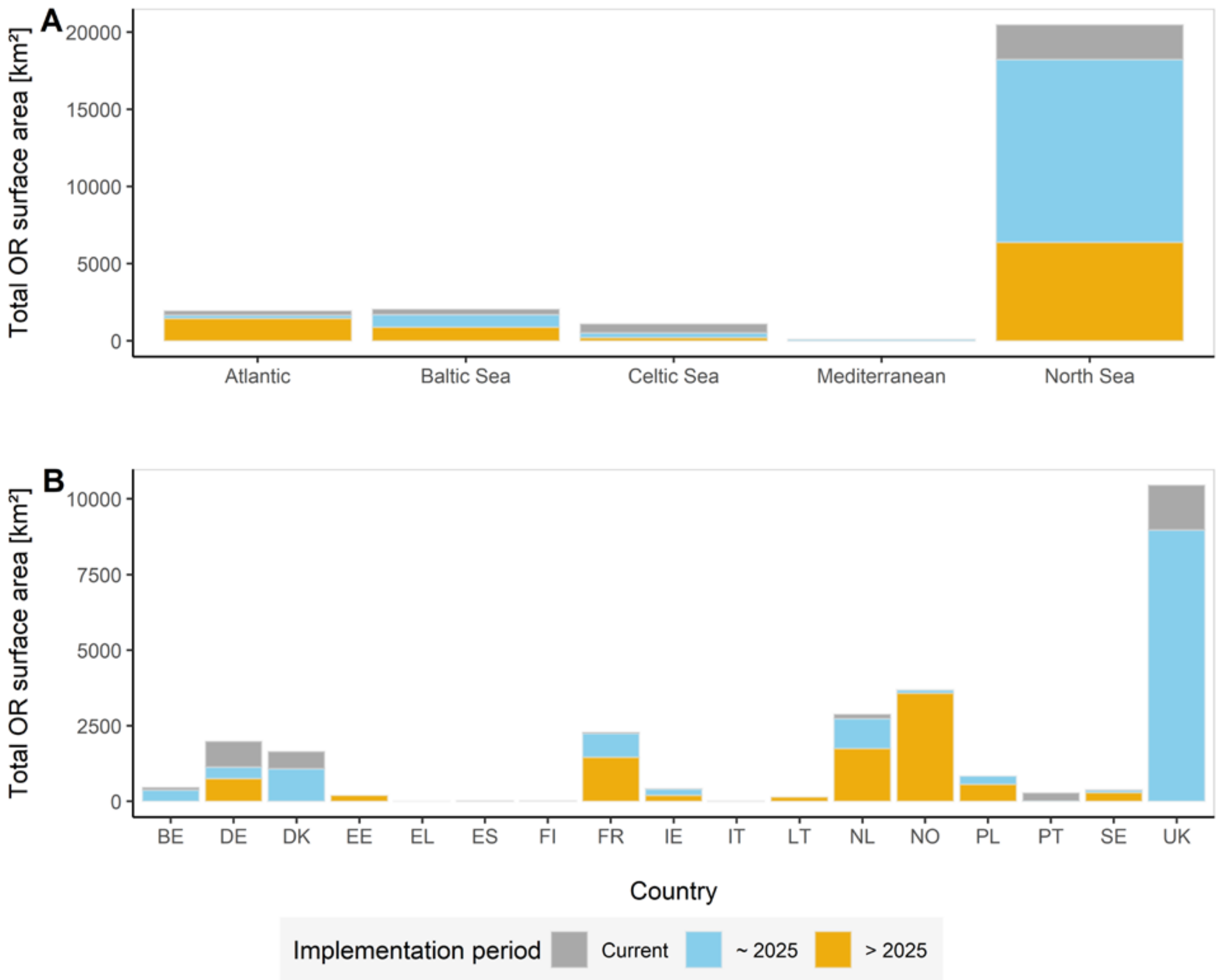


Source: Author based on data provided by 4C Offshore Ltd. and EMODnet

Note: Geographic positions of the offshore renewables that are or will be implemented (or constructed) before August 2020 (black), until the end of 2025 (blue), and after 2025 (red)

Current OR installations show the **greatest spatial expansion** in the **North Sea and Baltic Sea**, with the **UK** having allocated the largest surface area of **1,483 km²** to marine energy sectors followed by Germany and Denmark. In general, OR installations cover coastal and offshore waters. In the **Black Sea** there are **no records of OR**, whereas in the **Mediterranean Sea** there is a **single OWF** in Italy (**Figure 3**). The **existing OWF** in the **Baltic Sea** are clustered near Finland and between Sweden, Denmark, and Germany. Other types of OR do not yet occur here. In the North Sea there are a **few tidal and wave installations**, mainly in Belgium, the Netherlands, Denmark, Sweden, Norway, and Scotland. OWF are the most important and common OR in this region. In the **Atlantic Ocean** most installations comprise **wave energy** (Spain, France, UK), whereas **tidal installations occur in France and UK**. Note that we made no distinction between coastal (overlap with fisheries that have AIS or VMS tracking less likely) and offshore (potential for overlap with fisheries as shown) OR installations. **Mixed wave/wind installations** are exclusively located in **Portugal and Spain**.

Figure 3: Total surface area (km²) of current, mid-term (~ 2025), and long-term (> 2025) offshore renewable installations across (A) European seas and (B) countries



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet

Note: This does not account for surface regained as fishing areas due to decommissioning of OR installations. The OR surface area for each development scenarios were added to present the total surface by region and country and potential decommission processes were neglected

In the **mid-term** the main OR installations comprise **OWF in the North Sea and Baltic Sea**, whereby UK defined by far the largest area for the OR development (8,972 km^2). Furthermore, the **installation of OWF** will advance in the **Atlantic Ocean** (Spain and Portugal), and in the **Mediterranean** (France, Italy and Greece).

All **planned OR** after **2025** are **OWF installations**. The centre of these developments remains in the **North Sea**, with fewer new installations along the **French Atlantic coast, Baltic Sea and the English Channel**. However, the largest spatial expansion of the sector is planned for **Norway, the Netherlands, France and Germany**.

4. CURRENT AND FUTURE IMPACT OF THE EXPANSION OF MARINE ENERGY DEVELOPMENT ON EUROPEAN FISHERIES

KEY FINDINGS

- The added value of **high resolution VMS data** was exemplified by a **case study** covering the **German** exclusive economic zones (EEZ) of the **Baltic Sea** and **North Sea**.
- Based on the available data, there was **no overlap** between commercial **aquaculture and current or future OR installations**. Further, **no offshore renewable** (OR) installations are planned in the **Black Sea**, therefore it was excluded.
- A relative comparison of the degree of spatial overlap of fisheries and offshore renewables (OR) suggests a **sharp increase of conflict potential** in the **North Sea, Baltic Sea and Mediterranean** over the **next five years**.
- The **Atlantic and Celtic Sea** regions will likely face a **significant increase of conflict potential** due to the expansion of OR installations **after 2025**.
- Overall, the **greatest spatial overlap between fisheries and OR occurs in the North Sea** region, followed by the Celtic Sea, where mainly fleets deploying bottom contacting gears targeting demersal fish, Norway lobster and common shrimp are affected.
- Across the **Baltic Sea, Celtic Sea and North Sea** the fleet most affected by the cumulative spatial OR development is the **otter board fleet** targeting **mixed demersal fish.**
- Absolute **fishing effort** at individual planning sites **varied greatly** between years as well as the composition of fleets affected highlighting the **need for small scale assessments** based on data with **high spatial and temporal resolutions**.

Below we illustrate in detail the **spatial overlap** between the **OR sectors and aquaculture and fisheries** and conclude on the subsequent **conflict potential and impact**. We found no overlap between aquaculture and current or future OR installations which might be a direct consequence of the data being available as spatial points rather than as polygons.

As described in **Chapter 2** we analysed temporal trends in fishing effort within or in the close vicinity of current OR installations, installations on a mid-term view and on a long-term view. It is important to note that a **direct comparison of the absolute fishing effort estimates across regions is very uncertain** since these are based on **different types of data** (VMS or GFW) and therefore entail numerous restrictions regarding spatial and temporal coverage, and type of gear included (**Chapter 2** and **Annex 4** for further details). Thus, in other words the accuracy of overlap of fishing effort estimates in a given OR installation area varies greatly and does not allow for a direct comparison of absolute values across the European seas considered. Results for Atlantic or Mediterranean regions (assessed with the help of the GFW data) can be found in **Annex 5**.

4.1. Spatial overlap between marine energy sectors and European fisheries

For the Atlantic, North Sea, Baltic Sea and Mediterranean we quantified the **spatial overlap** for the **three different scenarios** of OR development (current, mid-term and long-term). This was based on the total fishing effort (h) across all years of available fishing effort data (**Table 1**) occurring in or in the close vicinity of the respective OR. A qualitative comparison showed that the **Atlantic and Celtic Sea** regions will likely face a **significant increase of conflict** potential for the long-term scenario of OR installations **after 2025 (Figure 4**). This reflects the regions pace and strategy of spatial expansion of OR installations. In contrast, for the **North Sea, Baltic Sea and Mediterranean** the degree of **spatial overlap will at least double** over the **mid-term period** compared to the current overlap. While the overlap in terms of absolute hours fished in the Mediterranean is very minor, the mid-term scenario revealed still a drastic increase in absolute hours fished, which might reflect a significant loss for fishing fleets operating in these areas. Despite the limitations of a direct comparison across all regions, it is obvious that the **North Sea** region showed the **highest degree of fishing effort in areas of OR development**, followed by the Atlantic and Celtic Sea, Baltic Sea, and finally the Mediterranean. Specifically in the North Sea where OR development progresses the most, local fishing effort displacements might have further knock-on effects on the modus operandi of the individual fishing fleets, which cannot be captured by the here presented analysis. Thus, this would require considering factors such as competition and subsequent local depletions of fishing resources.

In the **Atlantic region** (Bay of Biscay and Portuguese coast), **trawlers** and **set gillnets** were the most affected gear group in terms of total effort for current future OR scenarios (**Figure 4**). According to the annual economic *Scientific, Technical and Economic Committee for Fisheries* (STECF) report of 2018 (STECF 2018), the most important species in those areas include Norway lobster and monkfish (*Lophius* spp.) targeted by international fishing fleets. It is also worth mentioning that the Spanish and French fleets based in this region show a high dependency on UK waters, although the impacts of the Brexit are not clear, which might be fuelling further potential spatial use conflicts.

In the **Mediterranean**, the areas with most OR were the Gulf of Lions, the Ionian Sea (Gulf of Tarento) and the Aegean Sea. For all three areas the GFW data revealed a clear spatial overlap with **trawl fisheries**. Primarily French and Spanish trawlers operate in the Gulf of Lions targeting a diversity of demersal species. Thus, up to a radius of three miles from the coast reflecting the borders of the upper zone of the continental shelf, target species comprise red mullets (*Mullus barbatus*, *Mullus surmuletus*), common sole (*Solea solea*), gurnards (*Trigla sp.*), poor cod (*Trisopterus minutus capelanus*), Black Sea whiting (*Merlangius merlangus*), and some shrimps (UNEP 2013). **Four different trawling fleets** operating in the Gulf of Tarento have been described: otter trawl targeting demersal species, otter trawl targeting deep-water species, and otter trawl targeting mixed demersal and deep-water species (Russo *et al.* 2017). Furthermore, authors listed hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), deep water rose shrimp (*Parapenaeus longirostris*), blue and red shrimp (*Aristeus antennatus*) as the most important target species in this area. Likewise, in the Aegean Sea the most important species targeted by bottom trawling are red mullet and hake (Katağan *et al.* 2015).

For the **Baltic Sea**, we identified five fleets to be generally affected by OR installations, whereby the **otter trawl fleet** targeting Atlantic cod (*Gadus morhua*) and European plaice (*Pleuronectes platessa*) showed by far the **highest level of overlap** for all three scenarios (**Figures 4** and **5**). The other fleets are otter trawls targeting small pelagic fish such as sprat (*Sprattus sprattus*) or sandeel (*Ammodytes*) (OTB_SPF), or Danish seines targeting demersal fish such as plaice and cod (SDN_DEF). In the German EEZ of the Baltic Sea (**Figure 5**; bottom), other fleets such as (pelagic) pair trawls and set gillnets emerged from the overlap analysis, since the VMS data analysis comprised all gears.

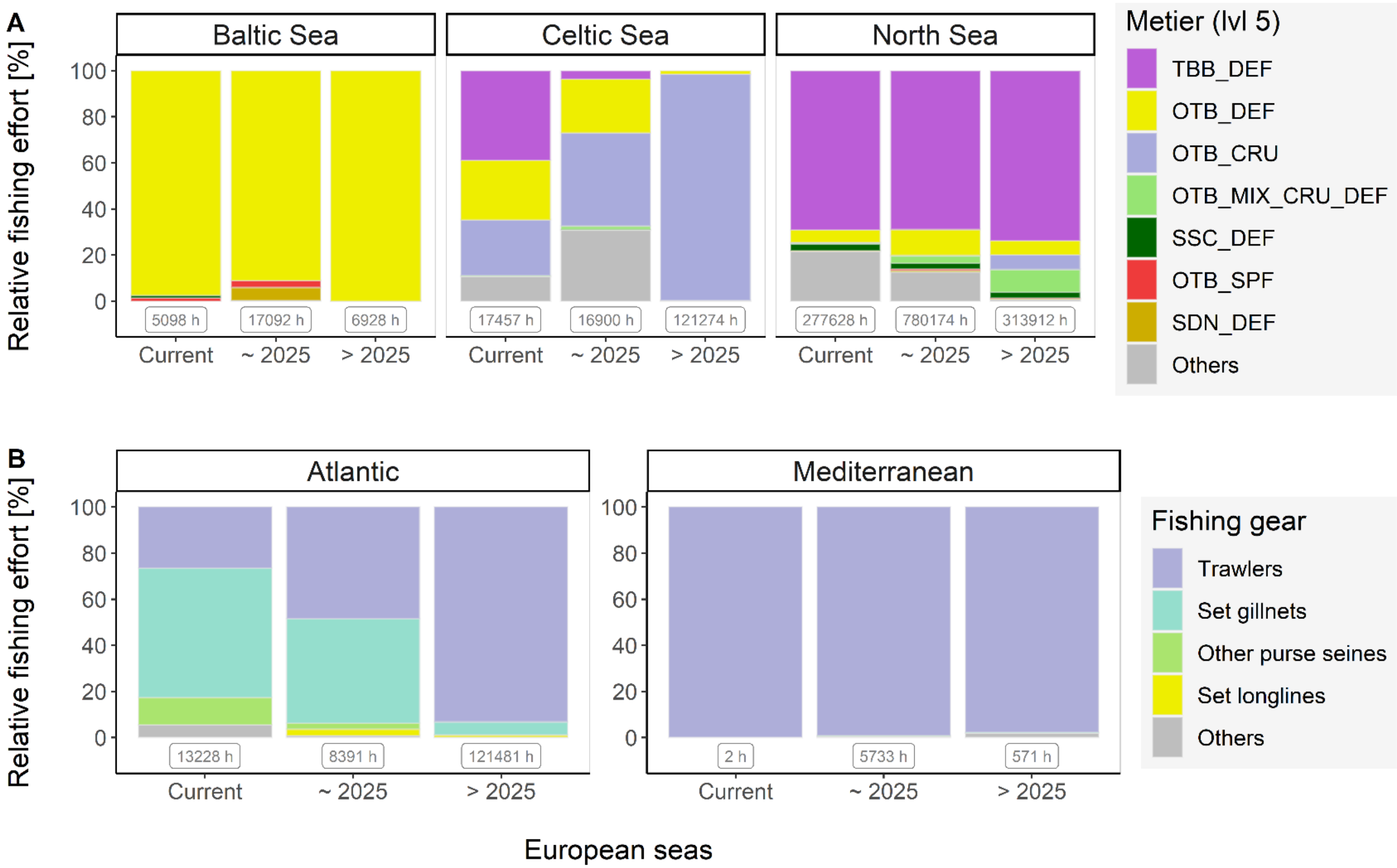
In the **Celtic Sea** demersal fisheries have in general a mixed catch comprising various gadoid species such as haddock (*Melanogrammus aeglefinus*) or whiting[18][19]. Our analysis showed that the **otter trawls**

18 http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2003/oct/o-3-9.pdf
19 https://stecf.jrc.ec.europa.eu/dd/effort/graphs-quarter

targeting mainly Norway lobster will be affected the most by the future spatial expansion of marine energy (**Figure 5**).

For the **North Sea** we found the largest overlap with **beam trawlers targeting common sole and European plaice** (TBB_DEF), otter trawlers targeting cod and plaice (OTB_DEF), and beam trawlers targeting common shrimp (*Crangon crangon*; OTB_CRU) (**Figures 4** and **5**). The conflict potential will increase almost equally for all affected fleets. The cumulative OR scenarios showed also a relatively high degree of overlap with otter trawlers targeting mainly Norway lobster and shrimp (**Figure 5**). There is a potential for critical overlap in the long-term view for the Scottish seine fisheries targeting cod, haddock and flatfish (SSC_DEF). The high-resolution VMS analysis in the German EEZ of the North Sea revealed some overlap with fleets deploying dredges to target molluscs, set gillnets to target demersal fish and otter midwater trawls targeting small pelagic fish (**Figure 5**, bottom).

Figure 4: Relative proportion of the total fishing effort [%] of the main fishing fleets overlapping with the areas of the current, mid-term (~ 2025), and long-term (> 2025) scenarios of offshore renewable installations across European sea basins

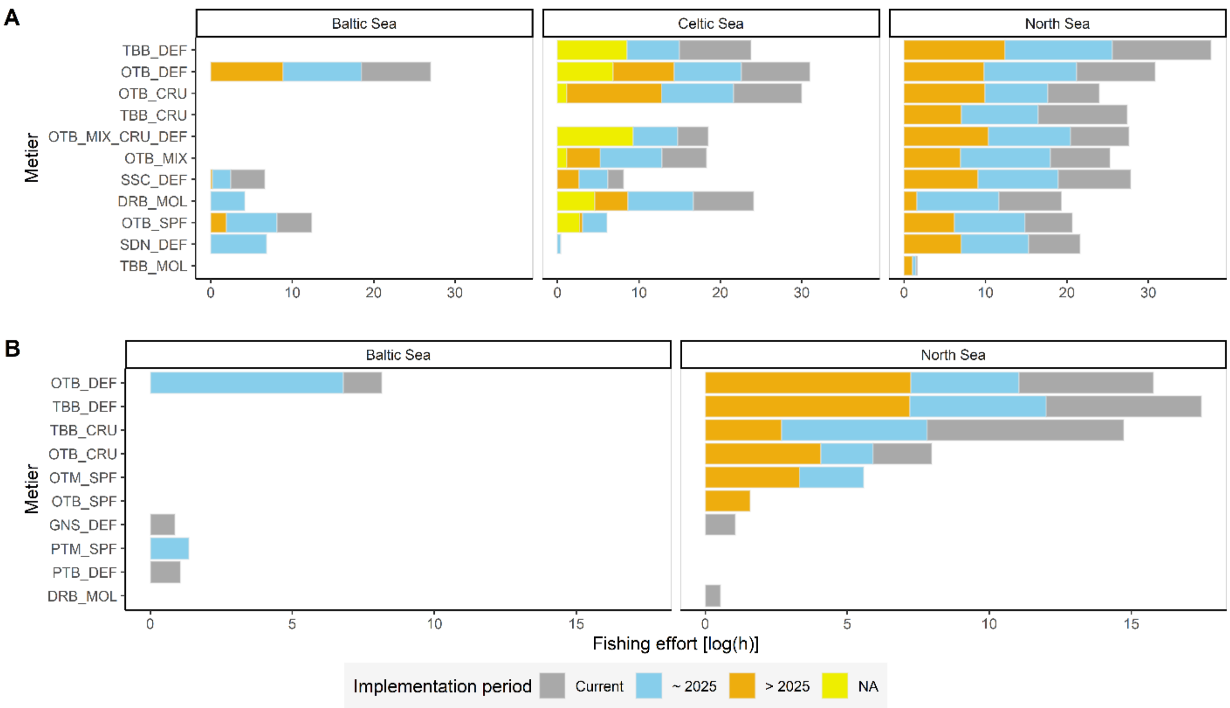


Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by (A) OSPAR (the Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (Helsinki Commission for the protection of the Baltic Sea) and the German Federal Office for Agriculture and Food (BLE) and (B) by Global Fishing Watch (GFW) for fisheries

Note: TBB_DEF: Beam trawl targeting demersal fish; OTB_DEF: Otter trawl targeting demersal fish; OTB_CRU: Otter trawl targeting crustaceans; OTB_MIX_CRU_DEF: Otter trawl targeting crustaceans (*Nephrops norvegicus*) and demersal fish; SSC_DEF: Scottish seine targeting demersal fisheries, mainly Atlantic cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*) and flatfish species; OTB_SPF: Otter trawl targeting small pelagic fish, mainly European sprat (*Sprattus sprattus*) or sandeel (*Ammodytes*); SDN_DEF: Danish seine targeting demersal fish, mainly European plaice (*Pleuronectes platessa*) and Atlantic cod (*Gadus morhua*)

Figure 5 allows for a **direct comparison of the affected fleets** across the Baltic Sea, Celtic Sea and North Sea (top) and the German EEZs of the Baltic Sea and North Sea, since the standardised OSPAR/HELCOM and VMS data have been used to estimate the particular fishing effort. Across the different OR scenarios and regions the **otter trawlers targeting cod and plaice** (OTB_DEF) seemed to be **affected the most** compared to the other fisheries. This was followed by otter trawls targeting crustaceans such as the Norway lobster.

Figure 5: Fishing fleets [average annual effort in hours] affected by the current, mid-term (~ 2025), and long-term (> 2025) offshore renewable expansion in (A) the Baltic Sea, Celtic Sea, and North Sea and (B) the German EEZs of the North Sea and Baltic Sea



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by OSPAR (the Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (Helsinki Commission for the protection of the Baltic Sea), and the German Federal Office for Agriculture and Food (BLE) for fisheries in the German EEZ

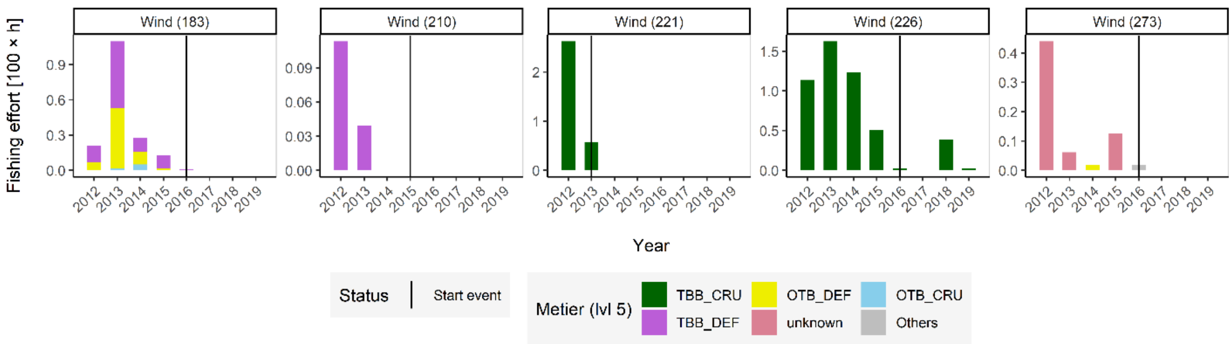
Note: Respective estimates of fishing effort are based on OSPAR/HELCOM data (A) and VMS data (B). The OSPAR/HELCOM data (A) only comprised effort of bottom contacting gears, those however represent the dominant fishing fleets. "NA" scenarios (A) refer to cases where no temporal indication was available for the respective OR areas. EEZ = Exclusive economic zone; TBB_CRU: Beam trawl targeting crustaceans; TBB_DEF: Beam trawl targeting demersal fish; TBB_MOL: Beam trawl targeting molluscs; DRB_MOL: Dredge targeting scallops and mussels; OTM_SPF: Midwater otter trawl targeting small pelagic fish; OTB_CRU: Otter trawl targeting crustaceans; OTB_DEF: Otter trawl targeting demersal fish; OTB_MIX_CRU_DEF: Otter trawl targeting crustaceans (*Nephrops norvegicus*) and demersal fish; OTB_SPF: Otter trawl targeting small pelagic fish, mainly European sprat (*Sprattus sprattus*) or sandeel (*Ammodytes*); PTB_DEF: Pair trawl targeting demersal fish; PTM_SPF: Pelagic pair trawl targeting small pelagic fish; SSC_DEF: Scottish seine targeting demersal fisheries, mainly Atlantic cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*) and flatfish species; GNS_DEF: Set gillnet targeting demersal fish

For each of the European seas we showed that **more than one fishing fleet is affected** by the spatial expansion of the marine energy sectors. A more detailed time series analysis of local fishing activities would allow to further assess the potential impact on fishing opportunities and activities. Further effects like climate change induced shifts in fishing resource distributions, changes in oil prices, Brexit, or even the current COVID 19 crises will affect the actual spatial-temporal distribution of fishing effort of the respective fleets. The here presented overlap analysis represents a static approach which does not comprise simulation studies which explore fishing effort dynamics with respects to variations in those factors.

4.2. Fisheries affected by current offshore renewable installations

Fishing effort in OR areas varied greatly (**Figures 6** and **7**; **Annex 5** for GFW data), **ranging from no fishing** over very limited fishing, **to more than 1 000 hrs annually**. The high-resolution VMS data covering the German EEZ and the coarser OSPAR and HELCOM data showed that in the vicinity of OR **various types of trawling are the most common fishing activities** (**Figure 6**), which is in line with the aggregated results for the European seas (**Figures 4** and **5**). The results also show a high level of variation of annual fishing effort (e.g. Wind 106, 226, and 183 **Figures 6** and **7**) within a given area. This **highlights the need** to consider **best available time series** of fishing effort **to analyse potential impacts**. At the beginning of an installation (start event) fishing is restricted and consequently local fishing intensities change. For instance, in the German EEZs fishing within an OWF is prohibited usually leading to a decline of fishing effort in subsequent years (**Figure 6**). In contrast, in the OSPAR and HELCOM regions, fishing mostly continues after the start dates of OR, which might be due to the higher spatial resolution (**Figure 7**). However, depending on the prevailing legislation, fishing intensity can afterwards increase, decrease or both. Moreover, fishermen can also **be attracted to the edges of OR areas** (cf. attracted by the (perceived or realised) spill-over effect) and at the same time **be excluded from the OR area itself**. Except for the high-resolution VMS data (German EEZ), the spatial resolution of available international fishing effort data is insufficient to pick up such trends. Finally, no installations with a known start/end year within our study period were available to offer a **clear picture on the impact of area closures and reopening**. Further, the number of affected fishing fleets can clearly vary across OR areas (**Figure 7**). Hence, in some cases only one fleet will lose fishing opportunities (e.g. Wind 129), while in other cases (**Figure 7**) various fleets will be affected.

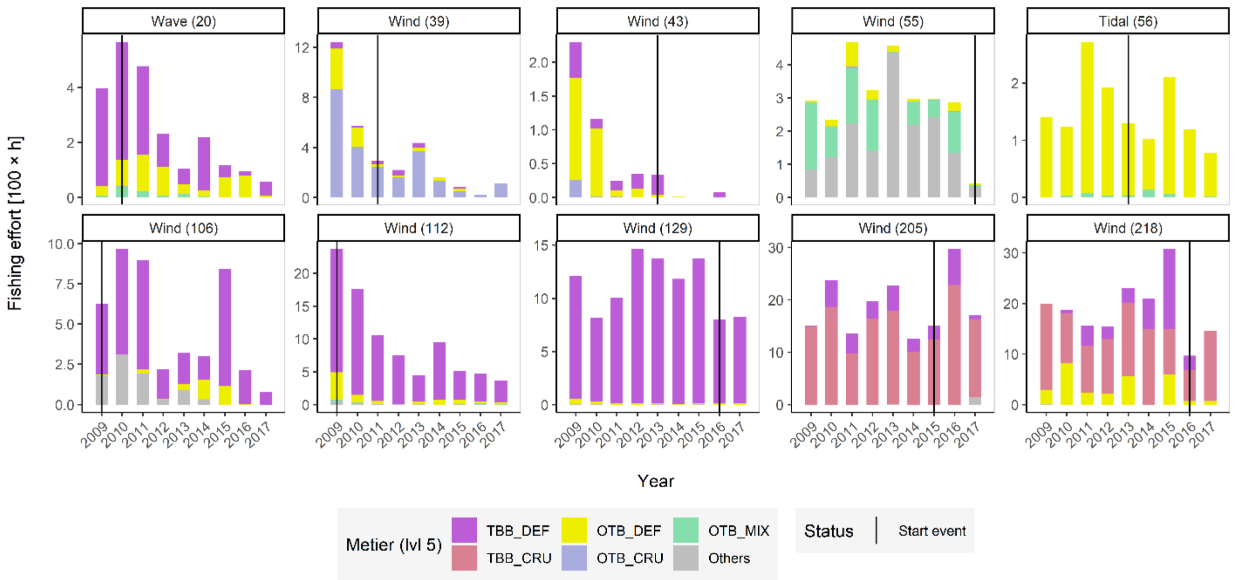
Figure 6: Average annual fishing effort per metier in the German EEZ overlapping with current offshore renewable installations, based on VMS (2012-2019) data



Source: Author based on data provided by 4C Offshore Ltd. for the offshore renewables; and the German Federal Office for Agriculture and Food (BLE) for fisheries

Note: Numbers refer to individual installations (Annex 3). Starting (solid vertical line) of the installation is shown. EEZ = Exclusive economic zone, VMS = Vessel monitoring system, TBB_CRU: Beam trawl targeting common shrimp (*Crangon crangon*); TBB_DEF: Beam trawl targeting common sole (*Solea solea*) and European plaice (*Pleuronectes platessa*); OTB_DEF: Otter trawl targeting demersal fish; OTB_CRU: Otter trawl targeting crustaceans

Figure 7: Average annual fishing effort per metier overlapping with current offshore renewable installations in the North Sea and Baltic Sea, based on OSPAR (2009-2017) and HELCOM (2009-2016) data



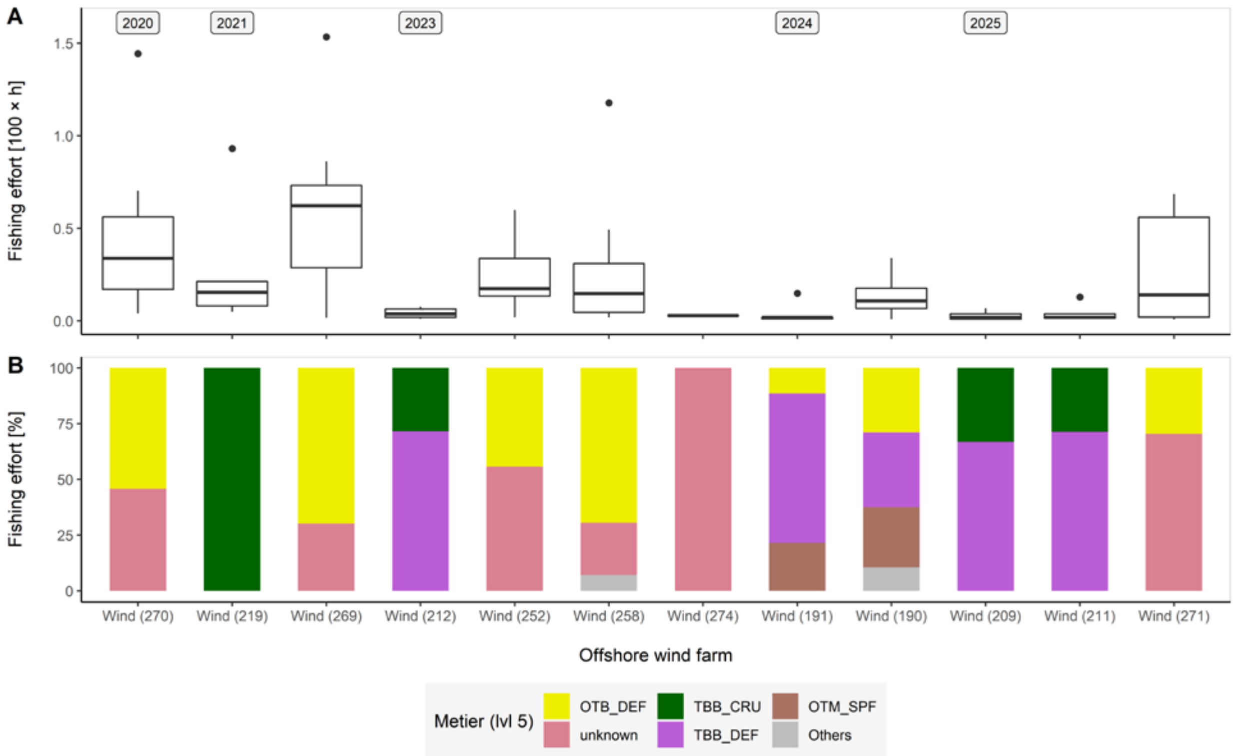
Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by OSPAR (the Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (Helsinki Commission for the protection of the Baltic Sea) for fisheries

Note: Numbers refer to individual installations (Annex 3). Starting (solid vertical line) of the installation is shown. TBB_DEF: Beam trawl targeting common sole (*Solea solea*) and European plaice (*Pleuronectes platessa*); TBB_CRU: Beam trawl targeting common shrimp (*Crangon crangon*); OTB_DEF: Otter trawl targeting demersal fish; OTB_CRU: Otter trawl targeting crustaceans; OTB_MIX: Otter trawl targeting Norway lobster (*Nephrops norvegicus*) and demersal fish

4.3. Fisheries affected by offshore renewable installations on a mid-term view

Similar to current OR, **mid-term OR installations** are also positioned in areas **where various types of fisheries occur**. Note that the following assessment assumes that **current fisheries patterns** remain **constant** over time, which is consistent with ongoing research showing similarity of fishermen's patch-choice over time (Stelzenmüller *et al.* 2008, van der Reijden *et al.* 2018). However, this does not take into account potential und currently unknown displacements related to **upcoming Brexit regulations or climate induced shifts in fisheries resource distributions**. The **largest OR development** will take place within the **Baltic Sea and North Sea region** until 2025. In the German EEZ, bottom trawling fleets targeting demersal fish and mid water otter trawler targeting small pelagic fish will be affected the most (**Figure 8**). An analysis of the entire North and Baltic Sea revealed additional affected fleets, e.g. beam trawlers targeting sole and plaice. Hence, **Figure 9** shows clearly that bottom trawling fleets will not just loose a few high effort fishing areas, but will be confronted with **a cumulative loss** of fishing opportunities, since these fleets operated in the past in almost all the OR planning sites in the Baltic Sea and North Sea.

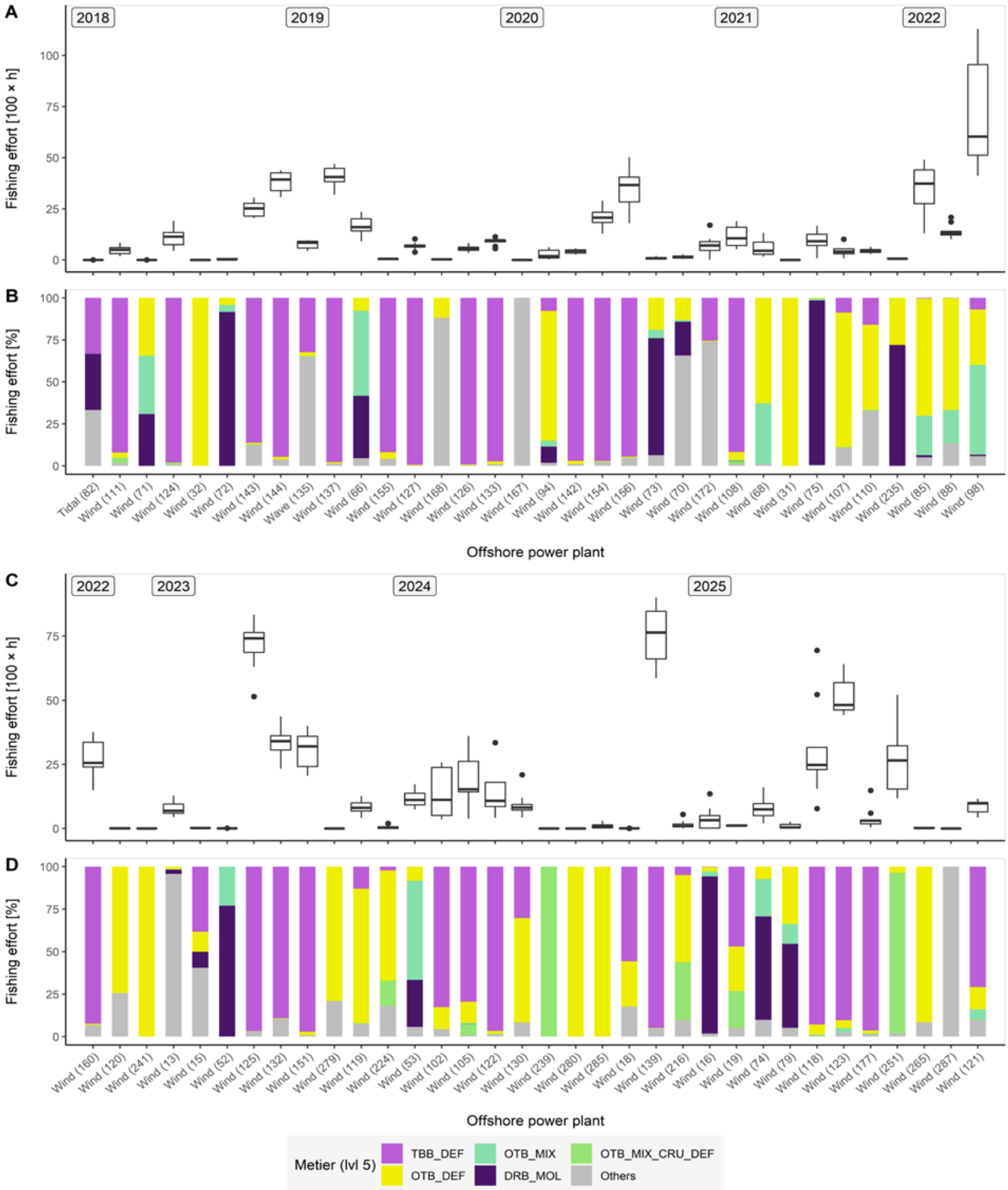
Figure 8: (A) VMS (2012-2019) data representing fishing effort [100 x h] overlapping with mid-term offshore renewable installations (~ 2025) in the German EEZ of the Baltic Sea and North Sea; (B) Fishing effort by fishing metier



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by the German Federal Office for Agriculture and Food (BLE) for fisheries

Note: Numbers refer to individual OR installations (Annex 3). VMS = Vessel monitoring system; OTB_DEF: Otter trawl targeting demersal fish; TBB_CRU: Beam trawl targeting common shrimp (*Crangon crangon*); TBB_DEF: Beam trawl targeting common sole (*Solea solea*) and European plaice (*Pleuronectes platessa*); OTM_SPF: Midwater otter trawl targeting small pelagic fish

Figure 9: (A), (C) Variation of annual fishing effort based on OSPAR (2009–2017) & HELCOM (2009–2016) data overlapping with mid-term offshore renewable installations (~ 2025); (B), (D) relative proportion [%] of fishing effort by metier to the respective total annual effort



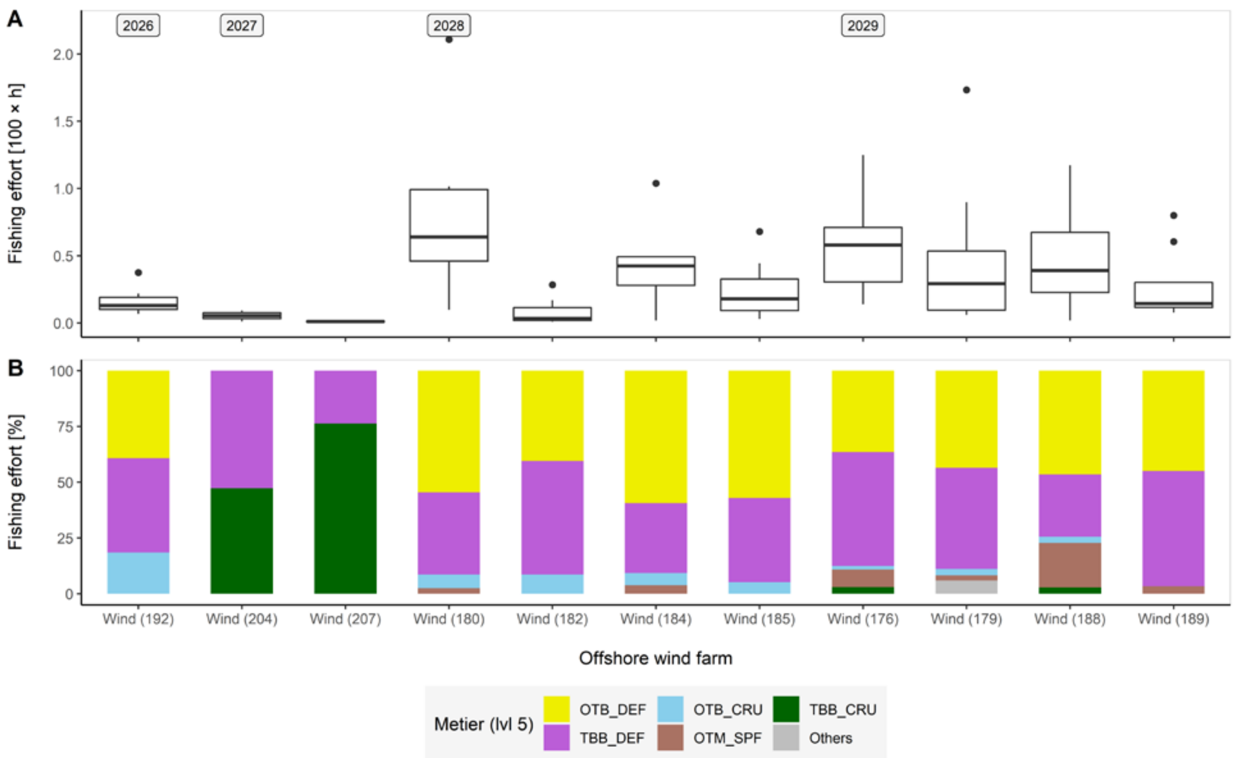
Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by OSPAR (the Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (Helsinki Commission for the protection of the Baltic Sea) for fisheries

Note: Numbers refer to individual OR installations. TBB_DEF: Beam trawl targeting demersal fish; OTB_DEF: Otter trawl targeting demersal fish; OTB_MIX_CRU_DEF: Otter trawl targeting crustaceans (*Nephrops norvegicus*) and demersal fish; DRB_MOL: Dredge targeting scallops and mussels

4.4. Fisheries affected by offshore renewable installations on a long term view

The **OR installations** planned after 2025 continue to overlap mostly with **demersal trawling fleets** (**Figures 10** and **11**). However, in particular for the wider North Sea region and the German EEZ of the North Sea the future OR sites will now **interfere with beam trawlers targeting common shrimp (e.g. Wind 204, 207)**. Thus, future planning will cause in particular **more conflict potential** with this fishing sector, which mainly operates in coastal waters.

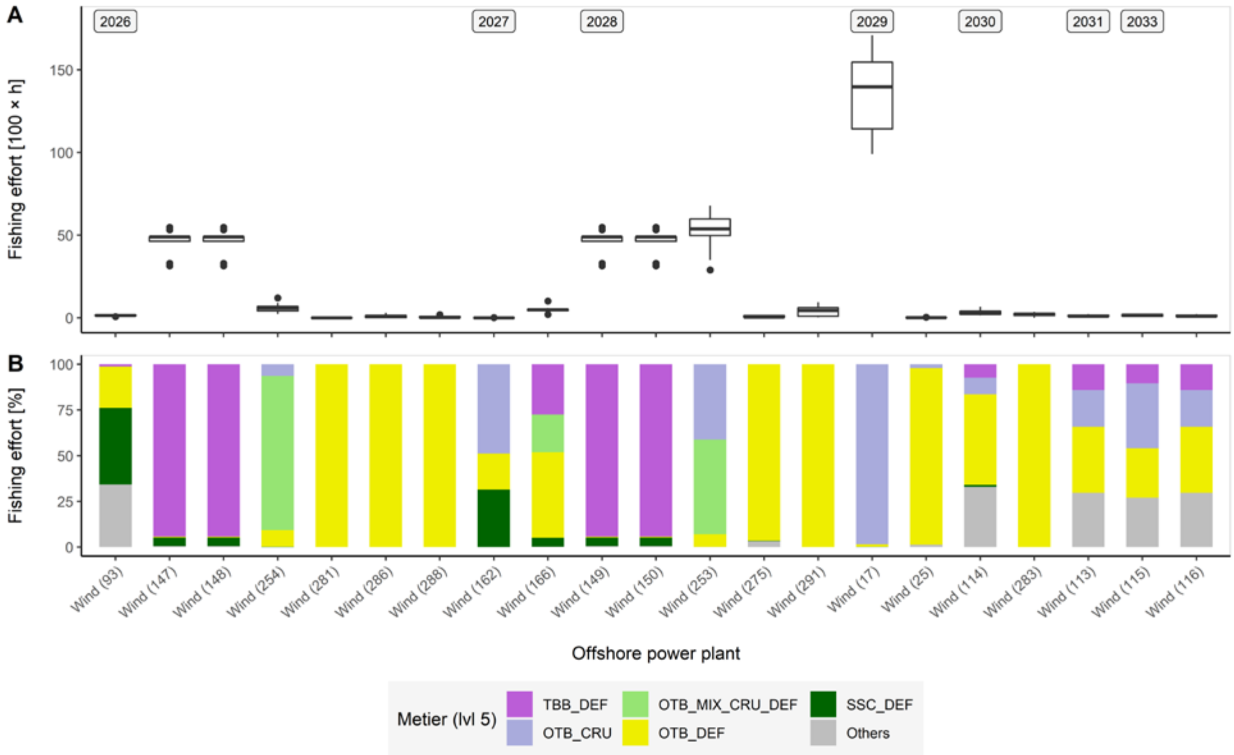
Figure 10: (A) Variation of annual fishing effort based on VMS data (2012-2019), overlapping with long-term offshore wind farms (> 2025) in the German EEZ of the Baltic Sea and North Sea; (B) relative proportion [%] of fishing effort by metier to the respective total annual effort



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by the German Federal Office for Agriculture and Food (BLE) for fisheries

Note: Numbers refer to individual installations (Annex 3) with starting years indicated. VMS = Vessel monitoring system; OTB_DEF: Otter trawl targeting demersal fish; TBB_DEF: Beam trawl targeting common sole (*Solea solea*) and European plaice (*Pleuronectes platessa*); OTB_CRU: Otter trawl targeting crustaceans; OTM_SPF: Midwater otter trawl targeting small pelagic fish; TBB_CRU: Beam trawl targeting common shrimp (*Crangon crangon*)

Figure 11: (A) Variation of annual fishing effort based on OSPAR (2009-2017) & HELCOM (2009-2016) data overlapping with long-term offshore renewable installation (> 2025); (B) relative proportion [%] of fishing effort by metier to the respective total annual effort



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by OSPAR (the Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (Helsinki Commission for the protection of the Baltic Sea) for fisheries

Note: Numbers refer to individual OR installations (Annex 3) with starting years indicated. TBB_DEF: Beam trawl targeting demersal fish; OTB_CRU: Otter trawl targeting crustaceans; OTB_MIX_CRU_DEF: Otter trawl targeting crustaceans (*Nephrops norvegicus*) and demersal fish; OTB_DEF: Otter trawl targeting demersal fish; SSC_DEF: Scottish seine targeting demersal fisheries, mainly Atlantic cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*) and flatfish species

5. REPRESENTATIVE CASE STUDIES: INTEGRATED MANAGEMENT EXAMPLES

KEY FINDINGS

- **Marine spatial planning (MSP)** facilitates integrated management, but **good practice examples** of co-existence and co-location still are **scarce**.
- Co-locating activities at sea requires an **integrated assessment** of ecological and socio-economic costs and benefits.
- The case studies revealed a number of **measures that potentially mitigate** the conflict potential between fisheries and offshore renewables (OR):
  1) **early stakeholder consultation** detects conflict potential at an early stage and acknowledges the importance of all actors;
  2) independent **third parties** and the creation of guidelines can facilitate negotiation processes;
  3) **compensation payments** for the disturbance and the associated loss of income or additional expenditures can reduce the impact potential.
- Co-design approaches for the **co-location of OR with other uses can reduce the impact potential on fisheries**, strengthen the relationship of the sectors of concern and even enable beneficial co-operation between them.
- The **promotion of co-operation examples** allows for mutual learning and informs MSP regarding acceptable mitigation measures.

In the following we first define the concepts of co-existence, co-location and co-operation and synthesise subsequently the lessons learnt from representative cases from the UK, Denmark, Belgium Germany and the Netherlands. The concept of **co-existence** refers here to the idea that two activities (e.g. fishing activities and OR) exist at the same time and/or in the same place (Defra 2019). The concept of **co-location** (sometimes also referred to as co-use or multi-use; see **Chapter 1**) describes the fact that at least two activities are actively managed together while sharing space at sea. The implementation of co-location depends on site-specific characteristics and the prevailing integrated management approach such as MSP (Christie *et al.* 2014, Gimpel *et al.* 2015, Kaiser *et al.* 2010). **Co-operation** refers to an interaction between two activities, where both sectors benefit from that relationship, leading to a growth for both (Defra 2019).

There are several studies exploring multiple interests of marine activities in order to facilitate **co-existence** (Ramos *et al.* 2014) or seeking for co-existence options, e.g. of OWF and fisheries in Taiwan (Zhang *et al.* 2017). The number of studies exploring **co-location** effects (Christie *et al.* 2014) or co-location options, such as for offshore aquaculture in combination with OWF in Danish waters (Benassai *et al.* 2014) or German waters (Gimpel *et al.* 2015), continue to increase.

Despite the increasing acceptance of co-existence of marine sectors and its explicit promotion by the MSP Directive (European Commission 2014) **real world examples still are scarce** and refer mainly to pilot projects. Hence, while legally binding procedures and frameworks are still lacking (Buck *et al.* 2004, Buck and Langan 2017, Gimpel *et al.* 2015), numerous **best practice guidelines** for co-existence, co-location and co-operation have been developed through **European research initiatives**:

- *COEXIST*[20] (EU, FP7; 2010-2013) was a multidisciplinary project which evaluated competing activities and interactions in European coastal areas. Results included a **roadmap for integration of aquaculture and fisheries with other activities** in the coastal zones (Stelzenmüller *et al.* 2013).
- *Celtic Seas Partnership*[21] (2013-2016) has drawn people together from across the Celtic Seas to set up collaborative and innovative approaches to support the delivery of the *Marine Strategy Framework Directive* (MSFD) (European Commission 2008b). Key results comprised **best practice guidelines to support marine stakeholders** in the field of transboundary marine governance, co-location of marine renewable energy projects with other marine uses and conflict resolution between marine stakeholders.
- *MARIBE*[22] (Horizon 2020, 2015-2016) explored co-location and co-operation opportunities for different sectors in four sea basins (Atlantic; Baltic/North Sea; Mediterranean; and Caribbean). Altogether **twelve co-location options were identified and presented with strategic roadmaps**.
- *MUSES*[23] (Horizon 2020, 2016-2018) explored the opportunities for co-location in European seas based on a stakeholder engagement process. Results included **practical solutions and an Action Plan on how to overcome existing barriers and minimise risks** associated with potential sectors and sea areas identified as suitable for co-location (Schultz-Zehden *et al.* 2018).
- *UNITED*[24] (Horizon 2020, January 2020 – July 2023) analyses the economic, social and environmental perspectives of co-existence of different activities in the same marine space and **promotes the co-location of different activities in the same area** across the North Sea, the Baltic and the Mediterranean.
- *The German/EU project 'Offshore wind farms in the context of ecosystem-based marine spatial management*[25], co-funded by the European Regional Development Fund (ERDF), and the Dutch/EU project *WinWind*[26], co-funded by Horizon 2020, both assessed the potential of co-operation of OWF and fisheries in the Southern North Sea. Both projects designed low-risk techniques to fish brown crab and explored the market potential of this resource.

International research initiatives include among others the New York States *Fisheries Technical Working Group* (F-TWG), a technical working group aiming to ease the co-existence of OR and fisheries in New York waters[27]. Another example is the *Responsible Offshore Science Alliance* (ROSA), an independent organisation promoting co-existence of fisheries and OWF in US federal waters[28].

20 https://www.msp-platform.eu/projects/interaction-european-coastal-waters-roadmap-sustainable-integration-aquaculture-and
21 https://www.msp-platform.eu/projects/celtic-seas-partnership
22 https://www.msp-platform.eu/projects/marine-investment-blue-economy
23 https://www.msp-platform.eu/projects/multi-use-european-seas
24 https://www.msp-platform.eu/projects/multi-use-platforms-and-co-location-pilots-boosting-cost-effective-and-eco-friendly
25 https://www.thuenen.de/en/sf/projects/offshore-wind-farms-in-the-context-of-ecosystem-based-marine-spatial-management/
26 https://winwind-project.eu/home/
27 https://www.nyftwg.com/
28 https://www.rosascience.org/

5.1. Best practice examples for co-existence: Fisheries and offshore wind farms

United Kingdom

The UK offshore wind industry was driven by the UK Government's requirement to reach EU renewable energy targets[29]. The Crown Estate funded the *Fishing Liaison with Offshore Wind and Wet Renewables* group (FLOWW)[30], facilitating consultancies and discussion between the fisheries and wind energy sectors since 2002. FLOWW further developed '*Best Practice Guidelines for the Fishing of Offshore Energy Developers*' that provide **mitigation and co-existence planning** such as **disruption compensation** for disturbance and loss of earnings for fisheries (community fund set up after construction) [31 32]. **Passive fishing techniques or navigation are still allowed in English OWF**, fishermen are only excluded when a project is under construction or closed for maintenance (Zhang *et al.* 2017).

Further, a **market for tourism and recreational fisheries** with charter boats inside OWF emerged[33] Artificial reef effects improve the opportunities for sea angling, but a study on recreational angling in OWF revealed that *there is little evidence that this kind of recreational fisheries will have a significant economic impact* in the future, reasoned by the socio-demographics of the anglers and their angling behaviour (Hooper *et al.* 2017).

Hence, despite the developed best practice guidelines on co-existence **fishing in OWF is not yet common practice** (Gusatu *et al.* 2020). Although insurance companies did not increase prices or restrict certain areas for fishing inside OWF, the fishing sector is reluctant due to uncertainties around safety, gear retrieval, insurance and liability[34] (Hooper *et al.* 2015).

Denmark

The *Danish Energy Agency* (DEA) mapped suitable sites to produce **18 GW with OWF** in the North Sea and the Baltic Sea[35]. The *Danish Fisheries Act* foresees a **consultancy process**, in which developers present and discuss their development plan directly to the fishing industry. Negotiations include potential **mitigation measures** as well as **financial disruption** or **displacement compensation** (due to the OWF itself or the export cable corridor)[36]. Mitigation measures are for instance the i**nclusion of fishermen** in the construction and operation of the OWF or **permitting passive fisheries** inside the OWF. Negotiations about compensations are carried out by the *Danish Fishermen's Association* (verified by an independent consultant). The **amount of the compensation** payment depends on the analysed impact for fisheries, which is part of the Environmental Impact Assessment and based on existing data from the *Danish Fishery Agency* (log book data, VMS data, etc.) (DEA 2018).

In contrast to the UK, potential uncertainty regarding insurance have been resolved through **cooperative organizations for insurance**. The membership in such insurance co-operative societies is mandatory for all parties involved[37].

29 http://www.offshorewindfarms.co.uk/
30 https://www.politico.eu/article/fishermen-offshore-wind-farms-struggle-to-share-sea/
31 http://www.seakeeper.org/?page_id=971
32 https://www.rechargenews.com/wind/fisheries-and-offshore-wind-must-co-operate-if-europe-is-to-hit-net-zero/2-1-741028
33 http://www.seakeeper.org/?page_id=971
34 http://www.seakeeper.org/?page_id=971
35 https://www.offshorewind.biz/2020/06/05/denmark-rolls-out-18-gw-offshore-wind-map/
36 https://www.politico.eu/article/fishermen-offshore-wind-farms-struggle-to-share-sea/
37 Personal communication about Fishing inside and around offshore wind farms in Denmark with representatives of the fishing industry at the Federal Maritime and Hydrographic Agency (BSH) in Germany. June the 6th 2018.

5.2. Best practice examples for co-location: Fisheries, aquaculture and offshore wind farms

Belgium

By 2020**, 5.3 GW** should be produced in Belgium by renewables, **2.3 GW** of this should be generated by **offshore wind power**. A study by the Monitoring Programme *WinMon.BE* revealed no **negative effects for the fishing sector** due to OWF, although commercial fishing vessels were excluded from OWF areas. Fleets adapted the fishing restrictions and relocated to the outer boundaries of the OWF where catch rates remained stable or even increased[38]. The exclusion of (mobile bottom trawling) fisheries now even allows for **pilots of co-locating OWF with aquaculture and nature restoration activities**, investigated within the *UNITED* project (**Chapter 5**). The possible emergence of wild flat oyster beds (*Ostrea edulis)* is being tested at an OWF operated by *Parkwind*[39], with the introduction of hard substrate favouring the settlement of oyster larvae[40]. The production of oysters would **help reaching the good environmental status** (European Commission 2008b) of the Belgian waters providing important ecosystem services such as habitat services for epibenthic species, invertebrates and fish or water quality regulation (Kamermans *et al.* 2018) for restoration as well as future seafood production for aquaculture[41].

Despite this pilot initiative, it has to be acknowledged that a general site selection for the co-location of aquaculture and OWF depends aside of biological and ecological factors, on hydrological and economic factors (Christie *et al.* 2014, Gimpel *et al.* 2015). For instance, **large scale applications** would require a comprehensive analysis of the **economic viability** (accounting for the operation costs due to the distance of potential sites to the coast) and **technical feasibility** (accounting for the increased maintenance of aquaculture systems due to harsh weather conditions offshore in the North Sea)[42] (Buck *et al.* 2004, Gimpel *et al.* 2015).

While fisheries in the UK, Denmark and Belgium have achieved a form of co-existence with the offshore wind energy industry, fisheries regulations in the proximity of OWF in the Netherlands and Germany are still under negotiation[43] [44].

5.3. Best practice examples for co-operation: Fisheries and offshore wind farms

The Netherlands

According to plans drafted by the Dutch government, **4.5 GW** of **offshore wind power** should be generated annually **by 2023**, and **11.5 GW by 2030**.

The fishing industry was excluded from OWF until 2015, afterwards three farms were opened up on a test level. In order to agree on the underlying co-use regulations and mitigation measures, **risk assessments** were carried out by the Dutch government itself, by the OWF operators and an independent third party. The Dutch government **adapted the regulations and mitigation measures**

38 https://www.naturalsciences.be/en/news/item/19116
39 http://parkwind.be/
40 https://www.h2020united.eu/pilots/2-uncategorised/42-offshore-wind-and-flat-oyster-aquaculture-restoration-in-belgium
41 https://www.h2020united.eu/pilots/2-uncategorised/42-offshore-wind-and-flat-oyster-aquaculture-restoration-in-belgium
42 https://www.h2020united.eu/pilots/2-uncategorised/42-offshore-wind-and-flat-oyster-aquaculture-restoration-in-belgium
43 https://thefishingdaily.com/latest-news/netherlands-fishermen-objection-to-north-sea-offshore-wind-farms/
44 https://www.welt.de/wirtschaft/plus166743138/Fischer-wollen-in-Offshore-Windparks-auf-Fang-gehen.html

accordingly and **opened up the remaining OWF in 2018** for navigation and specific fishing techniques. **Guidelines for the fishing sector** include among others a permission procedure led by the Dutch government for fishing gear specifications[45].

Nevertheless, the so-called *North Sea Agreement* specifies that with the additional implementation of OWF and MPAs the **Dutch fleet must be modernised and reduced** in order to meet the requirements of sustainable fishing (e.g. a reduction of bottom-trawling activities). Although funding was promised for this, the majority of the fishermen refused to sign the agreement[46 47].

Germany

The Federal Government of Germany has set the target to reach **15 GW by 2030** by **offshore wind energy**. Until 2020, navigation or fishing was not allowed within 500 metres of the OWF for safety of the facilities and shipping traffic[48]. The German fishing industry must accept a **loss of fishing grounds** due to OWF development and approached the *Federal Maritime and Hydrographic Agency*[49] to request access to the wind farm areas under "the principle of equal treatment", similarly to their colleagues in Denmark[50], and succeeded: **Navigation got allowed in 2020 under certain conditions** (minimum 50 metres distance to turbines, good visibility, etc.), negotiations about passive fishing techniques within 500 metres of the OWF are still ongoing in the course of the MSP revision[51 52].

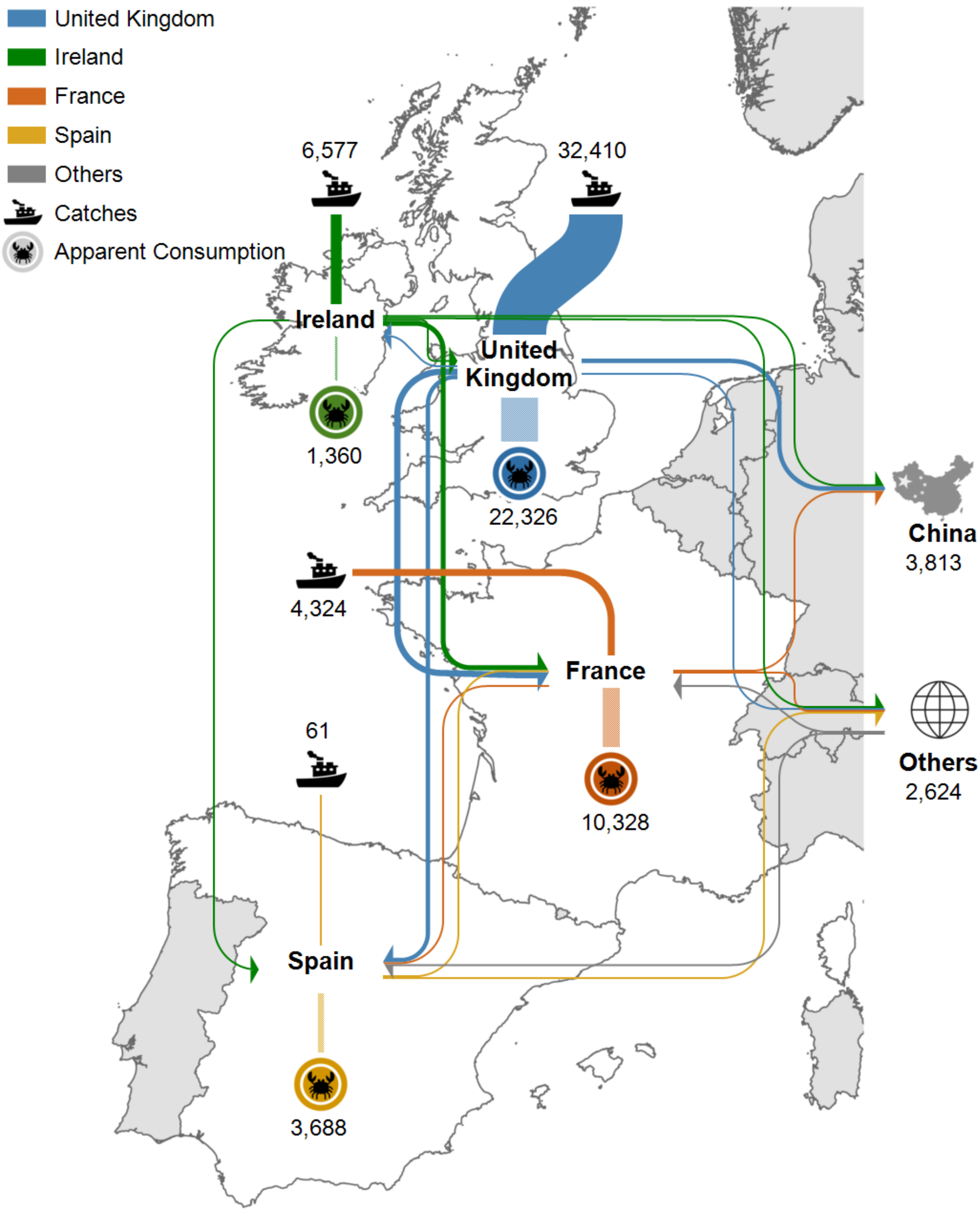
While the Dutch and German fishing sectors need to prepare for modernisation and alternative fishing resources, the projects '*Offshore wind farms in the context of ecosystem-based marine spatial management*' and '*WinWind*' (**Chapter 5**) already explored the potential of **alternative resources such as brown crab which likely benefit from OWF installations** (Stelzenmüller *et al.* 2016). Both projects pursued a potential co-operation of OWF and fisheries in the Southern North Sea. They designed **low-risk fishing techniques** such as pots equipped with weights instead of anchors to fish for brown crab. Further, they assess the market potential of this target species.

For instance, **Figure 12** shows the **supply balances of brown crab from the North Sea region** (Stelzenmüller *et al.* in prep.): in 2017 the catches of UK, Ireland, France and Spain amounted to approximately 44 kilo-tonnes. Here, the UK contributed for instance the largest share with 32,410 tonnes and exported nearly one third of the catches. Export markets to Asia, especially to China, Hong Kong, Taiwan and Vietnam are growing. In 2017, the United Kingdom exported 2,722 tonnes and Ireland 909 tonnes brown crab to China.

Recent findings suggest, that brown crab is **economically viable**, **local spill-over effects of OWF** seem to exist and the commercial brown crab fishery in the vicinity of OWF is already increasing (Stelzenmüller *et al.* in prep.).

45 https://www.msp-platform.eu/story-4-netherlands-offshore-wind-and-fisheries
46 https://mpanews.openchannels.org/news/mpa-news/perspective-north-sea-stakeholders-agreement-participative-policy-development
47 https://thefishingdaily.com/latest-news/netherlands-fishermen-objection-to-north-sea-offshore-wind-farms/
48 https://www.handelsblatt.com/23582948.html?share=mail
49 https://www.deutsche-flagge.de/en/german-flag/flag-state/bsh-federal-martime-and-hydrographic-agency-1
50 https://www.welt.de/wirtschaft/plus166743138/Fischer-wollen-in-Offshore-Windparks-auf-Fang-gehen.html
51 https://www.welt.de/print/die_welt/wirtschaft/article166744752/Frischer-Fisch-aus-dem-Windpark.html
52 https://www.welt.de/print/die_welt/wirtschaft/article166744752/Frischer-Fisch-aus-dem-Windpark.html

Figure 12: Catches and apparent consumption of brown crab (*Cancer pagurus*) in United Kingdom, Ireland, Spain and France and trade between these, "others" and to China in tonnes live weight equivalent



Source: Stelzenmüller *et al.* (in prep.)

Note: Patterned flows illustrate the apparent consumption

5.4. Lessons learnt: Mitigation measures reducing conflict potential

The **identification of mitigation measures** for fisheries can reduce the conflict potential in between the fisheries sector and OR sectors, simplify negotiation processes and should be part of the guidelines that promote co-existence, co-location or even co-operation. These measures should be picked up in a MSP process, for instance in the strategic environmental assessment (SEA) of a proposed plan. As described in **Chapter 5.1 to 5.3**, several mitigation measures already find application or have been suggested:

- **Early communication** and **stakeholder consultation** before the designation of potential sites for the development of OR is essential and identifies conflict potential at an early stage. An early integration of all stakeholders supports the siting process by the availability of knowledge of the fishing sector and acknowledges the importance of this sector.
- **Independent third parties** who are aware of and consider all concerns of the partners involved, can facilitate discussions, negotiations and the creation of guidelines for the joint use of designated areas. An independent entity can mediate between the partners and therefore support the finding of a compromise.
- **Compensation payments** for the disturbance and the associated loss of income (due to reduced fishing effort) or additional expenditure (due to detours to the fishing grounds) of the fishing sector caused by the expansion of OR can reduce the impact potential.
- **Co-design approaches** for the co-location of OR with other uses can reduce the impact potential on fisheries, strengthen the relationship of the sectors of concern and even enable beneficial co-operation between them. This can be combined with licensing processes that favour the fisheries most affected by displacement.
- **Promotion of co-operation examples** allows for mutual learning and informs MSP regarding acceptable mitigation measures.

6. KNOWLEDGE GAPS AND RESEARCH NEEDS TO INFORM INTEGRATED MANAGEMENT

KEY FINDINGS

- Current knowledge on the impact of offshore renewables (OR) on fisheries is focused on **ecological and environmental impacts**.
- Assessment of **economic and socio-cultural impacts** are lacking in recent empirical studies.
- Economic impact assessments for fisheries need to address **direct and indirect costs** of the loss of fishing opportunities as well as the **socio-cultural effects** thereof. More research is needed to assess possible negative impacts of investments in renewable energy, especially offshore wind farms (OWF), on the fishing sector, local communities and economic activities onshore.
- **Standardised monitoring strategies** and **freely available data** on OR development sites are required for a coherent impact assessment of OR on aquaculture and fisheries.
- **Standardised fishing effort data** with information on fishing gear, target assemblages and target species are a prerequisite to assess cumulative effects of OR development and a subsequent economic impact analysis.

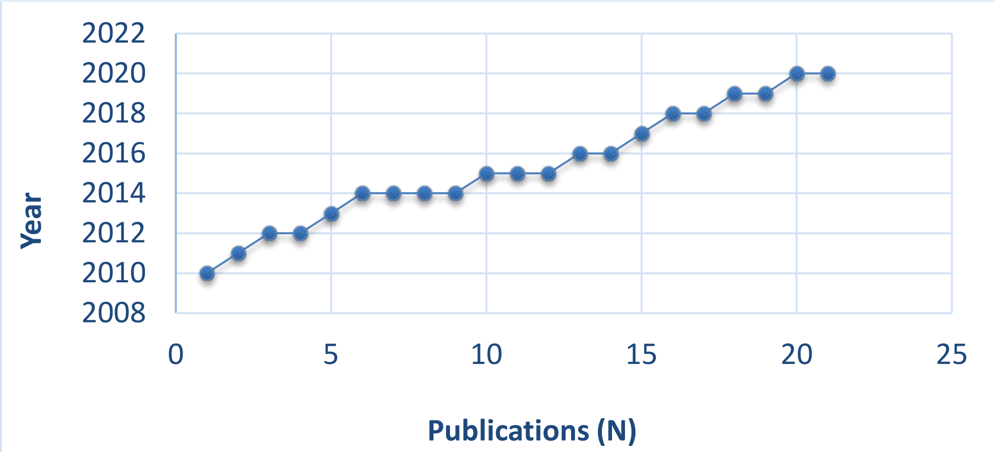
In **Chapter 6** we summarise **knowledge gaps** and **research needs** to inform an integrated management such as MSP. We first provide a synopsis of the current **approaches to assess the impact of OR** on fisheries by the means of a standardised literature review. As information about the assessment of **economic and socio-cultural impacts** were lacking, we conclude on the research needs to perform economic impact assessments. Further, we describe the **data available** for a coherent impact assessment of OR on fisheries and aquaculture.

6.1. Synopsis of current knowledge on the impact of offshore renewables on fisheries

We performed a **standardised literature review** to conclude on the current knowledge on the impact (referring to positive and negative effects) of OR on fisheries or aquaculture. With the help of the **literature data base *Scopus***[53] we performed a key word-search using multiple combinations of the key words "fishing/ fisheries" or “aquaculture/ mariculture”, "renewables/ wind energy/ tidal energy/ wave energy", "impact/ conflict" and "marine spatial planning/ management". We limited the research to the **past 25 years** and identified 50 publications. After a careful examination of the study contents we retained 21 publications for our review. We reviewed those empirical studies according to their characteristics (e.g. year of publication, case study region etc.) and classified each study according to the **type of impact** analysed, i.e. **ecological, economic or socio-cultural** impact. During this review, we equated the terms ‘impact’ and ‘conflict’. As shown in **Figure 13**, the number of publications related to the impact of OR on fisheries or aquaculture increased over time. From 2010 on, the **number of case studies reviewed has risen steadily**.

53 https://www.scopus.com/home.uri

Figure 13: Year of publication of the literature reviewed

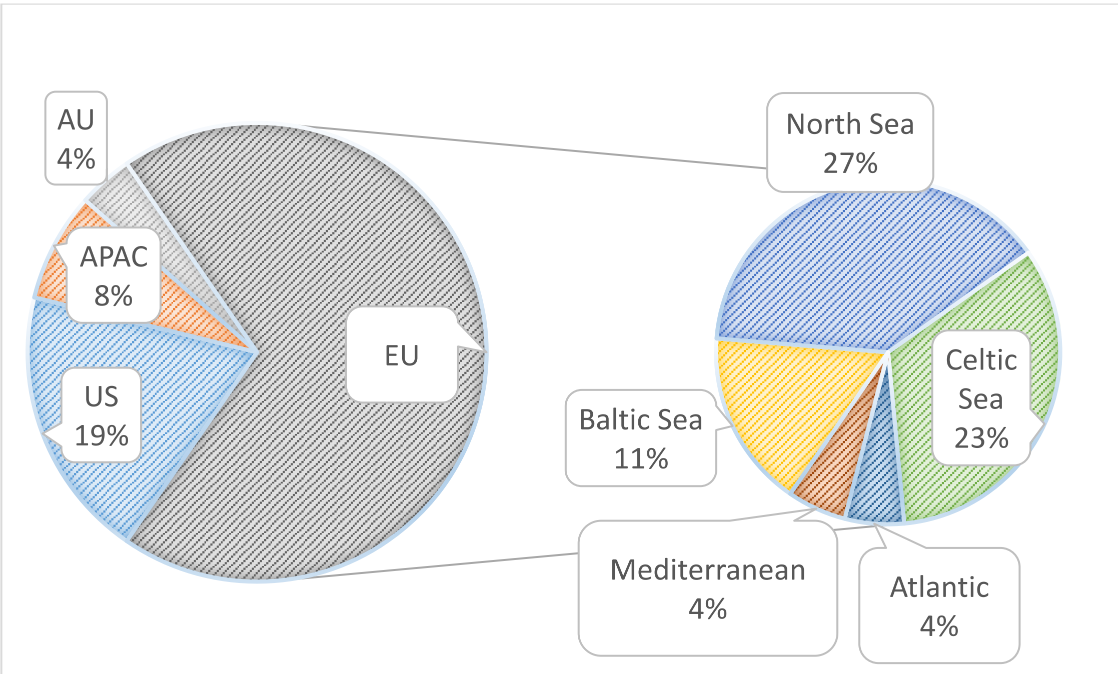


Source: Author based on data derived from a literature review

Note: 21 empirical studies focussed on the impact (incl. conflict assessment) of offshore renewables on fisheries or aquaculture (full review table in Annex 6)

The majority of **case study regions** assessed were **located in the EU**, five focused on US waters (Hoagland *et al.* 2015, Plummer and Feist 2016, Pomeroy *et al.* 2015, Shumchenia *et al.* 2012, White *et al.* 2012), two on Asian regions (Henriksson *et al.* 2019, Zhang *et al.* 2017) and one was related to Australian waters (Flocard *et al.* 2016). From the European case studies, **the majority included assessments in the North Sea** (Bergström *et al.* 2014, Berkenhagen *et al.* 2010, Campbell *et al.* 2014, Christie *et al.* 2014, Gusatu *et al.* 2020, Jongbloed *et al.* 2014, Kenny *et al.* 2018), followed by the Celtic Sea, the Baltic Sea, the Atlantic and the Mediterranean (**Figure 14** and **Annex 6**).

Figure 14: Case study regions of the literature reviewed



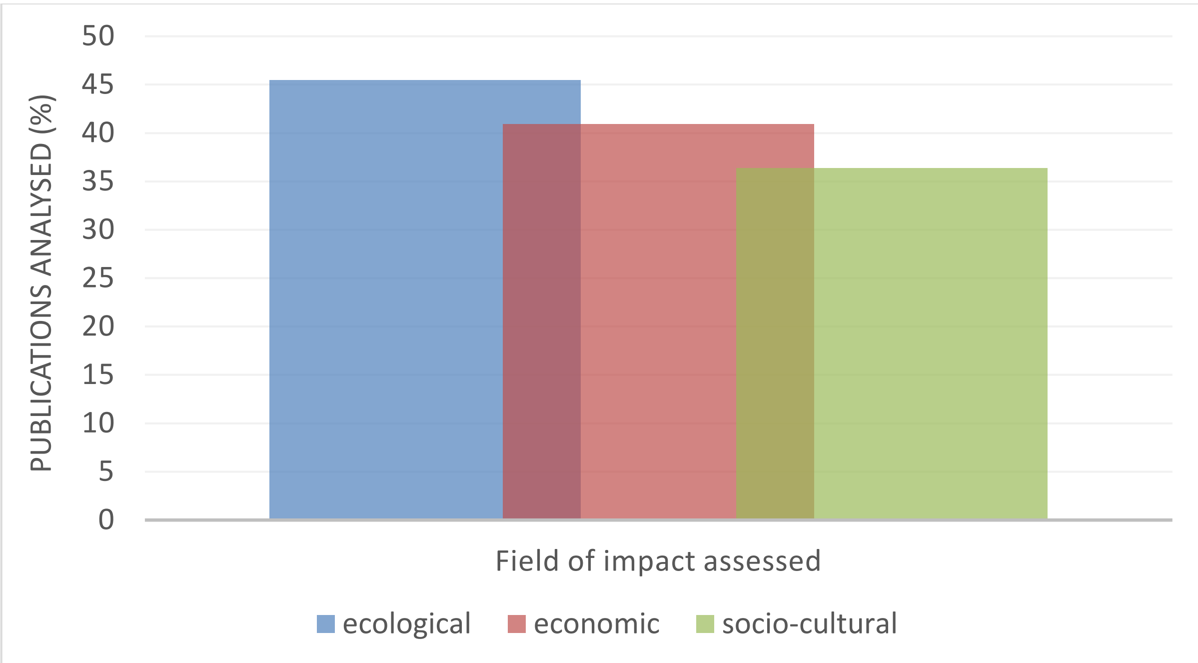
Source: Author based on data derived from a literature review

Note: The European regions correspond to the definition of European seas in Annex 1 (full review table in Annex 6)

While nine studies analysed the **potential of conflict in between different sectors** such as OR vs. fisheries or aquaculture (Campbell *et al.* 2014, Flocard *et al.* 2016, Jongbloed *et al.* 2014, Munoz *et al.* 2018, Plummer and Feist 2016, Pomeroy *et al.* 2015, White *et al.* 2012, Yates *et al.* 2015, Zhang *et al.* 2017), the same number of studies assessed the **environmental impact of OR on the ecosystem** and therefore fisheries resources (Bergström *et al.* 2014, Cronin 2011, Flocard *et al.* 2016, Henriksson *et al.* 2019, Janßen *et al.* 2013, Kenny *et al.* 2018, Munoz *et al.* 2018, Shumchenia *et al.* 2012, Whitton *et al.* 2020). Five studies conducted an **economic impact analysis** (Berkenhagen *et al.* 2010, Hoagland *et al.* 2015, Plummer and Feist 2016, Shumchenia *et al.* 2012, White *et al.* 2012) and only three studies analysed **co-location potential** (Calado *et al.* 2019, Christie *et al.* 2014, Gusatu *et al.* 2020). Hence, ecological impacts were assessed the most (impact on fishing resources), followed by economic (impact on revenues) and socio-cultural impact (conflict potential) (**Figure 15**).

Looking at the **share of the respective sectors** that were assessed across the retained studies, the sector **wave energy** was quite high (Campbell *et al.* 2014, Flocard *et al.* 2016, Plummer and Feist 2016) compared to **tidal energy** (Whitton *et al.* 2020), but still not comparable to the share of **wind energy** (Bergström *et al.* 2014, Berkenhagen *et al.* 2010, Gusatu *et al.* 2020, Hoagland *et al.* 2015, Janßen *et al.* 2013, Jongbloed *et al.* 2014, Munoz *et al.* 2018, Zhang *et al.* 2017). Unlike wave energy, tidal resources are not widely distributed and are located in specific areas, limiting the geographical extent of the tidal energy sector. The **primary locations** for wave energy resources are the Atlantic Ocean (United Kingdom, Ireland, Spain, Portugal and France) and the North Sea (Denmark)[54]. Despite the quick pace of OR expansion, only 30% of the publications (7) reviewed included a **future scenario analysis** (Gusatu *et al.* 2020, Henriksson *et al.* 2019, Munoz *et al.* 2018, Plummer and Feist 2016, White *et al.* 2012, Yates *et al.* 2015).

Figure 15:Type of impact assessed in the publications analysed



Source: Author based on data derived from a literature review

Note: Conflict potential is categorised here under socio-cultural impact (full review table in Annex 6)

54 https://www.msp-platform.eu/sector-information/tidal-and-wave

The review table with **further information about the empirical studies and outcomes** is given in **Annex 6**. The review revealed that **current knowledge** on the impact of OR on fisheries or aquaculture is **mostly related to ecological impacts**. Hence, these results clearly show the **gap on economic impact assessments** for fisheries (see also a description of requirements in **Chapter 1**).

6.2. Considerations for economic impact assessments

From an economic standpoint the **development of OR is a risky business**. Every company planning OR conducts a comprehensive economic assessment whether the investment is worthwhile doing – as was done in the past with the existing OWF. The companies weigh expected revenues vs. expected costs over the usual investment period.

The investment in a wind farm usually requires an **environmental impact assessment**. So far, an impact assessment for impacts on other sectors by the OWF is not required. The building of a OWF usually leads to a **fishing free zone** and economic impacts of such a closure could be analysed following the same methodologies as a fisheries management measure (Malvarosa *et al.* 2019). Developed **bio-economic models** could be utilised to assess the impacts (Nielsen *et al.* 2017, Simons *et al.* 2014). Fishers cannot claim a right to fish specifically for the area of the OWF. They have usually fishing opportunities for certain species or a general fishing licence. Therefore, the OWF leads to a reduction of the available space for fishing, fishing effort has to be moved to other areas, which may result in increasing costs for the company. In the past, only **few studies analysed the possible negative effects of OWF** on the fishing sector. Especially cumulative effects are not analysed because one OWF may not have large negative impacts but several wind farms together may have severe negative impacts (Berkenhagen *et al.* 2010). Therefore, assessment of cumulative effects, taking all existing and proposed area closures into account (in addition to OWF also e.g. Natura 2000 sites), is essential in future SEA. In addition, the progressing **implementation of fisheries management measures** in **Natura 2000 sites** adds to the loss of fishing opportunities.

Further, the direct impacts of OWF are, however, only one possible impact on the fishing sector. Fishers are part of coastal communities, the fish is sold or processed locally and is part of the value added of the fishing sector to the local economy. **Restricting fishing activities in a larger area** may lead to the necessity of fishing companies to search for **alternative fishing grounds and move to another harbour**. There are traditional fishing communities which rely on fishing or where the fishing tradition attracts tourists which then spend money in local businesses. Most direct or indirect economic **impacts of OWF on local communities are barely understood**. Only in cases where the offshore renewable industry is using a harbour as base for their activities there may be some information of the value added of those industry to the coastal community (Hattam *et al.* 2015).

Hence, **economic impacts** are strongly linked to **socio-cultural effects** (fisheries as tradition, shore side effect on fishing communities, anthropogenic perspectives) that are also not well understood. This points also to the urgent need to better understand **adaption strategies** and individual behaviour and choices. Over the past years ***agent-based models*** (ABM) are being developed to understand the socio-ecological implications of human behaviour (Cabral *et al.* 2010, Little *et al.* 2009, Wijermans *et al.* 2020).

Therefore, **more research is needed on a wider scale** to assess possible effects of investments in renewable energy, especially OWF, on the fishing sector, local communities and economic activities onshore.

6.3. Monitoring strategies and data availability

As to date, there are no European-wide **standardised research projects and monitoring strategies** with respect to the socio-ecological effects of the OR expansion. Monitoring and risk assessments are conducted mainly on a **project level or at local scales** that do not allow for a further extrapolation of observed local effects and large-scale impact assessments. Our review showed the **current focus on ecological assessments**, hence standardised data products would allow for cross-site comparisons for e.g. comparable habitats. Furthermore, such OR related monitoring strategies should also address the **need of socio-economic data**.

Detailed **data on fishing activities, aquaculture and OR** are not freely available across Europe, only allowing to conduct high-resolution studies for a limited number of areas. Thus, the integration of these data is often hampered by **lack of access**, and **different spatial and temporal resolutions** (Hinz *et al.* 2013, Kaiser *et al.* 2016). **Annex 4** demonstrates such differences, since only VMS pings are able to show if activities are actually located within the OR polygon. As described in **Chapter 2**, GFW, OSPAR, and HELCOM data are only available for spatial units that indeed overlap to some extent with the polygon of the OR, but this does not necessarily mean that fishing occurred within the OR area. Our analysis revealed the **need of harmonised data on fishing effort** at fine temporal and spatial resolutions. While for the OSPAR/HELCOM regions data calls are addressed by ICES to deliver such standardised data on fishing activities using bottom contacting gears including their target assemblages, such aggregated information is missing for other European seas and pelagic gears. The availability of such harmonised data across European seas is specifically important when assessing the **cumulative effect of OR expansion** and for fleets that encompass vessels operating in two different regions (e.g. North Sea and Baltic Sea). In addition, the precise definition of affected fleets is also a prerequisite for an **economic impact assessment**.

7. POLICY RECOMMENDATIONS TO THE EUROPEAN PARLIAMENT

KEY FINDINGS

- **Standardised monitoring** programmes and a **harmonisation of fishing effort data** are needed to enable cumulative ecological and socio-economic environmental impact assessment of the expansion of marine energy.
- More research is required to **understand the effects of offshore renewable** (OR) **on fisheries** and provide a **guidance for Marine spatial planning** (MSP) to plan with fisheries.
- **Additional data** is needed to unfold the impacts of investments in renewable energy, especially OWF, on the fishing sector, local communities, and economic activities onshore.
- MSP processes should put **more emphasis** on the assessment of **co-location options**.
- MSP requires **best practice guidance** on the implementation of **standardised mitigation measures** to ease conflict potential between fisheries and OR development and to promote co-operation between sectors.

In the following we list the key issues identified in this study and provide respective policy recommendations.

7.1. Holistic assessment of the impacts of the expansion of marine energy on fisheries are hampered due to the lack of suitable data

- **EU-wide efforts for standardised monitoring programmes** to assess the cumulative ecological and socio-economic effects of OR expansion.
- The **harmonisation of fishing effort data** with a sufficient level of details should be perused also for southern European seas. Such data would enable researchers and managers to not only detect local impacts of new OR on fisheries.
- **Assessing the cumulative effects of many OR installations**.
- Integrated and spatially explicit assessments of cumulative effects of OR are urgently needed to inform **strategic planning and marine conservation** in order to enable a sustainable integration of human activities.
- Monitoring programmes are a prerequisite for sustainable management, the development needs to follow EU and *Common Fisheries Policy* (CFP) standards, comply with the *Environmental Quality Objectives* (EQOs), *Environmental Quality Standards* (EQSs) and build on best practice examples. A standardised monitoring programme will **improve reproducibility and collaboration** in management and research.

7.2. Fisheries benefits of OR expansions are not well understood

- We highlight the **need for future research on the fisheries benefits of OR installations**. Empirical evidence is slowly growing on the ecological benefits due to the construction of **artificial reef structures**. However, little is known on how these **ecological benefits** could manifest in fisheries benefits, such as the spill-over of fisheries resources from an OR area to its surrounding waters, the change in size and biomass, or the distribution of species, since such areas could also function as stepping stone or improve connectivity between habitats.
- A **quantification of such fisheries benefits** also requires an economic viability analysis for the respective resources. Further, after 30 years of operation the **decommissioning of OWF will start**, undoubtedly having specific impacts on the marine environment.

- MSP processes that plan for marine energy sectors should **consider the whole OR life cycle** by providing standardised methodologies that minimise environmental impacts. Decommissioning of OR needs European attention to **identify criteria on how the decommissioning process should be designed**.
- Gathering more knowledge on the actual fisheries benefits of OR installations will allow MSP to plan with fisheries by strengthening its adaptive capacities through appropriate measures.

7.3. Economic impact assessments of OR expansion need to address direct and indirect costs for the fishing sector as well as socio-cultural effects

- We suggest fostering **more research** to unfold the impacts of investments in renewable energy, especially OWF, on the fishing sector, local communities and economic activities onshore.
- The analyses of direct OR impact is complicated by the **lack of the spatial allocation of fishing rights**, the unpredictable behaviour of the fishing sector in the case of displacement (as the vessels have to move to other fishing grounds) and the unpredictable effects on the local communities (shoreside effects).
- The analysis of **cumulative effects due to multiple OWF** is further obscured by the different characteristics of the fishing fleets, fishing assemblages, target species, fishing behaviour, the characteristics of the lost fishing opportunities and the varying characteristics of the different OWF.
- However, the developed methodologies for **impact assessments accompanied by social science** research can provide the information for better regulating or mitigating spatial use conflicts between OWF and fisheries.

7.4. The regulation of co-location of human activities through MSP is still in its infancy

- As a consequence, MSP processes should put **more emphasis on the assessment of co-location options**. This should entail the development of an **EU best practice guidance on the implementation of mitigation measures** to ease conflict potential between fisheries and OR development and to promote co-operation between sectors.
- The here described best practice examples showed that mitigation measures have been developed e.g. through bottom-up processes where **compensation payments** and **mutual agreements** have been defined for individual sites.
- In contrast, top-down regulations comprised the **involvement of independent third parties** to develop common agreements. Additional mitigation measures may comprise **temporal variations in the expansion of OR areas** to prevent permanent closures of the total area of concern, the **planning for corridors** to enable the transit of fishing vessels further reduces conflict potential, the **designation of priority areas for fisheries** through MSP to stabilise the fisheries displaced from former fishing grounds, or **financial support** for the modification of vessels and/or fishing gears when fishermen got displaced and need to change their target species.
- **More "best practice" examples are needed** to understand the effectiveness of any of those mitigation measures to reduce conflict potential and to strengthen the adaptive capacities of the fisheries affected.
- In view of the Brexit and progressing climate change, **European fisheries need to strengthen their adaptive capacity** to mitigate fisheries losses. Co-operations with other sectors such as wind energy might be a start and should be supported by MSP.

REFERENCES

- Armstrong, M. P., Dean, M. J., Hoffman, W. S., Zemeckis, D. R., Nies, T. A., Pierce, D. E., Diodati, P. J. and McKiernan, D. J. (2013). *The application of small scale fishery closures to protect Atlantic cod spawning aggregations in the inshore Gulf of Maine*. Fisheries Research, 141, 62-69. https://doi.org/10.1016/j.fishres.2012.09.009.
- Benassai, G., Mariani, P., Stenberg, C. and Christoffersen, M. (2014). *A Sustainability Index of potential co-location of offshore wind farms and open water aquaculture*. Ocean & Coastal Management, 95, 213-218. https://doi.org/10.1016/j.ocecoaman.2014.04.007.
- Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Åstrand, C. N. and Wilhelmsson, D. (2014). *Effects of offshore wind farms on marine wildlife—a generalized impact assessment*. Environmental Research Letters, 9, (3), 034012.
- Bergström, L., Sundqvist, F. and Bergström, U. (2013). *Effects of an offshore wind farm on temporal and spatial patterns in the demersal fish community*. Marine Ecology Progress Series, 485, 199-210.
- Berkenhagen, J., Döring, R., Fock, H. O., Kloppmann, M. H. F., Pedersen, S. A. and Schulze, T. (2010). *Decision bias in marine spatial planning of offshore wind farms: Problems of singular versus cumulative assessments of economic impacts on fisheries*. Marine Policy, 34, (3), 733-736. https://doi.org/10.1016/j.marpol.2009.12.004.
- 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. https://doi.org/10.1016/j.ocecoaman.2004.04.002.
- Buck, B. H. and Langan, R. (2017). *Aquaculture Perspective of Multi-Use Sites in the Open Ocean: The Untapped Potential for Marine Resources in the Anthropocene*. Springer International Publishing, 404. https://doi.org/10.1007/978-3-319-51159-7.
- Cabral, R. B., Geronimo, R. C., Lim, M. T. and Aliño, P. M. (2010). *Effect of variable fishing strategy on fisheries under changing effort and pressure: An agent-based model application*. Ecological Modelling, 221, 362-369.
- Calado, H., Papaioannou, E. A., Caña-Varona, M., Onyango, V., Zaucha, J., Przedrzymirska, J., Roberts, T., Sangiuliano, S. J. and Vergílio, M. (2019). *Multi-uses in the Eastern Atlantic: Building bridges in maritime space*. Ocean & Coastal Management, 174, 131-143. https://doi.org/10.1016/j.ocecoaman.2019.03.004.
- Campbell, M. S., Stehfest, K. M., Votier, S. C. and Hall-Spencer, J. M. (2014). *Mapping fisheries for marine spatial planning: Gear-specific vessel monitoring system (VMS), marine conservation and offshore renewable energy*. Marine Policy, 45, 293-300. https://doi.org/10.1016/j.marpol.2013.09.015.
- Christie, N., Smyth, K., Barnes, R. and Elliott, M. (2014). *Co-location of activities and designations: A means of solving or creating problems in marine spatial planning?* Marine Policy, 43, 254-263. https://doi.org/10.1016/j.marpol.2013.06.002i.
- Coccoli, C., Galparsoro, I., Murillas, A., Pınarbaşı, K. and Fernandes, J. A. (2018). *Conflict analysis and reallocation opportunities in the framework of marine spatial planning: A novel, spatially explicit Bayesian belief network approach for artisanal fishing and aquaculture*. Marine Policy, 94, 119-131. https://doi.org/10.1016/j.marpol.2018.04.015.

- Cote, D., Ollerhead, L. M. N., Scruton, D. A. and McKinley, R. S. (2003). *Microhabitat use of juvenile Atlantic cod in a coastal area of Newfoundland determined by 2D telemetry*. Marine Ecology Progress Series, 265, 227-234.
- Cronin, M. A. (2011). *The conservation of seals in Irish waters: How research informs policy*. Marine Policy, 35, (6), 748-755. https://doi.org/10.1016/j.marpol.2011.01.006.
- DEA (2018). *Danish Energy Agency. Offshore Wind and Fisheries in Denmark.* https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjyulvLtLPrAhUqlYsKHUbvCO4QFjABegQIBhAB&url=https%3A%2F%2Fens.dk%2Fsites%2Fens.dk%2Ffiles%2FGlobalcooperation%2Foffshore_wind_and_fisheries_in_dk.pdf&usg=AOvVaw1IAohNwq8ddBnl7gcyww5W. Retrieved 25 August 2020, 16:00.
- Dean, M. J., Hoffman, W. S. and Armstrong, M. P. (2012). *Disruption of an Atlantic Cod Spawning Aggregation Resulting from the Opening of a Directed Gill-Net Fishery*. North American Journal of Fisheries Management, 32, (1), 124-134. https://doi.org/10.1080/02755947.2012.663457.
- Defra (2019). *Department for Environment, Food and Rural Affairs, Marine Management Organisation. South West Marine Plan Iteration 3 Engagement. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiSyZnJmrbrAhXGyqQKHRX7DxYQFjAGegQIChAB&url=https%3A%2F%2Fconsult.defra.gov.uk%2Fmmo%2Fsw-mp-iteration-3-online-engagement%2Fuser_uploads%2Fsw-co-1_clean.pdf&usg=AOvVaw3SSLyG6SsLH2c-1XgrlyOZ. Retrieved: 25 August 2020. 13:40.*
- Dowle, M. and Srinivasan, A. (2019). *Data.table: Extension of 'data.frame'*. https://cran.r-project.org/package=data.table, Retrieved: 29 August 2020. 10:15.
- European Commission (2008a). *Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the common fisheries policy. Nor 199/2008*. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:346:0037:0088:EN:PDF#page=16, Retrieved: 29 August 2020. 10:00.
- European Commission (2008b). *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)*. Official Journal of the European Union, L 164/19.
- European Commission (2012). *Progress of the EU's Integrated Maritime Policy – Report from the commission to the European Parliament, the council, the European Economic and social committee and the committee of the Regions*. Luxembourg: Publications Office of the European Union, 11 pp. 10.2771/44682.
- European Commission (2014). *Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning*. Official Journal of the European Union, L 257/135.
- European Commission (2015). *Paris Agreement. https://ec.europa.eu/clima/policies/international/negotiations/paris_en. Retrieved 5 May 2020. 10:50.*
- European Commission (2018). *2030 climate & energy framework. https://ec.europa.eu/clima/policies/strategies/2030_en. Retrieved on 5 May 2020. 11:15.*
- Ehler, C., Zaucha, J. and Gee, K. (2019). *Maritime/marine spatial planning at the interface of research and practice*. Maritime Spatial Planning. Springer, 1-21.

- Europêche (2020). *Fishermen losing grounds. http://europeche.chil.me/post/fishermen-losing-grounds-266098. Retrieved on 5 May 2020. 11:00.*
- Flocard, F., Ierodiaconou, D. and Coghlan, I. R. (2016). *Multi-criteria evaluation of wave energy projects on the south-east Australian coast*. Renewable Energy, 99, 80-94. https://doi.org/10.1016/j.renene.2016.06.036.
- Frazão Santos, C., Agardy, T., Andrade, F., Calado, H., Crowder, L. B., Ehler, C. N., García-Morales, S., Gissi, E., Halpern, B. S., Orbach, M. K., Pörtner, H.-O. and Rosa, R. (2020). *Integrating climate change in ocean planning*. Nature Sustainability, https://doi.org/10.1038/s41893-020-0513-x.
- Gimpel, A. (2015). *Evaluation of spatial management strategies in the German Bight: How to balance sustainable use and ecosystem health? Dissertation*. Hamburg: Universität, 303 pp.
- Gimpel, A., Stelzenmüller, V., Cormier, R., Floeter, J. and Temming, A. (2013). *A spatially explicit risk approach to support marine spatial planning in the German EEZ*. Marine Environmental Research, 86, 56-69. https://doi.org/10.1016/j.marenvres.2013.02.013.
- Gimpel, A., Stelzenmüller, V., Grote, B., Buck, B. H., Floeter, J., Núñez-Riboni, I., Pogoda, B. and Temming, A. (2015). *A GIS modelling framework to evaluate marine spatial planning scenarios: Co-location of offshore wind farms and aquaculture in the German EEZ*. Marine Policy, 55, https://doi.org/102-115. 10.1016/j.marpol.2015.01.012.
- Gimpel, A., Stelzenmüller, V., Topsch, S., Galparsoro, I., Gubbins, M., Miller, D., Murillas, A., Murray, A. G., Pinarbasi, K., Roca, G. and Watret, R. (2018). *A GIS-based tool for an integrated assessment of spatial planning trade-offs with aquaculture*. Sci Total Environ, 627, 1644-1655. https://doi.org/10.1016/j.scitotenv.2018.01.133.
- Gregory, R. S. and Anderson, J. T. (1997). *Substrate selection and use of protective cover by juvenile Atlantic cod Gadus morhua in inshore waters of Newfoundland*. Marine Ecology Progress Series, 146, 9-20.
- Gusatu, Yamu, Zuidema and Faaij. (2020). *A Spatial Analysis of the Potentials for Offshore Wind Farm Locations in the North Sea Region: Challenges and Opportunities*. ISPRS International Journal of Geo-Information, 9, (2), https://doi.org/10.3390/ijgi9020096.
- GWEC (2019). *Global Wind Energy Council. Global wind report 2018. https://gwec.net/wp-content/uploads/2019/04/GWEC-Global-Wind-Report-2018.pdf. Retrieved: 8 July 8 2020, 13:25.*
- Halpern, B. S., Frazier, M., Afflerbach, J. and al., e. (2019). *Recent pace of change in human impact on the world's ocean*. Sci Rep, 9, https://doi.org/10.1038/s41598-019-47201-9.
- Hattam, C., Hooper, T. and Papathanasopoulou, E. (2015). *Understanding the Impacts of Offshore Wind Farms on Well-Being*. The Crown Estate, 77 pp., ISBN: 978-1-906410- 65-0.
- Henriksson, P. J. G., Banks, L. K., Suri, S. K., Pratiwi, T. Y., Fatan, N. A. and Troell, M. (2019). *Indonesian aquaculture futures—identifying interventions for reducing environmental impacts*. Environmental Research Letters, 14, (12), https://doi.org/10.1088/1748-9326/ab4b79.
- Hinz, H., Murray, L. G., Lambert, G. I., Hiddink, J. G. and Kaiser, M. J. (2013). *Confidentiality over fishing effort data threatens science and management progress*. Fish Fisher, 14, 110-117.
- Hoagland, P., Dalton, T. M., Jin, D. and Dwyer, J. B. (2015). *An approach for analyzing the spatial welfare and distributional effects of ocean wind power siting: The Rhode Island/Massachusetts area of mutual interest*. Marine Policy, 58, 51-59. https://doi.org/10.1016/j.marpol.2015.04.010.

- Hooper, T., Ashley, M. and Austen, M. (2015). *Perceptions of fishers and developers on the co-location of offshore wind farms and decapods fisheries in the UK*. Marine Policy, 61, 16-22.
- Hooper, T., Beaumont, N. and Hattam, C. (2017). *The implications of energy systems for ecosystem services: A detailed case study of offshore wind*. Renewable and Sustainable Energy Reviews, 70, 230-241. https://doi.org/10.1016/j.rser.2016.11.248.
- Janßen, H., Augustin, C. B., Hinrichsen, H. H. and Kube, S. (2013). *Impact of secondary hard substrate on the distribution and abundance of Aurelia aurita in the western Baltic Sea*. Mar Pollut Bull, 75, (1-2), 224-234. https://doi.org/10.1016/j.marpolbul.2013.07.027.
- Jennings, S. and Kaiser, M. J. (1998). *The effects of fishing on marine ecosystems*. Adv Mar Biol, 34, 201-352.
- Jentoft, S. and Knol, M. (2014). *Marine spatial planning: risk or opportunity for fisheries in the North Sea?* Maritime Studies, 12, (1), https://doi.org/10.1186/2212-9790-12-13.
- Jongbloed, R. H., van der Wal, J. T. and Lindeboom, H. J. (2014). *Identifying space for offshore wind energy in the North Sea. Consequences of scenario calculations for interactions with other marine uses*. Energy Policy, 68, 320-333. https://doi.org/10.1016/j.enpol.2014.01.042.
- Kaiser, M. J., Hilborn, R., Jennings, S., Amaroso, R., Andersen, M., Balliet, K., Barratt, E., Bergstad, O. A., Bishop, S., Bostrom, J. L., Boyd, C., Bruce, E. A., Burden, M., Carey, C., Clermont, J., Collie, J. S., Delahunty, A., Dixon, J., Eayrs, S., Edwards, N., Fujita, R., Gauvin, J., Gleason, M., Harris, B., He, P., Hiddink, J. G., Hughes, K. M., Inostroza, M., Kenny, A., Kritzer, J., Kuntzsch, V., Lasta, M., Lopez, I., Loveridge, C., Lynch, D., Masters, J., Mazor, T., McConnaughey, R. A., Moenne, F. M., Nimick, A. M., Olsen, A., Parker, D., Parma, A. M., Penney, C., Pierce, D., Pitcher, R., Pol, M., Richardson, E., Rijnsdorp, A. D., Rilatt, S., Rodmell, D. P., Rose, C., Sethi, S. A., Short, K., Suuronen, P., Taylor, E., Wallace, S., Webb, L., Wickham, E., Wilding, S. R., Wilson, A., Winger, P. and Sutherland, W. J. (2016). *Prioritization of knowledge-needs to achieve best practices for bottom trawling in relation to seabed habitats*. Fish Fisher, 17.
- Kaiser, M. J., Yu, Y. and Snyder, B. (2010). *Economic feasibility of using offshore oil and gas structures in the Gulf of Mexico for platform-based aquaculture*. Marine Policy, 34, (3), 699-707. https://doi.org/10.1016/j.marpol.2010.01.002.
- Kamermans, P., Walles, B., Kraan, M., van Duren, L., Kleissen, F., van der Have, T., Smaal, A. and Poelman, M. (2018). *Offshore Wind Farms as Potential Locations for Flat Oyster (Ostrea edulis) Restoration in the Dutch North Sea*. Sustainability, 10, (11), https://doi.org/10.3390/su10113942.
- Katağan, T., Tokaç, A., Beşiktepe, Ş. and Öztürk, B. (2015). *The Aegean Sea Marine Biodiversity, Fisheries, Conservation and Governance*. Turkish Marine Research Foundation (TUDAV), Publication No: 41, Istanbul, TURKEY.
- Kenny, A. J., Jenkins, C., Wood, D., Bolam, S. G., Mitchell, P., Scougal, C., Judd, A. and Degraer, S. (2018). *Assessing cumulative human activities, pressures, and impacts on North Sea benthic habitats using a biological traits approach*. ICES Journal of Marine Science, 75, (3), https://doi.org/1080-1092. 10.1093/icesjms/fsx205.
- Kyvelou, S. S. and Ierapetritis, D. (2019). *Discussing and Analyzing "Maritime Cohesion" in MSP, to Achieve Sustainability in the Marine Realm*. Sustainability, 11, (12), https://doi.org/10.3390/su11123444.

- Leonhard, S. B., Stenberg, C., Støttrup, J., Deurs, M. V., Christensen, A. and Pedersen, J. (2013). *Fish benefits from offshore wind farm development*. In Danish offshore wind - key environmental issues – a follow-up. Danish Energy Agency. Copenhagen., 31-45.
- Lindeboom, H., Degraer, S., Dannheim, J., Gill, A. B. and Wilhelmsson, D. (2015). *Offshore wind park monitoring programmes, lessons learned and recommendations for the future*. Hydrobiologia, 756, (1), 169-180. https://doi.org/10.1007/s10750-015-2267-4.
- Lindholm, J. and Auster, P. (2003). *Site Utilization by Atlantic Cod (Gadus morhua) in Off-Shore Gravel Habitat as Determined by Acoustic Telemetry: Implications for the Design of Marine Protected Areas*. Marine Technology Society Journal, 37, (1), 27-34. https://doi.org/10.4031/002533203787537401.
- Little, L. R., Punt, A. E., Mapstone, B. D., Begg, G. A., Goldman, B. and A.J., W. (2009). *An agent-based model for simulating trading of multi-species fisheries quota*. Ecological Modelling, 220, 3404-3412.
- Lough, R., Valentine, P., Potter, D., Auditore, P., Bolz, G., Neilson, J. and Perry, R. (1989). *Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank*. Marine Ecology Progress Series, 56, 1-12.
- Malvarosa, L., Murillas, A., Lehuta, S., Nielsen, J., Macher, C., Goti, L., Motova, A., Döring, R., Haraldson, G., Accadia, P. R., Hamon, K. G., Bastardie, F., Maravelias, C. D., Mardle, S. and Thogersen, T. (2019). *Sustainability Impact Assessment (SIA) in fisheries: Implementation in EU fishing regions*. Marine Policy, 101, 63-79.
- Methratta, E. T. and Secor, D. (2020). *Monitoring fisheries resources at offshore wind farms: BACI vs. BAG designs*. ICES Journal of Marine Science, https://doi.org/10.1093/icesjms/fsaa026.
- Morgan, M. J., DeBlois, E. M. and Rose, G. A. (1997). *An observation on the reaction of Atlantic cod (Gadus morhua) in a spawning shoal to bottom trawling*. Canadian Journal of Fisheries and Aquatic Sciences, 54, (S1), 217-223. https://doi.org/10.1139/f96-151.
- Munoz, M., Reul, A., Gil de Sola, L., Lauerburg, R. A. M., Tello, O., Gimpel, A. and Stelzenmuller, V. (2018). *A spatial risk approach towards integrated marine spatial planning: A case study on European hake nursery areas in the North Alboran Sea*. Mar Environ Res, 142, https://doi.org/190-207. 10.1016/j.marenvres.2018.10.008.
- Nielsen, J. R., E. Thunberg, D. S. Holland, J. O. Schmidt, E. A. Fulton, F. Bastardie, A. E. Punt, I. Allen, H. Bartelings, M. Bertignac, E. Bethke, S. Bossier, R. Buckworth, G. Carpenter, A. Christensen, V. Christensen, J. M. Da-Rocha, R. Deng, C. Dichmont, R. Doering, A. Esteban, J. A. Fernandes, H. Frost, D. Garcia, L. Gasche, D. Gascuel, S. Gourguet, R. A. Groeneveld, J. Guillén, O. Guyader, K. G. Hamon, A. Hoff, J. Horbowy, T. Hutton, S. Lehuta, L. R. Little, J. Lleonart, C. Macher, S. Mackinson, S. Mahevas, P. Marchal, R. Mato-Amboage, B. Mapstone, F. Maynou, M. Merzéréaud, A. Palacz, S. Pascoe, A. Paulrud, E. Plaganyi, R. Prellezo, E. I. van Putten, M. Quaas, L. Ravn-Jonsen, S. Sanchez, S. Simons, O. Thébaud, M. T. Tomczak, C. Ulrich, D. van Dijk, Y. Vermard, R. Voss and Waldo, R. (2018). *Integrated ecological-economic fisheries models –Evaluation, review and challenges for implementation*. Fish and Fisheries, 19, 1-29.
- Nielsen, J. R., Thunberg, E., Holland, D. S., Schmidt, J. O., Fulton, E. A., Bastardie, F., Punt, A. E., Allen, J. I., Bartelings, H., Bertignac, M., Bethke, E., Bossier, S., Buckworth, R., Carpenter, G., Christensen, A., Christensen, V., Da-Rocha, J. M., Deng, R., Döring, R., Simons, S. L. and al., e. (2017). *Integrated ecological-economic fisheries models – Evaluation, review and challenges for implementation*. Fish & Fisheries, 19, 1-29.

- Noble, M. M., Harasti, D., Pittock, J. and Doran, B. (2019). *Understanding the spatial diversity of social uses, dynamics, and conflicts in marine spatial planning*. Journal of Environmental Management, 246, 929-940. https://doi.org/10.1016/j.jenvman.2019.06.048.
- Pascual, M., Borja, A., Galparsoro, I., Ruiz, J., Mugerza, E., Quincoces, I., Murillas, A. and Arregi, L. (2013). *Total fishing pressure produced by artisanal fisheries, from a Marine Spatial Planning perspective: A case study from the Basque Country (Bay of Biscay)*. Fisheries Research, 147, (0), 240-252. http://dx.doi.org/10.1016/j.fishres.2013.06.010.
- Pebesma, E. (2018). *Simple Features for R: Standardized Support for Spatial Vector Data*. The R Journal, 10, (1), 439. https://doi.org/10.32614/RJ-2018-009.
- Pezy, J.-P., Raoux, A., Dauvin, J.-C. and Degraer, S. (2018). *An ecosystem approach for studying the impact of offshore wind farms: a French case study*. ICES Journal of Marine Science, https://doi.org/10.1093/icesjms/fsy125.
- Pınarbaşı, K., Galparsoro, I., Borja, Á., Stelzenmüller, V., Ehler, C. and Gimpel, A. (2017). *Decision Support Tools in Marine Spatial Planning: Present Applications, Gaps and Future Perspectives*. Marine Policy, 83, 83-91. https://doi.org/10.1016/j.marpol.2017.05.031.
- Plummer, M. L. and Feist, B. E. (2016). *Capturing Energy from the Motion of the Ocean in a Crowded Sea*. Coastal Management, 44, (5), 464-485. https://doi.org/10.1080/08920753.2016.1208877.
- Pomeroy, C., Hall-Arber, M. and Conway, F. (2015). *Power and perspective: Fisheries and the ocean commons beset by demands of development*. Marine Policy, 61, 339-346. https://doi.org/10.1016/j.marpol.2014.11.016.
- R Core Team (2019). *R: A language and environment for statistical computing. R Foundation for Statistical Computing'. Vienna, Austria*. https://www.r-project.org/, Retrieved: 27 August 2020. 11:00.
- Ramos, J., Soma, K., Bergh, O., Schulze, T., Gimpel, A., Stelzenmuller, V., Makinen, T., Fabi, G., Grati, F. and Gault, J. (2014). *Multiple interests across European coastal waters: the importance of a common language*. ICES Journal of Marine Science, 72, (2), 720-731. https://doi.org/10.1093/icesjms/fsu095.
- Raoux, A., Tecchio, S., Pezy, J.-P., Lassalle, G., Degraer, S., Wilhelmsson, D., Cachera, M., Ernande, B., Le Guen, C., Haraldsson, M., Grangeré, K., Le Loc'h, F., Dauvin, J.-C. and Niquil, N. (2017). *Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning?* Ecological Indicators, 72, 33-46. https://doi.org/10.1016/j.ecolind.2016.07.037.
- Reubens, J. T., Braeckman, U., Vanaverbeke, J., Van Colen, C., Degraer, S. and Vincx, M. (2013). *Aggregation at windmill artificial reefs: CPUE of Atlantic cod (Gadus morhua) and pouting (Trisopterus luscus) at different habitats in the Belgian part of the North Sea*. Fisheries Research, 139, 28-34. https://doi.org/10.1016/j.fishres.2012.10.011.
- Roberts, C. M., Bohnsack, J. A., Gell, F., Hawkins, J. P. and Goodridge, R. (2001). *Effects of marine reserves on adjacent fisheries*. Science of the Total Environment, 294, 1920–1923.
- Russ, G. R. and Alcala, A. C. (1996). *Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines*. Marine Ecology Progress Series, 132, 1–9.
- Russo, T., Bitetto, I., Carbonara, P., Carlucci, R., D'Andrea, L., Facchini, M. T., Lembo, G., Maiorano, P., Sion, L., Spedicato, M. T., Tursi, A. and Cataudella, S. (2017). *A Holistic Approach to Fishery Management: Evidence and Insights from a Central Mediterranean Case Study (Western Ionian Sea)*. Frontiers in Marine Science, 4, (193), https://doi.org/10.3389/fmars.2017.00193.

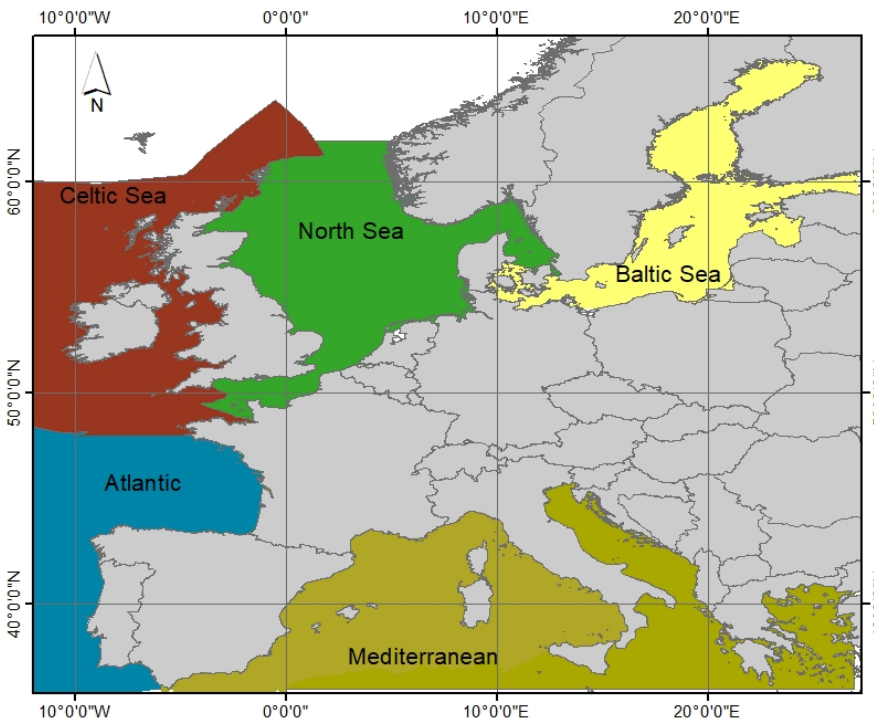
- Schultz-Zehden, A., Ivana Lukic, Joseph Onwona Ansong, Susanne Altvater, Rebecca Bamlett, Andrea Barbanti, Martina Bocci, Bela H. Buck, Helena Calado, Mario Caña Varona, Chiara Castellani, Daniel Depellegrin, Maximilian Felix Schupp, Ioannis Giannelos, Andronikos Kafas, Aneta Kovacheva, Gesche Krause, Zacharoula Kyriazi, Rianne Läkamp, Marija Lazić, Athena Mourmouris, Vincent Onyango, Eva Papaioannou, Joanna Przedrzymirska, Emiliano Ramieri, Stephen Sangiuliano, Ilse van de Velde, V., Vassilopoulou, Chiara Venier, Marta Vergílio, Jacek Zaucha and Buchanan, B. (2018). *Ocean Multi-Use Action Plan, MUSES project. Edinburgh.*
- Schupp, M. F., Bocci, M., Depellegrin, D., Kafas, A., Kyriazi, Z., Lukic, I., Schultz-Zehden, A., Krause, G., Onyango, V. and Buck, B. H. (2019). *Toward a Common Understanding of Ocean Multi-Use*. Frontiers in Marine Science, 6, https://doi.org/10.3389/fmars.2019.00165.
- Shumchenia, E. J., Smith, S. L., McCann, J., Carnevale, M., Fugate, G., Kenney, R. D., King, J. W., Paton, P., Schwartz, M., Spaulding, M. and Winiarski, K. J. (2012). *An adaptive framework for selecting environmental monitoring protocols to support ocean renewable energy development*. ScientificWorldJournal, 2012, 450685. https://doi.org/10.1100/2012/450685.
- Simons, S. L., Döring, R. and Temming, A. (2014). *Modelling the spatio-temporal interplay between North Sea saithe (Pollachius virens) and multiple fleet segments for management evaluation*. Aquatic Liv Res, 27, (1), 1-16.
- STECF (2018). *Scientific, Technical and Economic Committee for Fisheries. The 2018 Annual Economic Report on the EU Fishing Fleet (STECF-18-07). Publications Office of the European Union, Luxembourg*. JRC112940, https://doi.org/10.2760/56158.
- Stelzenmüller, V., Diekmann, R., Bastardie, F., Schulze, T., Berkenhagen, J., Kloppmann, M., Krause, G., Pogoda, B., Buck, B. H. and Kraus, G. (2016). *Co-location of passive gear fisheries in offshore wind farms in the German EEZ of the North Sea: A first socio-economic scoping.* Journal of Environmental Management, 183, 794-805.
- Stelzenmüller, V., Gimpel, A., Haslob, H., Letschert, J., Berkenhagen, J. and Brüning, S. (in prep.). *Fisheries can benefit from offshore windfarms- lessons learned for marine spatial planning*.
- Stelzenmüller, V., Rogers, S. I. and Mills, C. M. (2008). *Spatio-temporal patterns of fishing pressure on UK marine landscapes, and their implications for spatial planning and management*. Ices Journal of Marine Science, 65, 1081-1091.
- Stelzenmüller, V., Schulze, T., Fock, H. O. and Berkenhagen, J. (2011). *Integrated modelling tools to support risk-based decision-making in marine spatial management*. Marine Ecology Progress Series, 441, 197-212. https://doi.org/10.3354/meps09354.
- Stelzenmüller, V., Schulze, T., Gimpel, A., Bartelings, H., Bello, E., Bergh, O., Bolman, B., Caetano, M., Davaasuren, N., Fabi, G., Ferreira, J. G., Gault, J., Gramolini, R., Grati, F., Hamon, K., Jak, R., Kopke, K., Laurans, M., Mäkinen, T., O'Donnell, V., O'Hagan, A. M., O'Mahony, C., Oostenbrugge, H., Ramos, J., Saurel, C., Sell, A., Silvo, K., Sinschek, K., Soma, K., Stenberg, C., Taylor, N., Vale, C., Vasquez, F. and Verner-Jeffreys, D. (2013). *Guidance on a Better Integration of Aquaculture, Fisheries, and other Activities in the Coastal Zone: From tools to practical examples*. COEXIST project, 79pp..
- Stenberg, C., Støttrup, J. G., van Deurs, M., Berg, C. W., Dinesen, G. E., Mosegaard, H., Grome, T. M. and Leonhard, S. B. (2015). *Long-term effects of an offshore wind farm in the North Sea on fish communities*. Marine Ecology Progress Series, 528, 257-265. https://doi.org/10.3354/meps11261.
- UNEP (2013). *United Nations Environment Programme. UNEP-MAP-RAC/SPA. Fisheries in the Gulf of Lions. By Farrugio, H.Ed. RAC/SPA, Tunis*. 79pp.

- van der Reijden, K. J., Hintzen, N. T., Govers, L. L., Rijnsdorp, A. D. and Olff, H. (2018). *North Sea demersal fisheries prefer specific benthic habitats*. PLoS One, 13, ((12): e0208338. https://doi.org/10.1371/journal.pone.0208338).
- White, C., Halpern, B. S. and Kappel, C. V. (2012). *Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses*. PNAS, 109, (12), 4696–4701.
- Whitton, T. A., Jackson, S. E., Hiddink, J. G., Scoulding, B., Bowers, D., Powell, B., D'Urban Jackson, T., Gimenez, L., Davies, A. G. and Heino, J. (2020). *Vertical migrations of fish schools determine overlap with a mobile tidal stream marine renewable energy device*. Journal of Applied Ecology, 57, (4), 729-741. https://doi.org/10.1111/1365-2664.13582.
- Wieland, K., Pedersen, E. M. F., Olesen, H. J. and Beyer, J. E. (2009). *Effect of bottom type on catch rates of North Sea cod (Gadus morhua) in surveys with commercial fishing vessels*. Fisheries Research, 96, (2), 244-251. https://doi.org/10.1016/j.fishres.2008.11.010.
- Wijermans, N., Boonstra, W. J., Orach, K., Hentati-Sundberg, J. and Schlüter, M. (2020). *Behavioural diversity in fishing—Towards a next generation of fishery models*. Fish and Fisheries, https://doi.org/10.1111/faf.12466.
- Yates, K. L., Schoeman, D. S. and Klein, C. J. (2015). *Ocean zoning for conservation, fisheries and marine renewable energy: assessing trade-offs and co-location opportunities*. J Environ Manage, 152, 201-9. https://doi.org/10.1016/j.jenvman.2015.01.045.
- Zhang, Y., Zhang, C., Chang, Y.-C., Liu, W.-H. and Zhang, Y. (2017). *Offshore wind farm in marine spatial planning and the stakeholders engagement: Opportunities and challenges for Taiwan*. Ocean & Coastal Management, 149, 69-80. https://doi.org/10.1016/j.ocecoaman.2017.09.014.

ANNEX 1 – EUROPEAN SEAS WITH META DATA USED

For this study we distinguished six European seas consisting of the Black Sea, Baltic Sea, North Sea, Celtic Sea, Atlantic and Mediterranean. As a starting point, we used the boundaries of the marine sub regions[55], defined for the MSFD[56] assessments. We merged the western and central Mediterranean, Ionian and Aegean Sea as well as the Adriatic Sea to one category representing the Mediterranean. The Bay of Biscay and the Iberian coast are categorised as Atlantic. Further our definition of the greater North Sea comprised the Kattegat and English Channel. The final regions used to summarise the conflict analysis are shown in the map below. Please note that the conflict analysis revealed no results for the Black Sea, which is therefore not shown.

Map 2: European seas considered in this study, consisting of the Baltic Sea, North Sea, Celtic Sea, Atlantic and Mediterranean



Source: Author based on data provided by the European Environment Agency (EEA)

Note: The western and central Mediterranean, Ionian and Aegean Sea as well as the Adriatic Sea were merged to one category representing the Mediterranean. The Bay of Biscay and the Iberian coast are categorised as Atlantic. The definition of the greater North Sea comprised the Kattegat and English Channel. The conflict analysis revealed no results for the Black Sea which is therefore not shown

55 www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions-1

56 https://eur-lex.europa.eu/eli/dir/2008/56/oj

Table 3: Meta data of the spatially explicit data used in this study

Category	Source	Data set	Spatial resolution	Temporal resolution	Effective	Portal & Title (data set name)	Access rights	Units of measure	Grouping variable
Regions	European Environment Agency	MSFD-Regions[57]	NA	NA	2016	European seas	free	Maritime boundary (country borders)	NA
Fisheries European-wide	Global Fishing Watch	Fishing effort at 100th degree[58]	0.01 * 0.01 degree	Daily	2012 - 2018 (last 2 years preliminary)	NA	free (2012 - 2016)	Fishing effort [h], vessel hours, number of vessels	Gear groups, flag state Gear groups, flag state, MMSI number (ship ID)
Fisheries OSPAR region	OSPAR	Ospar_bottom_f_*[59]	0.05 * 0.05 degree	Yearly	2009 - 2017	ODIM | ICES	free	Fishing effort [h], fishing effort [kw h], value [€], catch weight [kg], surface swept area [km^2], surface swept area ratio, sub-surface swept area [km^2], sub-surface swept area ratio	Metier groups [gear, target species assemblage
Fisheries HELCOM region	HELCOM	HELCOM fishing effort[60]	0.05 * 0.05 degree	Yearly	2009 - 2016	NA	free	Fishing effort [h], fishing effort [kw h], value [€], catch weight [kg], surface swept area [km^2], surface swept area ratio, sub-surface swept area [km^2], sub-surface swept area ratio	Metier groups [gear, target species assemblage
Aquaculture	EMODnet (European Marine Observation and Data Network)	Existing farms Shellfish[61]	Polygon	NA	2015	Human Activities: Shellfish production areas	free	Country, name, status, start, end date etc.	NA

57 https://www.eea.europa.eu/data-and-maps/data/europe-seas
58 https://globalfishingwatch.org/datasets-and-code/
59 http://www.ices.dk/sites/pub/Publication%20Reports/Forms/DispForm.aspx?ID=35169
60 http://www.ices.dk/sites/pub/Publication%20Reports/Forms/DispForm.aspx?ID=35243
61 http://emodnet-humanactivities.eu/search-results.php?dataname=Shellfish+Production

Category	Source	Data set	Spatial resolution	Temporal resolution	Effective	Portal & Title (data set name)	Access rights	Units of measure	Grouping variable
Aquaculture	EMODnet (European Marine Observation and Data Network)	Existing farms Finfish[62]	Polygon	NA	2016	Human Activities: Finfish farming sites	free	Country, name, status, start, end date etc.	NA
Renewables	4C Offshore Ltd.	Offshore Wind Farm Boundaries[63]	Polygon	yearly, updated monthly	2020	Research & Intelligence: GIS Offshore Wind Farm Boundaries Data	licensed	amount, sea coverage (km²), size of turbines (m), capacity (GW), water depth (m), distance to shore (km)	NA
Renewables	EMODnet (European Marine Observation and Data Network)	Wave energy[64]	Point data	NA	2016	Human Activities: Ocean Energy Projects	free	Country, name, status, start, end date etc.	NA
Renewables	EMODnet (European Marine Observation and Data Network)	Tidal energy[65]	Point data	NA	2016	Human Activities: Ocean Energy Projects	free	Country, name, status, start, end date etc.	NA

Source: Author

62 http://emodnet-humanactivities.eu/search-results.php?dataname=Finfish+Production
63 https://www.4coffshore.com/offshorewind/
64 http://emodnet-humanactivities.eu/search-results.php?dataname=Project+Locations
65 http://emodnet-humanactivities.eu/search-results.php?dataname=Project+Locations

ANNEX 2 – CHOOSING BETWEEN VMS AND AIS DATA IN A EUROPEAN CONTEXT

An important decision prior to identifying interactions between fisheries and current and future marine OR is to choose between VMS or AIS data to analyse fleet movements and patch-choice detection. Note that the positional accuracy of VMS and AIS are similar (Russo *et al.* 2016). Importantly, neither system is perfect since 36% of the European vessels belong to 'hidden' length classes, meaning they have an overall length < 12 metres and therefore are not mandatorily equipped with AIS or VMS tracking devices (Russo *et al.* 2019). This leads to large regional differences in data coverage, depending on the composition of the fleet, as illustrated for Spanish (0% coverage), Italian (3.2% coverage), and Croatian (80% coverage) fleets trawling the Mediterranean (Russo *et al.* 2019).

VMS data (so-called 'pings') are generally collected every 2 hrs from fishing vessels and include vessel ID, date, time, geographical position, speed, and bearing. These data, preferably in combination with logbook data on landings (Hintzen *et al.* 2012), allow determining fishing impacts of vessels > 15 metres (e.g. Pitcher *et al.* 2017), but also the behaviour of the fishers (e.g. Jennings and Lee 2012; van der Reijden *et al.* 2018), which then can be used to predict the outcome of different management scenarios. For example, displacement of fishing effort after an area closure (Dinmore *et al.* 2003). The resolution of the data should be approximately 1 nautical mile, since fisheries occur patchy at larger scales (Rijnsdorp *et al.* 1998). Coarser data potentially result in critical artefacts in fisheries assessments (Amoroso *et al.* 2018). Yet, due to confidentiality regulations, data are only freely available at a much coarser resolution (Hinz *et al.* 2013; Shepperson *et al.* 2018), the so-called ICES-rectangles (https://stecf.jrc.ec.europa.eu for the latest data). These data have a resolution of 30 minutes latitude by 1 degree longitude (approx. 30 x 30 nautical miles), where expected interactions occur at a scale of a few 100 metres. Other freely available data, such as provided by OSPAR, have a 0.050 x 0.050 nautical miles grid (approx. 15 km^2 at 60°N latitude), but these are limited in geographical coverage. Additionally, 2 hrs ping-intervals also lead to large differences between real and estimated fishing tracks, which stresses the need for high-resolution data (Hinzen *et al.* 2010; Katara and Silva 2017). 30 minutes intervals between polling would be ideal to achieve precise estimates of fishing activities, while economizing costs and handling-times (Lambert *et al.* 2012).

Based on VMS data from the German EEZ, we used logbook information to select all fishing vessels active in the EEZ. We deleted duplicates of vessel reference numbers and time stamps and identified points within a 3 kilometres radius of harbours using the *pointInHarbour*[66] function of the VMS tools package (Hintzen *et al.*, 2012) for the R programming language. Then, we removed all harbour points except the first and last of each period of consecutive harbour pings per vessel. Following a method proposed by Kroodsma *et al*. (2018), we calculated time steps and geographical distances for pings of each vessel by summing up half of the times and distances from the previous to the current, and current to the next ping, respectively. Based on the resulting distances and time steps, we calculated the speed in knots (nautical miles per hour) for each ping and removed those above 25 knots, representing unrealistic speeds and thus erroneous information. We then extracted fishing metier information from the logbooks with VMS pings on a yearly basis. We split the VMS data into groups with regard to gear and year and used the *activityTacsat*[67] function of the VMS tool package (Hinzen *et al.* 2012) to classify pings into steaming, hauling, and fishing. We removed all steaming and hauling pings, so that the time step values of the remaining pings represented fishing effort.

[66] This function allows to search for points that are in or near a harbour, which consequently should be excluded from further analysis since these do not reflect a fishing event.
[67] This function allows to define what activity vessels are doing based on their speed. Activity is separated in steaming, hauling and fishing.

AIS data transmissions can be as frequent as a few seconds, allowing fine-scale assessments of fleet movements and patch-choice (de Souza *et al.* 2016; Vespe *et al.* 2016; Taconet *et al.* 2019). Contrary to VMS data, global AIS point-data can be freely obtained from GFW (Taconet *et al.* 2019). But, caveats exist as reviewed by Taconet and colleagues (2019), such as lack of satellite coverage, not all vessels carrying AIS transponders, transponders and data can be altered or switched-off, multi-gear vessels cannot be identified or differentiate between their fishing activities (de Souza *et al.* 2016; Le Guyader *et al.* 2017; Kroodsma *et al.* 2018; Shepperson *et al.* 2018). This results in, for example, underestimating the offshore fishing activities (Russo *et al.* 2016; Taconet *et al.* 2019). A direct comparison of concurrent AIS and VMS scallop fishing data in the southern UK revealed that AIS data only captured 26% of the time spent fishing compared to VMS data (Shepperson *et al.* 2018). Moreover, contrary to VMS data (Lee *et al.* 2010; Hintzen *et al.* 2012), for AIS data there is no standardised workflow. In practice this means that AIS requires more data handling, wrangling, even machine-learning methods to define fishing activities, although some of this can be achieved using the R-package VMS tools (Hintzen *et al.* 2012).

For the current analysis we split the available fishing effort data in three to be able to match an OR installation to the most detailed data. GFW data are used for the Black Sea. Mediterranean Sea and the southern Eastern Atlantic. OSPAR/HELCOM data were used for the North Sea and Baltic Sea. For the German EEZ we used high resolution VMS pings. This allowed us to create a first inventory of the impact of OR on the European fishing sector. All results should be assessed mindful accounting for the caveats of available fishing data.

References

- Amoroso, R.O., Parma, A.M., Pitcher, C.R., McConnaughey, R.A. and Jennings, S. (2018), *Comment on "Tracking the global footprint of fisheries"*, Science, 361, 6713 pp.
- de Souza, E.N., Boerder, K., Matwin, S. and Worm, B. (2016), *Improving fishing pattern detection from satellite AIS using data mining and machine learning*, PLoS ONE, 11, e0158248. https://doi.org/10.1371/journal.pone.0158248.
- Dinmore, T.A., Duplisea, D.E., Rackham, B.D., Maxwell, D.L. and Jennings, S. (2003), *Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities*, ICES J Mar Sci, 60, 371-380.
- Hinz, H., Murray, L.G., Lambert, G.I., Hiddink, J.G. and Kaiser, M.J. (2013), *Confidentiality over fishing effort data threatens science and management progress*, Fish Fisher, 14, 110-117.
- Hintzen, N.T., Bastardie, F., Beare, D., Piet, G.J., Ulrich, C., Deporte, N., Egekvist, J. and Degel, H. (2012), *VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data*, Fisher Res, 115-116, 31-43.
- Jennings, S. and Lee, J. (2012), *Defining fishing grounds with vessel monitoring system data*, ICES J Mar Sci, 69, 51-63.
- Katara, I. and Silva, A. (2017), *Mismatch between VMS data temporal resolution and fishing activity time scales*, Fish Res, 188, 1-5.
- Kroodsma, D.A., Mayorga, J., Hochberg, T., Miller, N.A., Boerder, K., Ferretti, F., Wilson, A., Bergman, B., White, T.D., Block, B.A., Woods, P., Sullivan, B., Costello, C. and Worm, B. (2018), *Tracking the global footprint of fisheries*, Science, 359, 904-908.

- Lambert, G.I., Jennings, S., Hiddink, J.G., Hintzen, N.T., Hinz, H., Kaiser, M.J. and Murray, L.G. (2012), *Implications of using alternative methods of vessel monitoring system (VMS) data analysis to describe fishing activities and impacts*, ICES J Mar Sci, 69, 682-693.
- Lee, J., South, A.B. and Jennings, S. (2010), *Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data*, ICES J Mar Sci, 67, 1260-1271.
- Le Guyader, D., Ray, C., Gourmelon, F. and Brosset, D. (2017), *Defining high-resolution dredge fishing grounds with Automatic Identification System (AIS) data*, Aqua Liv Res, 30, 39 pp.
- Pitcher, C.R., Ellis, N., Jennings, S., Hiddink, J.G., Mazor, T., Kaiser, M.J., Kangas, M.I., McConnaughey, R.A., Parma, A.M., Rijnsdorp, A.D., Suuronen, P., Collie, J.S., Amoroso, R., Hughes, K.M. and Hilborn, R. (2017), *Estimating the sustainability of towed fishing-gear impacts on seabed habitats: a simple quantitative risk assessment method applicable to data-limited fisheries*, Methods Ecol Evol, 8, 472-480.
- Rijnsdorp, A.D., Buys, A.M., Storbeck, F. and Visser, E.G. (1998), *Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms*, ICES J Mar Sci, 55, 403-419.
- Russo, T., D'Andrea, L., Parisi, A., Martinelli, M., Belardinelli, A., Boccoli, F., Cignini, I., Tordoni, M. and Cataudella, S. (2016), *Assessing the fishing footprint using data integrated from different tracking devices: Issues and opportunities*, Ecol Ind, 69, 818-827.
- Russo, T., Franceschini, S., D'Andrea, L., Scardi, M., Parisi, A. and Cataudella, S. (2019), *Predicting fishing footprint of trawlers from environmental and fleet data: An application of artificial neural networks*, Front Mar Sci, 6, https://doi.org/10.3389/fmars.2019.00670.
- Shepperson, J.L., Hintzen, N.T, Szostek, C.L., Bell, E., Murray, L.G. and Kaiser, M.J. (2018), *A comparison of VMS and AIS data: the effect of data coverage and vessel position recording frequency on estimates of fishing footprints*, ICES J Mar Sci, 75, 988-998.
- Taconet, T., Kroodsma, D.A. and Fernandes, J.A. (2019), *Global Atlas of AIS-based fishing activity - Challenges and opportunities*, Rome, FAO. (also available at www.fao.org/3/ca7012en/ca7012en.pdf).
- van der Reijden, K.J., Hintzen, N.T., Govers, L.L., Rijnsdorp, A.D. and Olff, H. (2018), *North Sea demersal fisheries prefer specific benthic habitats*, PLoS ONE, 13, https://doi.org/10.1371/journal.pone.0208338.
- Vespe, M., Gibin, M., Alessandrini, A., Natale, F., Mazzarella, F. and Osio, G.C. (2016), *Mapping EU fishing activities using ship tracking data*, J Maps, 12, 520-525.

ANNEX 3 – OVERVIEW OF OFFSHORE RENEWABLE INSTALLATIONS

Table 4: The 314 offshore renewable installations within European seas regarded in this study

Plot	Country	Name	Status	Start	End	OR	Source	Scenario
Wave (1)	IE	Atlantic Marine Energy Test Site (AMETS) - test area A	In development	2014	NA	Wave	EMODnet	Current
Wind (2)	IE	AFLOWT (Accelerating market uptake of Floating Offshore Wind Technology)	Concept/Early Planning	2023	NA	Wind	4C Offshore	~ 2025
Wave (3)	IE	Atlantic Marine Energy Test Site (AMETS) - test area B	In development	2014	NA	Wave	EMODnet	Current
Wave (4)	IE	SmartBay: National Wave Energy Test Site	Operational	2006	NA	Wave	EMODnet	Current
Wave/Wind (5)	PT	Ocean Plug – Portuguese Pilot Zone (Phase I: demonstrations)	Operational	2010	2014	Wave/Wind	EMODnet	Current
Wind (6)	PT	WindFloat Atlantic (WFA)	Partial Generation/ Under Construction	2019	NA	Wind	4C Offshore	~ 2025
Wave/Wind (7)	PT	Sines	In development	NA	NA	Wave/Wind	EMODnet	NA
Wind (8)	PT	WindFloat 1 Prototype (WF1)	Decommissioned	2011	NA	Wind	4C Offshore	Current
Wave/Wind (9)	PT	Aguçadoura Test Site	Decommissioned	2004	NA	Wave/Wind	EMODnet	Current
Wave (10)	ES	Energy Mare Experimental Zone	Operational	2017	NA	Wave	EMODnet	Current
Wave (11)	UK	Isle of Harris Demonstration Zone	In development	NA	NA	Wave	EMODnet	NA
Tidal (12)	UK	EMEC Islay Demonstration Zone	Development	NA	NA	Tidal	EMODnet	NA
Wind (13)	IE	Oriel (Relevant Project)	Concept/Early Planning	2023	NA	Wind	4C Offshore	~ 2025
Wind (14)	IE	Arklow Bank Phase 1	Fully Commissioned	2003	NA	Wind	4C Offshore	Current
Wind (15)	IE	Arklow Bank Phase 2	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (16)	IE	Dublin Array (Relevant Project)	Concept/Early Planning	2025	NA	Wind	4C Offshore	~ 2025
Wind (17)	IE	SSE Renewables Braymore Point	Concept/Early Planning	2029	NA	Wind	4C Offshore	> 2025
Wind (18)	IE	Codling Bank I (Relevant Project)	Concept/Early Planning	2024	NA	Wind	4C Offshore	~ 2025
Wind (19)	UK	Erebus	Concept/Early Planning	2025	NA	Wind	4C Offshore	~ 2025
Wave (20)	UK	Wave Hub Test Site	Operational	2010	NA	Wave	EMODnet	Current
Wind (21)	UK	Wave Hub	Fully Commissioned	2010	NA	Wind	4C Offshore	Current
Wave (22)	UK	QUB Wave Test Site	Operational	NA	NA	Wave	EMODnet	NA
Tidal (23)	UK	QUB Tidal Demonstration Test Site	Operational	2004	NA	Tidal	EMODnet	Current
Wave (24)	UK	South Pembrokeshire Demo Zone	Pre-planning Application	NA	NA	Wave	EMODnet	NA
Wind (25)	FR	France - 2024 Tender(s) (Fixed/Floating)	Development Zone	2029	NA	Wind	4C Offshore	> 2025
Wave (26)	UK	Falmouth Bay Test Site	Operational	2012	NA	Wave	EMODnet	Current
Wind (27)	UK	Hunterston Test Centre (onshore)	Decommissioned	2013	NA	Wind	4C Offshore	Current
Wind (28)	UK	Hunterston Test Centre - Mitsubishi 7MW (onshore)	Decommissioned	2013	NA	Wind	4C Offshore	Current
Wind (29)	UK	Hunterston Test Centre - Siemens 6MW (onshore)	Decommissioned	2013	NA	Wind	4C Offshore	Current
Tidal (30)	UK	Morlais Tidal Demonstration Zone	Pre-planning Application	NA	NA	Tidal	EMODnet	NA
Wind (31)	FR	EOLINK 5 MW Demonstrator	Concept/Early Planning	2021	NA	Wind	4C Offshore	~ 2025
Wind (32)	FR	EOLINK 1/10 scale prototype - THeoREM offshore test site	Decommissioned	2018	NA	Wind	4C Offshore	~ 2025
Tidal (33)	UK	North Devon Tidal Demonstration Zone	Returned to The Crown Estate	2014	2017	Tidal	EMODnet	Current
Wind (34)	ES	BlueSATH	Partial Generation/ Under Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (35)	UK	Walney Extension	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wind (36)	UK	Robin Rigg	Fully Commissioned	2007	NA	Wind	4C Offshore	Current
Wind (37)	UK	Rhyl Flats	Fully Commissioned	2008	NA	Wind	4C Offshore	Current
Wind (38)	FR	Projet d'éolien flottant en mer au large du Morbihan - 2021 Tender (Floating)	Development Zone	2026	NA	Wind	4C Offshore	> 2025
Wind (39)	UK	Walney Phase 2	Fully Commissioned	2011	NA	Wind	4C Offshore	Current
Wind (40)	UK	Gwynt y Môr	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Wind (41)	UK	Walney Phase 1	Fully Commissioned	2010	NA	Wind	4C Offshore	Current

Plot	Country	Name	Status	Start	End	OR	Source	Scenario
Wind (42)	FR	Les éoliennes flottantes de Groix & Belle-Île	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (43)	UK	West of Duddon Sands	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (44)	UK	North Hoyle	Fully Commissioned	2003	NA	Wind	4C Offshore	Current
Wind (45)	UK	Ormonde	Fully Commissioned	2010	NA	Wind	4C Offshore	Current
Wave (46)	UK	EMEC Billia Croo	Operational	2004	NA	Wave	EMODnet	Current
Wind (47)	UK	Barrow	Fully Commissioned	2005	NA	Wind	4C Offshore	Current
Wind (48)	UK	Burbo Bank Extension	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (49)	UK	Burbo Bank	Fully Commissioned	2006	NA	Wind	4C Offshore	Current
Wind (50)	UK	Beatrice Demonstration	Decommissioned	2006	NA	Wind	4C Offshore	Current
Wind (51)	UK	Levenmouth demonstration turbine	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (52)	UK	ForthWind Offshore Wind Demonstration Project Phase 1	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (53)	UK	Moray West	Consent Authorised	2024	NA	Wind	4C Offshore	~ 2025
Wave (54)	UK	EMEC Scapa Flow Scale Wave Test Site	Operational	2011	NA	Wave	EMODnet	Current
Wind (55)	UK	Beatrice	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Tidal (56)	FR	Site d'essai hydrolien de Paimpol-Bréhat	Operational	2013	NA	Tidal	EMODnet	Current
Wave/Wind (57)	ES	Biscay Marine Energy Platform (BIMEP)	Operational	2008	NA	Wave/Wind	EMODnet	Current
Tidal (58)	UK	EMEC Shapinsay Sound	Operational	2011	NA	Tidal	EMODnet	Current
Wind (59)	ES	DemoSATH - BIMEP	Pre-Construction	2021	NA	Wind	4C Offshore	~ 2025
Wind (60)	ES	Nautilus Demonstration	Concept/Early Planning	2023	NA	Wind	4C Offshore	~ 2025
Tidal (61)	UK	EMEC Fall of Warness Tidal Energy Test Site	Operational	2006	NA	Tidal	EMODnet	Current
Wind (62)	FR	Floatgen Project	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wind (63)	FR	SEM-REV - SITE D'EXPERIMENTATION EN MER - MARINE TEST SITE	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Wave (64)	FR	Site d'Experimentation en Mer de Récuperation de l'Energie des Vagues	Operational	2013	NA	Wave	EMODnet	Current
Tidal (65)	UK	EMEC Stronsay Firth Demonstration Site	In development	NA	NA	Tidal	EMODnet	NA
Wind (66)	UK	Moray East	Under Construction	2019	NA	Wind	4C Offshore	~ 2025
Wind (67)	FR	Projet de parc éolien en mer de Saint-Nazaire	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (68)	FR	Projet éolien en mer de la Baie de Saint-Brieuc	Pre-Construction	2021	NA	Wind	4C Offshore	~ 2025
Wind (69)	FR	Parc des Iles d’Yeu et de Noirmoutier	Consent Authorised	2022	NA	Wind	4C Offshore	~ 2025
Wind (70)	UK	Neart na Gaoithe	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (71)	UK	Aberdeen Offshore Wind Farm (EOWDC)	Fully Commissioned	2018	NA	Wind	4C Offshore	~ 2025
Wind (72)	UK	Kincardine - Phase 1	Fully Commissioned	2018	NA	Wind	4C Offshore	~ 2025
Wind (73)	UK	Kincardine - Phase 2	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (74)	UK	Seagreen - Phase Three	Concept/Early Planning	2025	NA	Wind	4C Offshore	~ 2025
Wind (75)	UK	Seagreen - Phase One	Pre-Construction	2021	NA	Wind	4C Offshore	~ 2025
Wind (76)	FR	Parc éolien en mer d'Oléron - 2021-22 Tender (Fixed)	Development Zone	2027	NA	Wind	4C Offshore	> 2025
Wind (77)	FR	France - 2023 Tender (Fixed)	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (78)	UK	Blyth	Decommissioned	2000	NA	Wind	4C Offshore	Current
Wind (79)	UK	Seagreen - Phase Two	Concept/Early Planning	2025	NA	Wind	4C Offshore	~ 2025
Wind (80)	UK	Blyth Offshore Demonstrator Project - Array 2	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wind (81)	UK	Hywind Scotland Pilot Park	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Tidal (82)	UK	Perpetuus Tidal Energy Centre	Consented	2018	2041	Tidal	EMODnet	~ 2025
Wind (83)	UK	Teesside	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Tidal (84)	FR	Site Expérimental Estuaren National pour l'Essai et l'Optimisation d'Hydroliennes	Operational	2014	NA	Tidal	EMODnet	Current
Wind (85)	FR	Eoliennes Offshore du Calvados project	Consent Authorised	2022	NA	Wind	4C Offshore	~ 2025

Plot	Country	Name	Status	Start	End	OR	Source	Scenario
Wind (86)	UK	Rampion	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (87)	UK	Westermost Rough	Fully Commissioned	2014	NA	Wind	4C Offshore	Current
Wind (88)	FR	Parc éolien en mer de Fécamp	Pre-Construction	2022	NA	Wind	4C Offshore	~ 2025
Wind (89)	UK	Humber Gateway	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (90)	UK	Inner Dowsing	Fully Commissioned	2007	NA	Wind	4C Offshore	Current
Wind (91)	UK	Lynn	Fully Commissioned	2007	NA	Wind	4C Offshore	Current
Wind (92)	UK	Lincs	Fully Commissioned	2011	NA	Wind	4C Offshore	Current
Wind (93)	FR	Projet d'éoliennes en mer au large de la Normandie	Development Zone	2026	NA	Wind	4C Offshore	> 2025
Wind (94)	UK	Triton Knoll	Under Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (95)	UK	Race Bank	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (96)	UK	Kentish Flats Extension	Fully Commissioned	2015	NA	Wind	4C Offshore	Current
Wind (97)	UK	Kentish Flats	Fully Commissioned	2004	NA	Wind	4C Offshore	Current
Wind (98)	FR	Parc éolien en mer de Dieppe - Le Tréport	Consent Authorised	2022	NA	Wind	4C Offshore	~ 2025
Wind (99)	UK	Sheringham Shoal	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (100)	UK	Gunfleet Sands 3 - Demonstration Project	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Wind (101)	UK	Gunfleet Sands	Fully Commissioned	2008	NA	Wind	4C Offshore	Current
Wind (102)	UK	Hornsea Project Four	Concept/Early Planning	2024	NA	Wind	4C Offshore	~ 2025
Wind (103)	UK	Dudgeon	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (104)	UK	London Array	Fully Commissioned	2011	NA	Wind	4C Offshore	Current
Wind (105)	UK	Thanet Extension	Consent Application Submitted	2024	NA	Wind	4C Offshore	~ 2025
Wind (106)	UK	Thanet	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (107)	UK	Dogger Bank B	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (108)	UK	Hornsea Project Two	Pre-Construction	2021	NA	Wind	4C Offshore	~ 2025
Wind (109)	UK	Scroby Sands	Fully Commissioned	2003	NA	Wind	4C Offshore	Current
Wind (110)	UK	Dogger Bank A	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (111)	UK	Hornsea Project One	Fully Commissioned	2018	NA	Wind	4C Offshore	~ 2025
Wind (112)	UK	Greater Gabbard	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (113)	FR	France - 2026 Tender(s) (Fixed/Floating)	Development Zone	2031	NA	Wind	4C Offshore	> 2025
Wind (114)	FR	France - 2025 Tender(s) (Fixed/Floating)	Development Zone	2030	NA	Wind	4C Offshore	> 2025
Wind (115)	FR	France - 2028 Tender(s) (Fixed/Floating)	Development Zone	2033	NA	Wind	4C Offshore	> 2025
Wind (116)	FR	France - 2027 Tender(s) (Fixed/Floating)	Development Zone	2033	NA	Wind	4C Offshore	> 2025
Wind (117)	UK	Galloper	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (118)	UK	East Anglia Hub - TWO	Consent Application Submitted	2025	NA	Wind	4C Offshore	~ 2025
Wind (119)	UK	Sofia	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (120)	NO	Hywind Tampen	Pre-Construction	2022	NA	Wind	4C Offshore	~ 2025
Wind (121)	FR	L'éolien en mer région Dunkerque (troisième appel d'offres)	Concept/Early Planning	2025	NA	Wind	4C Offshore	~ 2025
Wind (122)	UK	East Anglia Hub - ONE North	Consent Application Submitted	2024	NA	Wind	4C Offshore	~ 2025
Wind (123)	BE	Princess Elisabeth Zone - Post 2020 Tender(s)	Development Zone	2025	NA	Wind	4C Offshore	~ 2025
Wind (124)	UK	East Anglia ONE	Partial Generation/ Under Construction	2018	NA	Wind	4C Offshore	~ 2025
Wind (125)	UK	Norfolk Vanguard	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (126)	BE	Seamade (Mermaid)	Under Construction	2019	NA	Wind	4C Offshore	~ 2025
Wind (127)	BE	Northwester 2	Fully Commissioned	2019	NA	Wind	4C Offshore	~ 2025
Wind (128)	BE	Belwind	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (129)	BE	Nobelwind	Fully Commissioned	2016	NA	Wind	4C Offshore	Current

Plot	Country	Name	Status	Start	End	OR	Source	Scenario
Wind (130)	UK	Dogger Bank C	Consent Authorised	2024	NA	Wind	4C Offshore	~ 2025
Wind (131)	BE	Belwind Alstom Haliade Demonstration	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (132)	UK	East Anglia Hub - THREE	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (133)	BE	Seamade (SeaStar)	Under Construction	2019	NA	Wind	4C Offshore	~ 2025
Wind (134)	BE	Northwind	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wave (135)	BE	Ostend Wave Energy Test Site	Operational	2019	NA	Wave	EMODnet	~ 2025
Wind (136)	BE	Thornton Bank phase III	Fully Commissioned	2011	NA	Wind	4C Offshore	Current
Wind (137)	NL	Borssele 3 and 4 - Blauwwind	Under Construction	2019	NA	Wind	4C Offshore	~ 2025
Wind (138)	BE	Thornton Bank phase I	Fully Commissioned	2008	NA	Wind	4C Offshore	Current
Wind (139)	UK	Norfolk Boreas	Consent Application Submitted	2024	NA	Wind	4C Offshore	~ 2025
Wind (140)	BE	Rentel	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wind (141)	BE	Thornton Bank phase II	Fully Commissioned	2010	NA	Wind	4C Offshore	Current
Wind (142)	NL	Borssele Site V -Leeghwater - Innovation Plot	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (143)	BE	Norther	Fully Commissioned	2018	NA	Wind	4C Offshore	~ 2025
Wind (144)	NL	Borssele 1 and 2	Partial Generation/ Under Construction	2018	NA	Wind	4C Offshore	~ 2025
Wind (145)	FR	Les éoliennes flottantes du Golfe du Lion	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (146)	FR	EolMed	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (147)	NL	IJmuiden Ver - Site I - (Tender 2023)	Development Zone	2026	NA	Wind	4C Offshore	> 2025
Wind (148)	NL	IJmuiden Ver - Site II - (Tender 2023)	Development Zone	2026	NA	Wind	4C Offshore	> 2025
Wind (149)	NL	IJmuiden Ver - Site III - (Tender 2025)	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (150)	NL	IJmuiden Ver - Site IV - (Tender 2025)	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (151)	NL	Hollandse Kust West - (Tender 2020/2021)	Development Zone	2023	NA	Wind	4C Offshore	~ 2025
Wind (152)	FR	France - 2022 Tender II (Floating)	Development Zone	2027	NA	Wind	4C Offshore	> 2025
Wind (153)	FR	France - 2022 Tender I (Floating)	Development Zone	2027	NA	Wind	4C Offshore	> 2025
Wind (154)	NL	Hollandse Kust Zuid Holland I and II - Chinook - (Tender 2017)	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (155)	NL	Haliade-X 12-14MW Prototype - Maasvlakte (Onshore)	Fully Commissioned	2019	NA	Wind	4C Offshore	~ 2025
Wind (156)	NL	Hollandse Kust Zuid Holland III and IV (Tender 2019)	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Tidal (157)	NL	TTC-GD	Operational	2018	NA	Tidal	EMODnet	~ 2025
Wind (158)	NL	Eneco Luchterduinen	Fully Commissioned	2014	NA	Wind	4C Offshore	Current
Wind (159)	NL	Prinses Amaliawindpark	Fully Commissioned	2006	NA	Wind	4C Offshore	Current
Wind (160)	NL	Hollandse Kust Noord (Tender 2019)	Concept/Early Planning	2022	NA	Wind	4C Offshore	~ 2025
Wind (161)	NL	Egmond aan Zee	Fully Commissioned	2006	NA	Wind	4C Offshore	Current
Wind (162)	NO	Utsira nord (Category A area)	Concept/Early Planning	2027	NA	Wind	4C Offshore	> 2025
Tidal (163)	NL	DMEC - Marsdiep	Operational	2013	NA	Tidal	EMODnet	Current
Wind (164)	FR	Les éoliennes flottantes de Provence Grand Large	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (165)	NO	SWAY 1:6 Prototype	Decommissioned	2011	NA	Wind	4C Offshore	Current
Wind (166)	NO	Sørlige Nordsjø II (Category A area)	Concept/Early Planning	2027	NA	Wind	4C Offshore	> 2025
Wind (167)	NO	TetraSpar Demonstrator - Metcentre	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (168)	NO	Karmøy - Marine Energy Test Centre (Metcentre) - Floating	Fully Commissioned	2019	NA	Wind	4C Offshore	~ 2025
Wind (169)	NO	UNITECH Zefyros by Hywind Technology	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (170)	NL	Lely	Decommissioned	1992	NA	Wind	4C Offshore	Current
Wind (171)	NO	SeaTwirl S2	Concept/Early Planning	2021	NA	Wind	4C Offshore	~ 2025
Wind (172)	NL	Windpark Fryslân	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (173)	NL	Westermeerwind	Fully Commissioned	2015	NA	Wind	4C Offshore	Current

Plot	Country	Name	Status	Start	End	OR	Source	Scenario
Wind (174)	NL	Irene Vorrink	Fully Commissioned	1996	NA	Wind	4C Offshore	Current
Wave (175)	NO	Runde Environmental Centre (REC)	Operational	2009	NA	Wave	EMODnet	Current
Wind (176)	DE	N-9.3	Development Zone	2029	NA	Wind	4C Offshore	> 2025
Wind (177)	NL	Ten noorden van de Waddeneilanden - (Tender 2022)	Development Zone	2025	NA	Wind	4C Offshore	~ 2025
Wind (178)	NO	Gwind - Spinwind 1	Decommissioned	2014	NA	Wind	4C Offshore	Current
Wind (179)	DE	N-9.4	Development Zone	2029	NA	Wind	4C Offshore	> 2025
Wind (180)	DE	N-9.1	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (181)	DE	Deutsche Bucht	Fully Commissioned	2018	NA	Wind	4C Offshore	Current
Wind (182)	DE	N-6.7	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (183)	DE	Veja Mate	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (184)	DE	N-9.2	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (185)	DE	N-6.6	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (186)	NL	Gemini	Fully Commissioned	2015	NA	Wind	4C Offshore	Current
Wind (187)	DE	BARD Offshore 1	Fully Commissioned	2010	NA	Wind	4C Offshore	Current
Wind (188)	DE	N-10.1	Development Zone	2029	NA	Wind	4C Offshore	> 2025
Wind (189)	DE	N-10.2	Development Zone	2029	NA	Wind	4C Offshore	> 2025
Wind (190)	DE	EnBW He Dreiht	Consent Authorised	2024	NA	Wind	4C Offshore	~ 2025
Wind (191)	DE	Borkum Riffgrund 3	Consent Authorised	2024	NA	Wind	4C Offshore	~ 2025
Wind (192)	DE	N-7.2	Development Zone	2026	NA	Wind	4C Offshore	> 2025
Wind (193)	DE	Albatros	Fully Commissioned	2019	NA	Wind	4C Offshore	Current
Wind (194)	NO	Havsul I	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (195)	DE	Hohe See	Fully Commissioned	2018	NA	Wind	4C Offshore	Current
Wind (196)	DE	Global Tech I	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Wind (197)	DE	Trianel Windpark Borkum I	Fully Commissioned	2011	NA	Wind	4C Offshore	Current
Wind (198)	DE	Trianel Windpark Borkum II	Partial Generation/ Under Construction	2018	NA	Wind	4C Offshore	Current
Wind (199)	DE	Riffgat	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Wind (200)	DE	Borkum Riffgrund 2	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wind (201)	DE	Borkum Riffgrund 1	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (202)	DE	Merkur	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wind (203)	DE	Alpha Ventus	Fully Commissioned	2008	NA	Wind	4C Offshore	Current
Wind (204)	DE	N-3.6	Development Zone	2027	NA	Wind	4C Offshore	> 2025
Wind (205)	NL	2B Energy Eemshaven Test (onshore)	Fully Commissioned	2015	NA	Wind	4C Offshore	Current
Wind (206)	DE	Nordsee One	Fully Commissioned	2015	NA	Wind	4C Offshore	Current
Wind (207)	DE	N-3.5	Development Zone	2027	NA	Wind	4C Offshore	> 2025
Wind (208)	DE	Sandbank	Fully Commissioned	2015	NA	Wind	4C Offshore	Current
Wind (209)	DE	N-3.8	Development Zone	2025	NA	Wind	4C Offshore	~ 2025
Wind (210)	DE	Gode Wind 1 and 2	Fully Commissioned	2015	NA	Wind	4C Offshore	Current
Wind (211)	DE	N-3.7	Development Zone	2025	NA	Wind	4C Offshore	~ 2025
Wind (212)	DE	Gode Wind 3	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (213)	DE	DanTysk	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (214)	DE	ENOVA Offshore Project Ems Emden	Fully Commissioned	2004	NA	Wind	4C Offshore	Current
Wind (215)	DK	Horns Rev 2	Fully Commissioned	2008	NA	Wind	4C Offshore	Current
Wind (216)	DK	Thor - 2020 Tender	Development Zone	2024	NA	Wind	4C Offshore	~ 2025
Wind (217)	DE	Nordsee Ost	Fully Commissioned	2012	NA	Wind	4C Offshore	Current

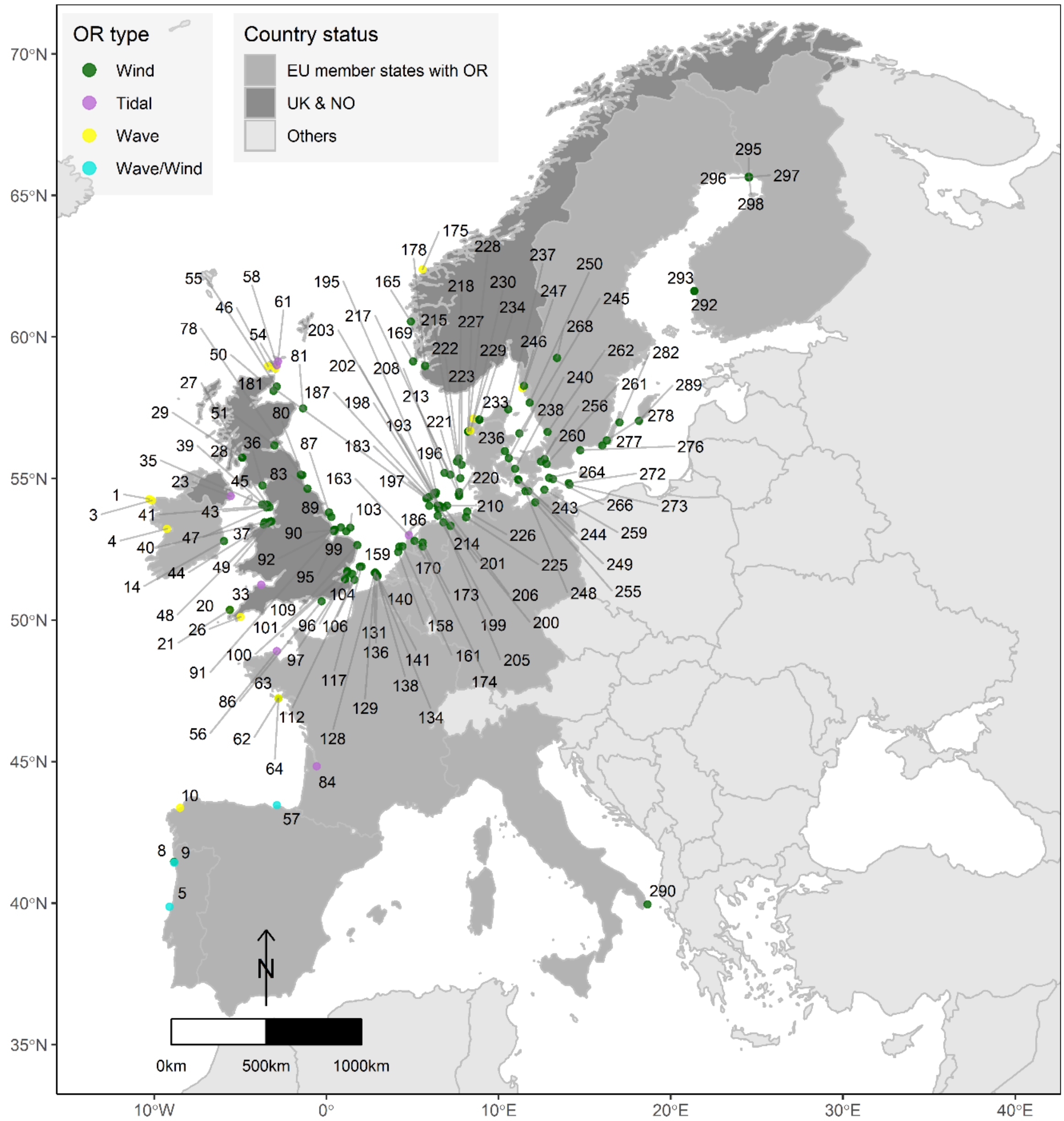
Plot	Country	Name	Status	Start	End	OR	Source	Scenario
Wind (218)	DK	Horns Rev 3	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (219)	DE	Kaskasi	Pre-Construction	2021	NA	Wind	4C Offshore	~ 2025
Wind (220)	DE	Meerwind Süd/Ost	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Wind (221)	DE	Amrumbank West	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (222)	DE	Butendiek	Fully Commissioned	2014	NA	Wind	4C Offshore	Current
Wind (223)	DK	Horns Rev 1	Fully Commissioned	2002	NA	Wind	4C Offshore	Current
Wind (224)	DK	Vesterhav Nord/Syd	Consent Application Submitted	2023	NA	Wind	4C Offshore	~ 2025
Wind (225)	DE	Hooksiel	Decommissioned	2008	NA	Wind	4C Offshore	Current
Wind (226)	DE	Nordergründe	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (227)	DK	Rønland	Fully Commissioned	2002	NA	Wind	4C Offshore	Current
Wind (228)	DK	Nissum Bredning Vind	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wave (229)	DK	Nissum Bredning Test Station for Wave energy	Operational	1999	NA	Wave	EMODnet	Current
Wave (230)	DK	Danish Wave Energy Center (DanWEC)	Operational	2016	NA	Wave	EMODnet	Current
Wind (231)	DE	Nezzy^2 1:10-scale prototype	Fully Commissioned	2020	NA	Wind	4C Offshore	~ 2025
Wind (232)	DK	Siemens - Østerild - stand 8 (onshore)	Fully Commissioned	2020	NA	Wind	4C Offshore	~ 2025
Wind (233)	DK	V164-9.5 MW - Østerild - stand 2 (onshore)	Decommissioned	2014	NA	Wind	4C Offshore	Current
Wind (234)	DK	Haliade 150-6MW - Østerild - stand 1 (onshore)	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (235)	DK	Lillebælt Syd (Lillegrund)	Concept/Early Planning	2021	NA	Wind	4C Offshore	~ 2025
Wind (236)	DK	Tunø Knob	Fully Commissioned	1995	NA	Wind	4C Offshore	Current
Wind (237)	DK	Frederikshavn	Fully Commissioned	2002	NA	Wind	4C Offshore	Current
Wind (238)	DK	Samsø	Fully Commissioned	2002	NA	Wind	4C Offshore	Current
Wind (239)	DK	Frederikshavn Offshore Wind Demo	Concept/Early Planning	2024	NA	Wind	4C Offshore	~ 2025
Wind (240)	DK	Sprogø	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (241)	DK	Jammerland Bugt	Concept/Early Planning	2022	NA	Wind	4C Offshore	~ 2025
Wind (242)	DK	Omø Syd	Concept/Early Planning	2022	NA	Wind	4C Offshore	~ 2025
Wind (243)	DK	Vindeby	Decommissioned	1990	NA	Wind	4C Offshore	Current
Wind (244)	DK	Poseidon P37	Decommissioned	2008	NA	Wind	4C Offshore	Current
Wind (245)	DK	Anholt	Fully Commissioned	2011	NA	Wind	4C Offshore	Current
Wave (246)	SE	Lysekil Wave Power Research Site	Operational	2004	2013	Wave	EMODnet	Current
Wind (247)	SE	SeaTwirl S1	Fully Commissioned	2015	NA	Wind	4C Offshore	Current
Wind (248)	DK	Rødsand 2	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (249)	DK	Nysted	Fully Commissioned	2002	NA	Wind	4C Offshore	Current
Wind (250)	SE	Göteborg Wind Lab (Onshore)	Fully Commissioned	2011	NA	Wind	4C Offshore	Current
Wind (251)	DK	Hesselø - 2021 Tender - Direct Connection to Land	Development Zone	2025	NA	Wind	4C Offshore	~ 2025
Wind (252)	DE	O-7	Development Zone	2023	NA	Wind	4C Offshore	~ 2025
Wind (253)	SE	Galatea-Galene	Concept/Early Planning	2028	NA	Wind	4C Offshore	> 2025
Wind (254)	SE	Stora Middelgrund	Concept/Early Planning	2026	NA	Wind	4C Offshore	> 2025
Wind (255)	DE	Breitling	Fully Commissioned	2006	NA	Wind	4C Offshore	Current
Wind (256)	DK	Avedøre Holme	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (257)	DK	Aflandshage	Concept/Early Planning	2023	NA	Wind	4C Offshore	~ 2025
Wind (258)	DE	Gennaker	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (259)	DE	EnBW Baltic 1	Fully Commissioned	2010	NA	Wind	4C Offshore	Current
Wind (260)	DK	Middelgrunden	Fully Commissioned	2000	NA	Wind	4C Offshore	Current
Wind (261)	SE	Lillgrund	Fully Commissioned	2006	NA	Wind	4C Offshore	Current

Plot	Country	Name	Status	Start	End	OR	Source	Scenario
Wind (262)	SE	SeaTwirl P3	Decommissioned	2011	NA	Wind	4C Offshore	Current
Wind (263)	DK	Nordre Flint	Concept/Early Planning	2023	NA	Wind	4C Offshore	~ 2025
Wind (264)	DK	Kriegers Flak	Under Construction	2017	NA	Wind	4C Offshore	Current
Wind (265)	SE	Kriegers Flak II	Consent Authorised	2025	NA	Wind	4C Offshore	~ 2025
Wind (266)	DE	EnBW Baltic 2	Fully Commissioned	2013	NA	Wind	4C Offshore	Current
Wind (267)	SE	Stenkalles grund	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (268)	SE	Vindpark Vänern	Fully Commissioned	2009	NA	Wind	4C Offshore	Current
Wind (269)	DE	Arcadis Ost 1	Consent Authorised	2021	NA	Wind	4C Offshore	~ 2025
Wind (270)	DE	Baltic Eagle	Consent Authorised	2020	NA	Wind	4C Offshore	~ 2025
Wind (271)	DE	O-1.3	Development Zone	2025	NA	Wind	4C Offshore	~ 2025
Wind (272)	DE	Wikinger	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (273)	DE	Arkona	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (274)	DE	Wikinger Süd	Consent Authorised	2023	NA	Wind	4C Offshore	~ 2025
Wind (275)	DK	Denmark - 2023 Tender	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (276)	SE	Nogersund - Svante 1	Decommissioned	1990	NA	Wind	4C Offshore	Current
Wind (277)	SE	Yttre Stengrund	Decommissioned	2001	NA	Wind	4C Offshore	Current
Wind (278)	SE	Utgrunden I	Decommissioned	2000	NA	Wind	4C Offshore	Current
Wind (279)	PL	FEW Baltic II	Concept/Early Planning	2023	NA	Wind	4C Offshore	~ 2025
Wind (280)	PL	Baltyk II - phase 1	Consent Authorised	2024	NA	Wind	4C Offshore	~ 2025
Wind (281)	PL	Baltyk II - phase 2	Consent Authorised	2026	NA	Wind	4C Offshore	> 2025
Wind (282)	SE	Kårehamn	Fully Commissioned	2012	NA	Wind	4C Offshore	Current
Wind (283)	PL	Baltica 2	Concept/Early Planning	2030	NA	Wind	4C Offshore	> 2025
Wind (284)	IT	Parco eolico nella rada esterna del porto di Taranto	Pre-Construction	2020	NA	Wind	4C Offshore	~ 2025
Wind (285)	PL	Baltyk III - phase 1	Consent Authorised	2024	NA	Wind	4C Offshore	~ 2025
Wind (286)	PL	Baltyk III - phase 2	Consent Authorised	2026	NA	Wind	4C Offshore	> 2025
Wind (287)	SE	Utposten	Consent Application Submitted	2025	NA	Wind	4C Offshore	~ 2025
Wind (288)	PL	Baltica 3	Concept/Early Planning	2026	NA	Wind	4C Offshore	> 2025
Wind (289)	SE	Bockstigen	Fully Commissioned	1997	NA	Wind	4C Offshore	Current
Wind (290)	IT	Brindisi	Decommissioned	2007	NA	Wind	4C Offshore	Current
Wind (291)	LT	Lithuanian Tender - 2022/2023	Development Zone	2028	NA	Wind	4C Offshore	> 2025
Wind (292)	FI	Reposaaren tuulipuisto	Fully Commissioned	2010	NA	Wind	4C Offshore	Current
Wind (293)	FI	Tahkoluoto Offshore Wind Power Project	Fully Commissioned	2017	NA	Wind	4C Offshore	Current
Wind (294)	EE	Hiiumaa	Concept/Early Planning	2027	NA	Wind	4C Offshore	> 2025
Wind (295)	FI	Kemin Ajoksen II	Decommissioned	2008	NA	Wind	4C Offshore	Current
Wind (296)	FI	Kemin Ajoksen Meriperustushanke	Decommissioned	2009	NA	Wind	4C Offshore	Current
Wind (297)	FI	Ajos	Fully Commissioned	2016	NA	Wind	4C Offshore	Current
Wind (298)	FI	Kemin Ajoksen I	Decommissioned	2007	NA	Wind	4C Offshore	Current
Wind (299)	EL	2020 Floating Tender(s)	Development Zone	2025	NA	Wind	4C Offshore	~ 2025

Source: Author based on data provided by 4C Offshore Ltd.

Note: The status of the data is August 2020

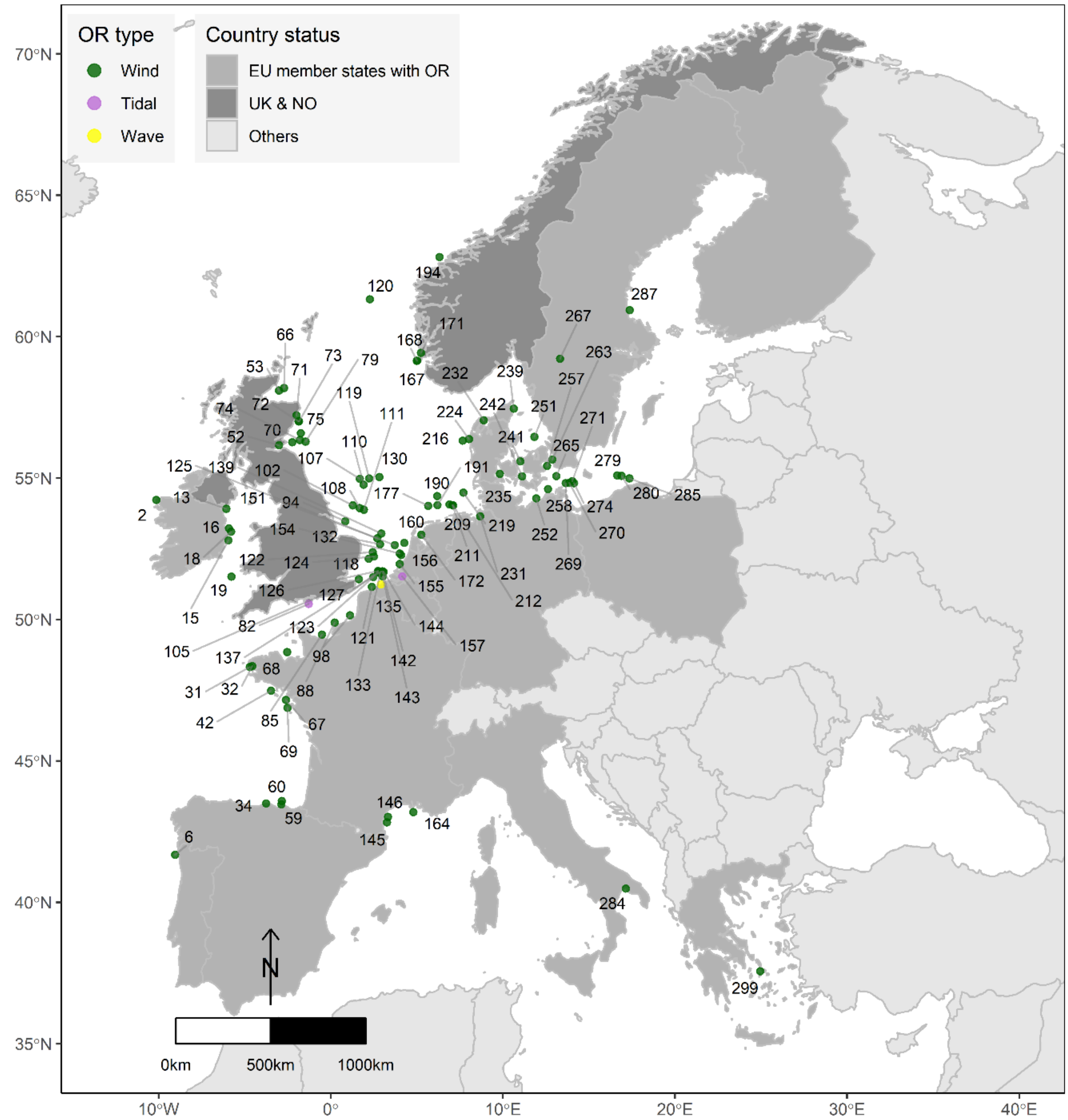
Map 3: Current offshore renewables in European seas



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet

Note: Numbers refer to individual installations (Annex 3)

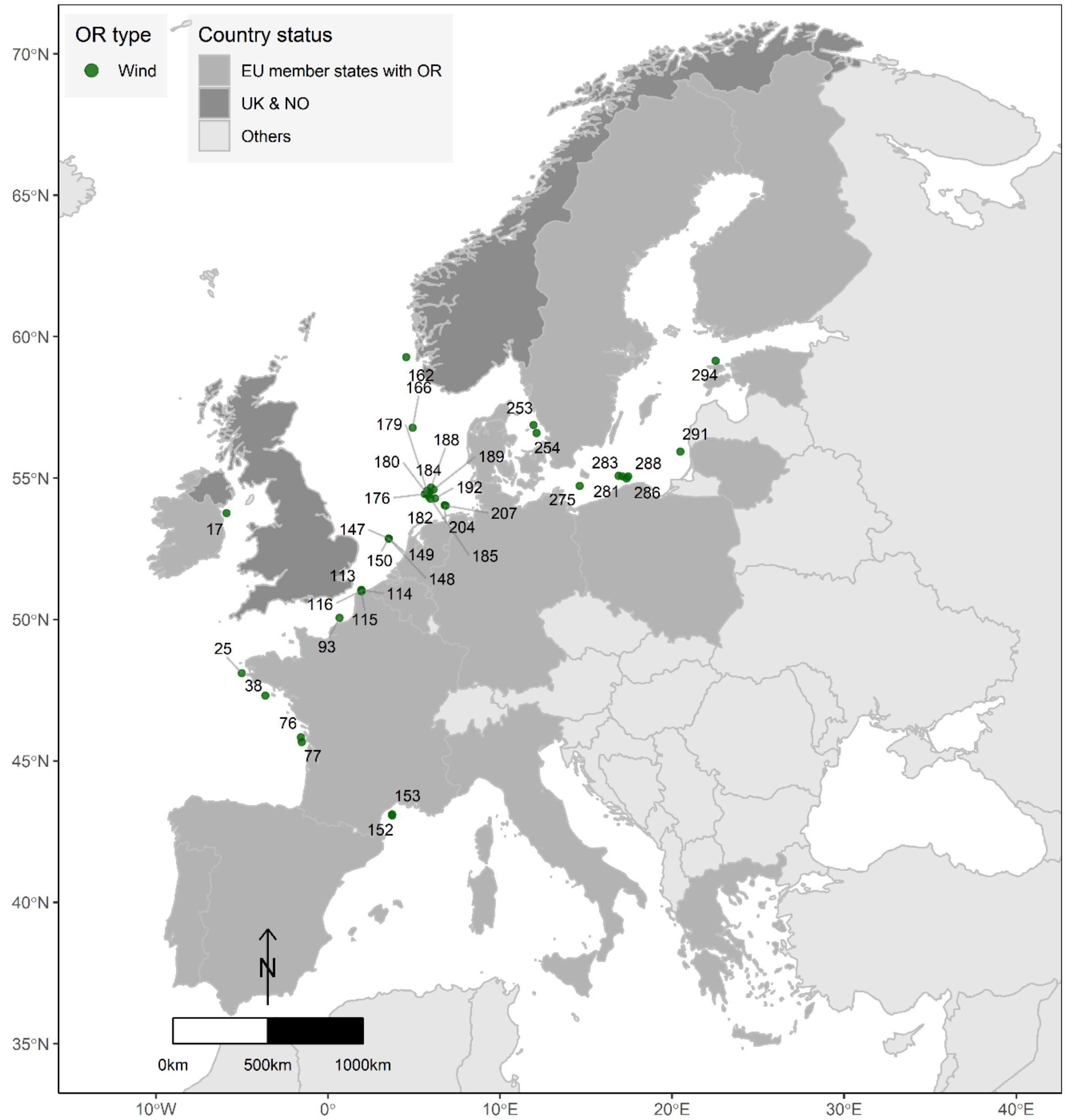
Map 4: Mid-term scenario offshore renewables in European seas (~ 2025)



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet

Note: Numbers refer to individual installations (Annex 3)

Map 5: Long-term scenario offshore renewables (> 2025) in European seas

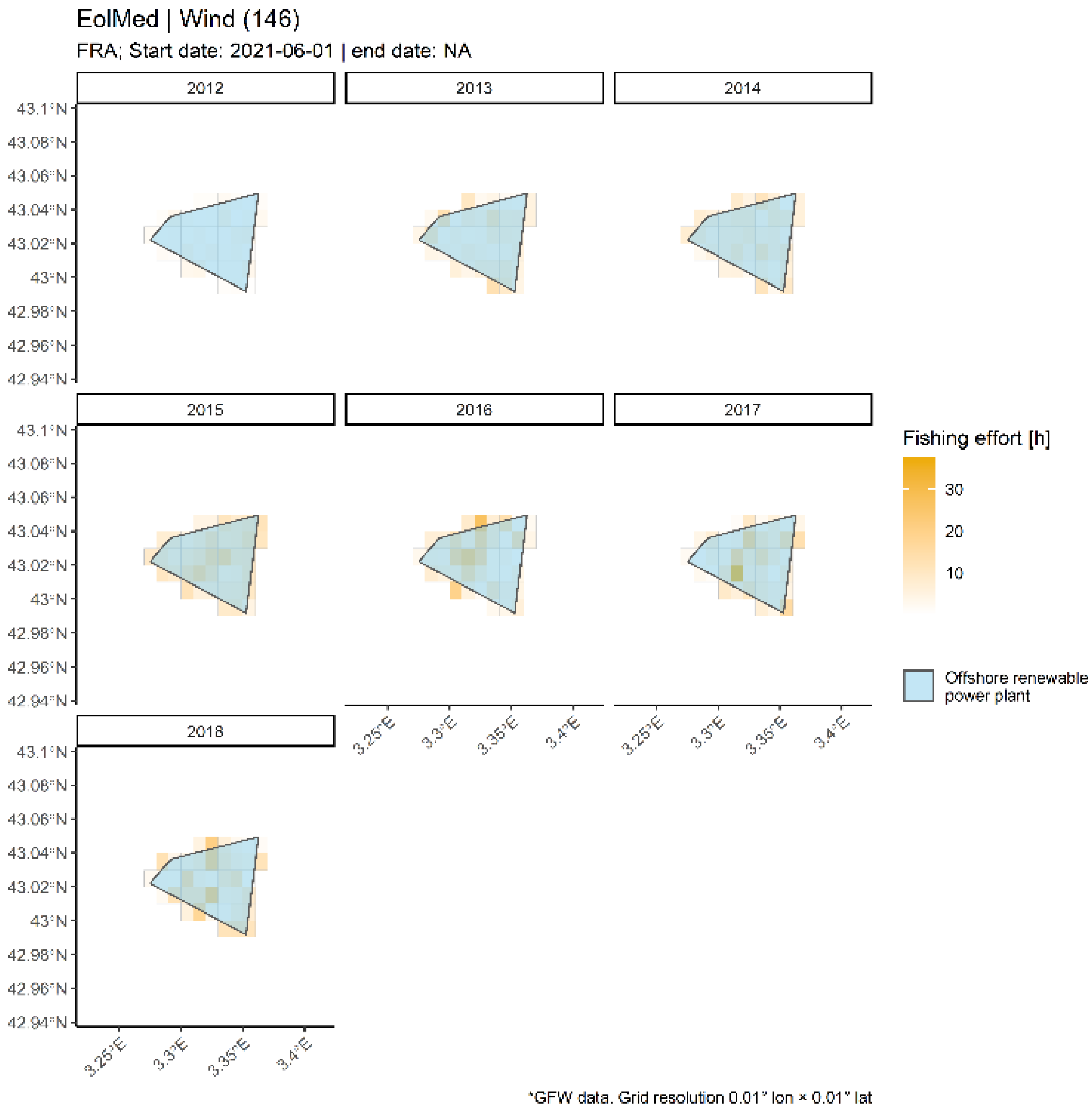


Source: Author based on data provided by 4C Offshore Ltd. and EMODnet
Note: Numbers refer to individual installations (Annex 3)

ANNEX 4 – EXAMPLES OF DIFFERENT SPATIAL RESOLUTIONS OF ESTIMATES OF FISHERIES EFFORT NEAR OR INSIDE MARINE ENERGY AREAS

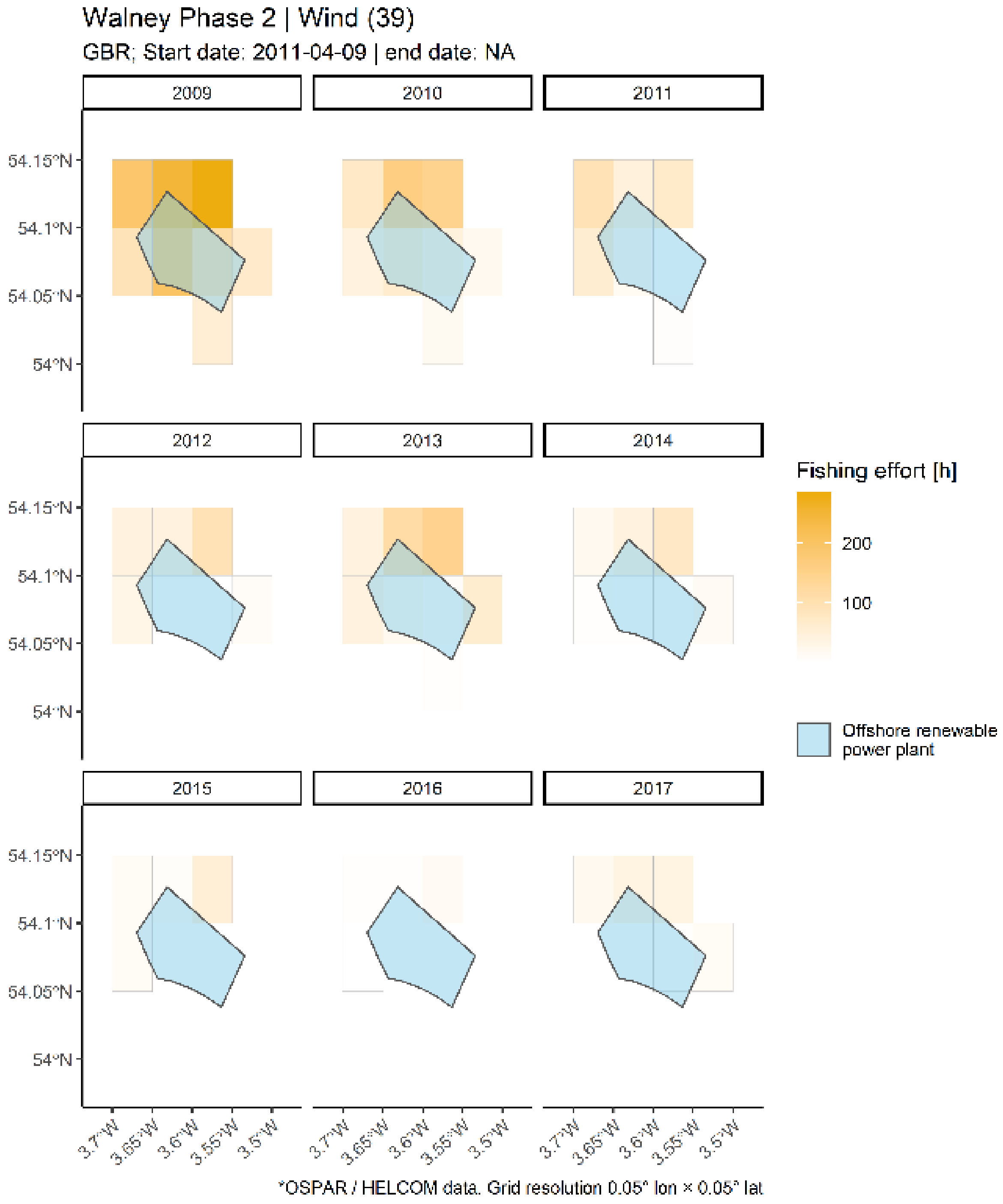
One key obstacle when assessing the spatial overlap of fishing activities and areas designated for OR installations is the differing spatial resolution. Below, we show examples of the overlap analysis with OR for three fishing effort data sets with different spatial resolutions. The panels show the spatial scales and fishing effort of the **GFW data** (Figure 1; Wind 146), **OSPAR/HELCOM** (Figure 2; Wind 39), and at the high-resolution **VMS data** (Figure 3; Wind 221). The spatial overlap of the GFW and OSPAR/HELCOM data are rather conservative and might overestimate the actual fishing effort related to an OR polygon.

Figure 16:Scale and resolution of fishing effort data used in this study, France, GFW data



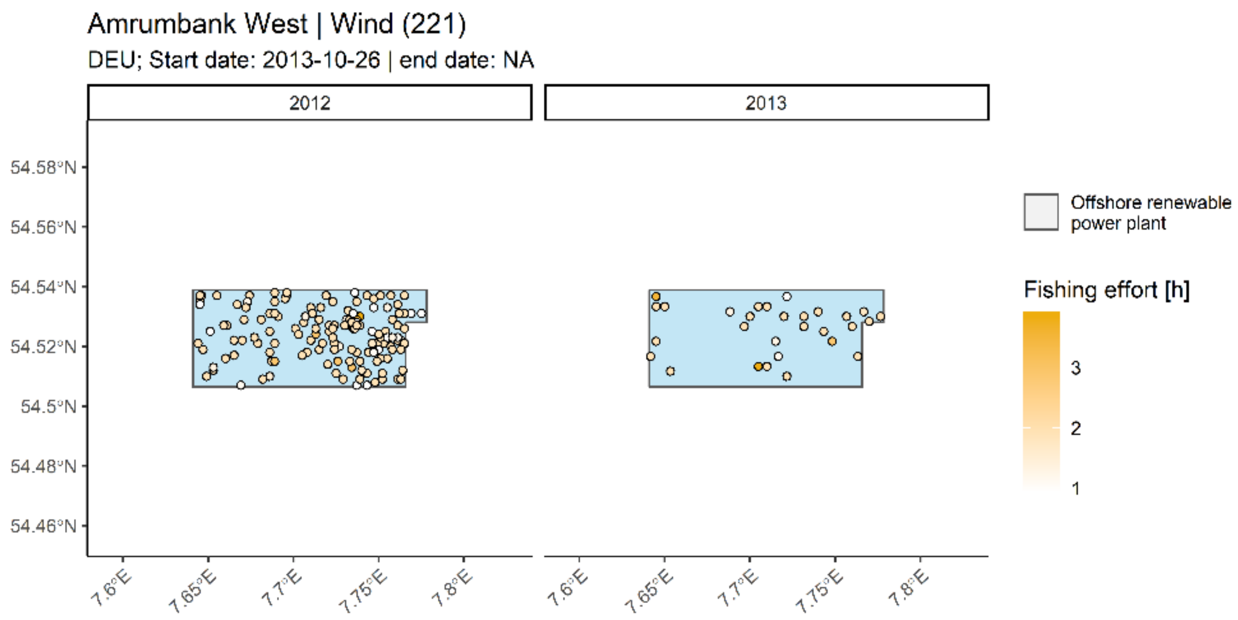
Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by Global Fishing Watch (GFW) for fisheries

Figure 17:Scale and resolution of fishing effort data used in this study, UK, OSPAR/HELCOM data



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by OSPAR (the Convention for the Protection of the Marine Environment of the North-East Atlantic) and HELCOM (Helsinki Commission for the protection of the Baltic Sea) for fisheries

Figure 18: Scale and resolution of fishing effort data used in this study, German EEZ, VMS data

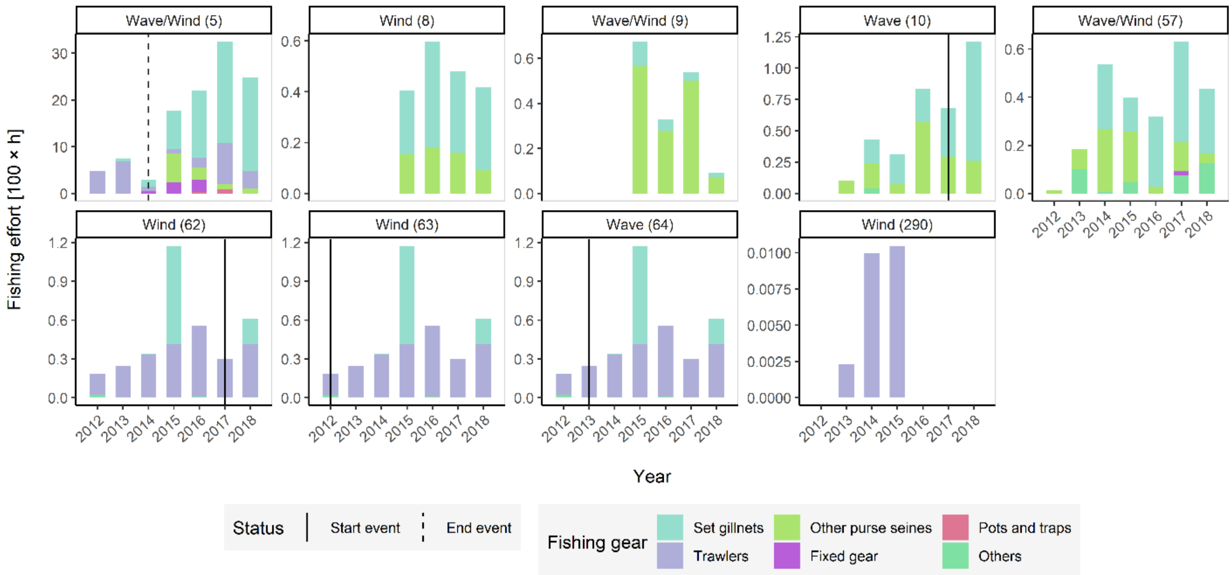


Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and VMS data provided by the German Federal Office for Agriculture and Food (BLE) for fisheries

ANNEX 5 – FISHERIES AFFECTED BY OFFSHORE RENEWABLE INSTALLATIONS IN THE ATLANTIC OCEAN AND MEDITERRANEAN SEA (GFW DATA)

Below the overlapping fishing effort, based on GFW (2012-2018) data, is shown per gear type for current, mid-term, and long-term OR installations (**Chapter 2**). Starting (solid vertical line) or ending (dashed vertical line) of the installation are shown. Numbers refer to individual OR installations. Fishing effort near existing OR varies greatly ranging from no fishing to very limited fishing, to more than 3000 hrs annually (e.g. installation No. 5). Overall this confirms the observed regional trend that mainly trawlers are affected. However, the fishing effort in the area of OR installation planned up to 2025 shows that pot and trap fisheries will not be affected anymore but in some areas spatial use conflicts will occur with the set longline fisheries. For the long-term scenario (> 2025) the overlap with purse seiners will be insignificant while the majority of overlap will occur with the trawlers. Further, the mid-term and long-term scenario individual planning areas show quite some differences in terms of their importance to fisheries. This indicates that the conflict potentials and subsequent economic losses due to fishing restrictions will vary greatly across the regions.

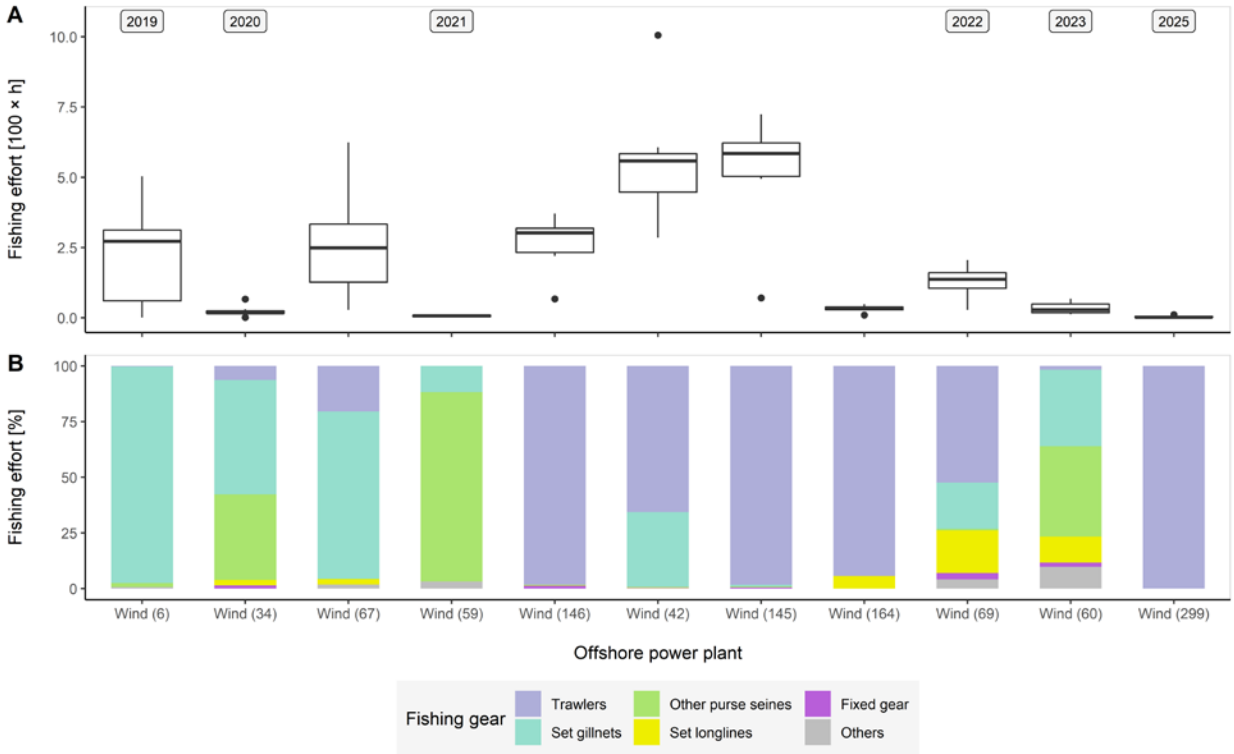
Figure 19: Current offshore renewable installations



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by Global Fishing Watch (GFW) for fisheries

Note: Numbers refer to individual installations (Annex 3)

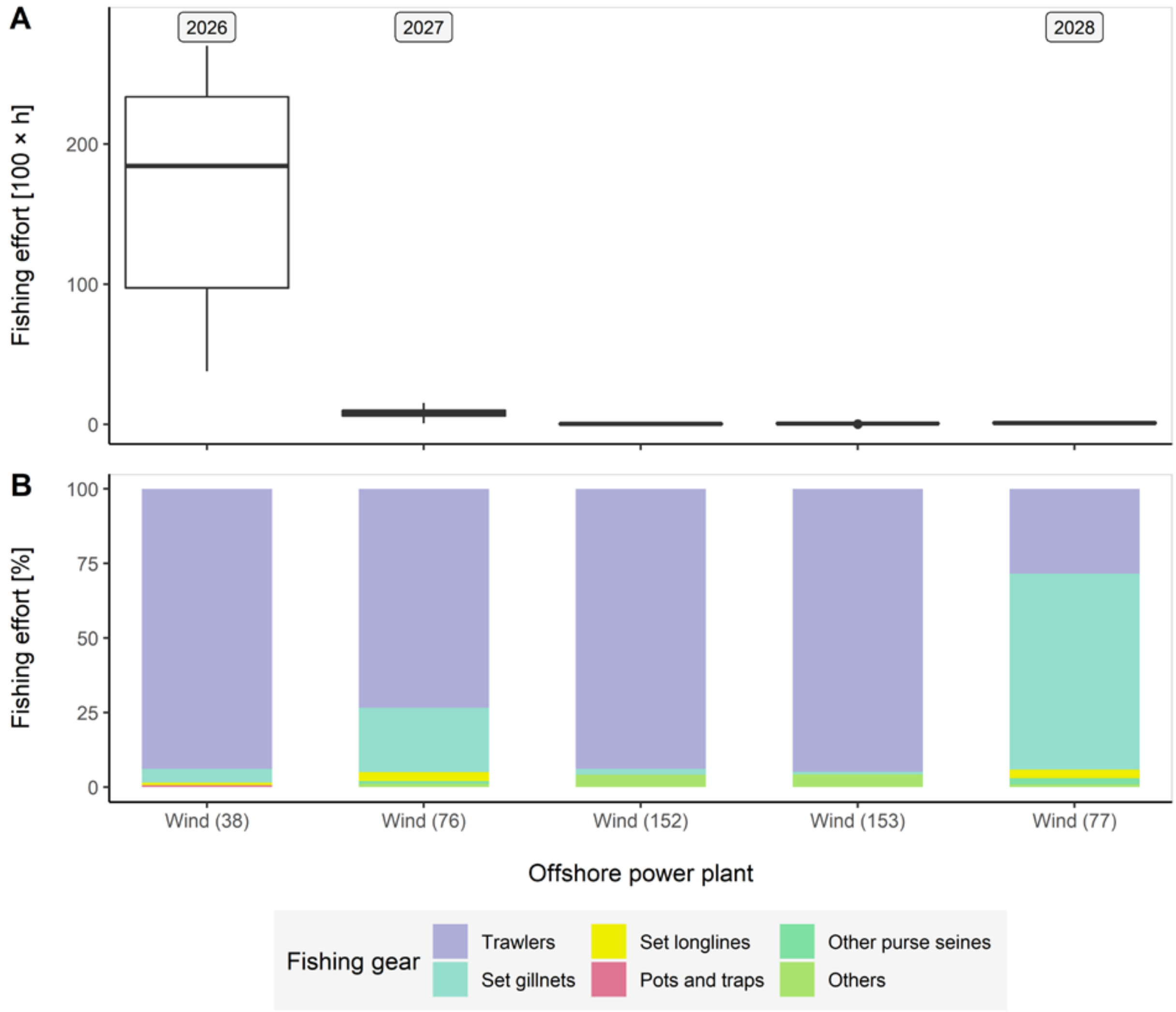
Figure 20:Mid-term scenario offshore renewable installations (~ 2025)



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by Global Fishing Watch (GFW) for fisheries

Note: Numbers refer to individual installations (Annex 3)

Figure 21: Long-term scenario offshore renewable installations (> 2025)



Source: Author based on data provided by 4C Offshore Ltd. and EMODnet for the offshore renewables; and data provided by Global Fishing Watch (GFW) for fisheries

Note: Numbers refer to individual installations (Annex 3)

ANNEX 6 – REVIEW TABLE AND FURTHER OUTCOMES

Table 5: Outcomes of the standardised literature review on the current knowledge on the impact of offshore renewables on fisheries or aquaculture (Part I)

Case study	Indicator of impact	Impact quantification	Measure of ecologic impact	Measure of economic impact	Measure of socio-cultural impact	Reference
Effects of OWF on marine wildlife in Sweden, Skagerrak to inner Baltic Sea	Impact of OWF on marine and aquatic wildlife (marine mammals, fish, benthos)	Review of empirical observations	Yes, during construction phase (acoustic disturbance, increased sediment dispersal) and operational phase (habitat gain, fisheries exclusion, acoustic disturbance, electromagnetic fields)	No	No	Bergström *et al.* (2014)
MSP with OWF and fisheries in Germany, North Sea & Baltic Sea EEZ	Economic impact of OWF on fisheries	Fraction loss of total catch in the German EEZ	No	Yes, cost-benefit analyses	No	Berkenhagen *et al.* (2010)
Multi-Use in the Eastern Atlantic Sea basin	Existing and potential co-location options, the main drivers and barriers thereof	None, qualitative analysis	Yes, co-location is not adequate for mass tourism due to environmental protection; Risk of looting, deterioration and destruction to sites	Yes, resulting in "limited expertise, lack of ideas for organised economic businesses of fishers"	Yes, several (e.g. Resistance to change in small fishing communities; Health and safety risks due to increased vessel traffic; OWF may have insufficient small size to allow for profitable aquaculture; Inconsistent or uncoordinated policy making within countries (local/regional/federal levels); Lack of clear, or complex administrative and legal procedures to implement offshore projects; Resistance of civil society and fishers to OWF)	Calado *et al.* (2019)
MSP with OR and fisheries in UK, Western English Channel	Fisheries displacement due to MPAs or wave energy	Fishing effort based on VMS	No	No	No	Campbell et al (2014)
Integrating co-location in MSP in UK	Review of regulation affecting co-location of key activities	None	No	No	No	Christie *et al.* (2014)
Conservation in Ireland	Impact of human activities on Seal populations	Monitoring of population-size	Yes, developments of Seal populations	No	No	Cronin (2011)

Case study	**Indicator of impact**	**Impact quantification**	**Measure of ecologic impact**	**Measure of economic impact**	**Measure of socio-cultural impact**	**Reference**
Siting of wave energy in Australia, South-east coast	The impact of wave energy (geo-spatial MCE considering ocean wave climatology, nature of the seabed, distance to key infrastructure, environmental factors and potential conflict with other users such as shipping and fisheries	GIS data on annual catch value for abalone (referenced grid of 20 km^2) and southern rock lobster (referenced grid of 270 km^2)	No	No	Yes, overlap with Fisheries	Flocard *et al.* (2016)
Siting of OWF (MSP & multi-use) in the North Sea	Estimation of potential OWF capacity (based on available surface incl. Co-location)	Estimated available surface (km^2), Estimation of GW capacity at 3.6 or 6.4 MW/km^2	No	Yes, scenario-based assessments of space and wind energy capacity	No	Gusatu *et al.* (2020)
Reduced impact of aquaculture due to OR in Indonesia	Impact and growth of the sector, based on mass allocation (e.g. kg Co2 produced during production), if e.g. renewable energy is used	Life Cycle Assessment (Software)	No	Yes, several (e.g. sustainable intensification of milkfish and Asian tiger shrimp polyculture) incl. the use of renewable electricity	No	Henriksson *et al.* (2019)
Siting of OWS (MSP & fishery effects) in the US	Economic and distributional effects of the siting of a OR	Loss of revenue (US Dollar)	No	Yes, the complete displacement of commercial fishing would result in estimated direct output impacts to the regional economy of $5 million, leading to $11 million in direct, indirect, and induced impacts	Yes, loss of 150 Jobs, Total economic welfare losses were estimated at $14 million	Hoagland *et al.* (2015)
Siting of OWF in the Western Baltic Sea	Impact of OWF on the distribution and population development of Jellyfish	Experiment with settlement plates	Yes, OWF can function as anthropogenic generated substrate for Jellies	No	No	Janßen *et al.* (2013)
Siting of wind energy in the North Sea	Conflicts of OWF with non-wind uses at the North Sea and the consequences thereof	Distribution of fisheries (map with ICES rectangles) and loss of area	No	No	Yes, overlap with Fisheries	Jongbloed *et al.* (2014)

Case study	Indicator of impact	Impact quantification	Measure of ecologic impact	Measure of economic impact	Measure of socio-cultural impact	Reference
Impact of OR on benthic habitats in North Sea, English Channel, Irish Sea, Celtic Sea	Impact of OR on benthic habitat (North Sea ecoregion scale)	Biological traits approach of benthic communities	Yes, the significance of the "actual" footprint of impact arising from these human activities and their associated pressures (sediment abrasion, sediment removal, smothering, and placement of hard structures)	No	No	Kenny *et al.* (2018)
Identification of priority areas for MSP in Spain, North Alboran Sea	Potential conflicts among human activities; Impact of human pressures on marine habitats (European hake nurseries)	Present AQ installation (area) vs. Demersal trawling (h yr–1) (based on 4 years VMS data of trawler >15 m, 2007–2010). Cell size (9,7 km × 9.2 km) vs. planned OWF (area)	Yes, mapping of vulnerability and human pressures	No, just to reason the analysis, e.g. "European hake, with a mean economic value of 1981284 ± 613993 € yr–1 is economically the most important vertebrate fished by bottom trawling in the Spanish contiguous zone of the Alboran Sea"	Yes, mapping of spatial conflict potential	Muñoz *et al.* (2018)
Conflict analysis: OR vs. other marine uses in the US, West coast	Potential spatial use conflicts with wave energy development; Economic trade-off analysis between wave energy and fishing	Measures per unit area and quantitative measures	No	Yes, comparison of annual bottom trawl net revenue for each grid cell with the predicted NPV for wave energy facilities	Yes, total duration (thousands of h) fishing gear was deployed in overlapping areas, overlap of VMS pings, total distance traversed (millions of km) by different vessel classes	Plummer & Feist (2016)
Conflict analysis: OR vs. other marine uses in the US, West and East Coasts	Space use conflicts between OR and i) commercial fishing-related users (e.g., harvesters, processors, charter operators); ii) commercial non-fishing users (e.g., shippers, tug operators); iii) non-commercial users (recreational fishermen, boaters and scientists)	None, qualitative comparison of ocean space use values for commercial fisheries and marine renewable energy (based on expert knowledge & interviews)	No	Yes, perceived economic, social and cultural impacts of space use and potential changes in access	Yes, perceived use of place, including compatible and conflicting uses and ways of handling potential or real conflict; valued characteristics of place; economic, social and cultural impacts of space use and potential changes in access; communication strategies; preferences for communication and engagement; and perspectives on potential mitigation strategies	Pomeroy *et al.* (2015)
OR and fish migrations in the UK, Irish Sea	Impact of tidal stream device on fish school migrations	Overlap between device activity and fish school distributions (% activity time)	Yes, empirical fish distribution data based on moorings and echo sounder trajectories	No	No	Whitton *et al.* (2020)

Case study	Indicator of impact	Impact quantification	Measure of ecologic impact	Measure of economic impact	Measure of socio-cultural impact	Reference
Monitoring of impact of OR in the US, Massachusetts and Rhode Island coasts	Impact defined as influence on the resource, activity, or community (e.g. fishing community)	Quantitative measurements (% changes, change in CPUE, flow rates, etc.)	NA, nor empirical assessment, indicators to assess fish, fisheries, benthos, habitats and birds	No	No	Shumchenia, *et al.* (2012)
Economic trade off and conflict analysis in the US, Massachusetts	Trade-off analyses from economics, assessment of potential conflicts among OWF, commercial fishing, and tourism based on ecosystem services and the values they provide to sectors	Economic gains and losses: Quantitative measures ($) per unit areas	Yes, the bio-economic model accounted for resource dynamics	Yes, bio-economic model to assess loss and gains of spatial use options	No	White *et al.* (2012)
Trade-offs of ocean zoning in Northern Ireland's territorial waters	Fishermen's' perceived value for the ocean per unit area	Fishing value per unit area	Yes, biodiversity measures, conservation zones	Yes, fishing value per unit area, areas for renewable energy development	No	Yates *et al.* (2015)
CBA for MSP with OWF & fisheries in Taiwan, Zhanghua Area	Qualitative analysis of C&B of OWF overlapping with traditional fishing grounds	Qualitative analysis (only proposed rewards from OWF presented)	Yes, costs: impact on the entire marine environment, displacement, increased costs; Benefits: artificial reef effects, decline in (over)- fishing, space for aquaculture	Yes, proposed reward form of Fuhai offshore wind power generation (Planned reward items, Amount (USD), Payment method & Payment objects)	Yes, costs: the loss of traditional fishing grounds, security incidents, difficulties in finding new jobs because of age and education will affect the living of fishermen; Benefits: sightseeing, tours, education, provision of local knowledge and service	Zhang *et al.* (2017)

Source: Author based on data derived from a literature review

Note: The Case study describes the assessment context of the case study with its respective case study region; the Indicator of impact with the variables examined; the Impact quantification (e.g. quantitative measures for given management units); the Measure of ecological impact, economic impact and/or socio-cultural impact, if possible, given with the type of measure used). CBA = cost and benefit analysis, EEZ = exclusive economic zone, MCE = multi-criteria evaluation, MSP = marine spatial planning, NPV = net present value, OR = offshore renewables, OWF = offshore wind farm, VMS = vessel monitoring system

Table 6: Outcomes of the standardised literature review on the current knowledge on the impact of offshore renewables on fisheries or aquaculture (Part II)

Assessment output	Management scenario analysis	Gaps identified (by the authors)	Reference
Vulnerability scores (1 to 3), based on temporal extent, spatial extent, and sensitivity of species. Summed scores determine overall impact: low (3-4), moderate (5-6), high (7-9). Certainty of assessment is evaluated against existing literature	No	Limited studies on cumulative impacts and long-term effects on the food web; Lack of combined effects with other human activities, e.g. fisheries. No studies on impacts during decommissioning of OWF	Bergström *et al.* (2014)
Loss of fishing opportunity, expressed as loss in metric tonnes or %	No	Costs of fisheries displacement not included in ongoing assessments to establish OWF	Berkenhagen *et al.* (2010)
25 co-location sites were identified and the three most relevant (Fisheries & Tourism & Environmental protection; Underwater cultural heritage & Tourism & Environmental protection, and; Offshore wind & Aquaculture) were analysed in-depth. Result are among others general recommendations for overcoming obstacles to co-location development	No	No	Calado *et al.* (2019)
Maps of fishing effort per gear-type are provided	No	Logbook data are not available	Campbell *et al.* (2014)
Co-location of marine activities is feasible from an environmental and legal perspective, but the success and extent are site-specific	No	No	Christie *et al.* (2014)
Maps and counts of seal population numbers	No	No coordinated population monitoring or data collation of seal numbers	Cronin (2011)
Suitability maps	No	No	Flocard *et al.* (2016)
GIS based scenarios	Yes, development and visualisation of four scenarios that depict both the potential and the constraints of future OWF in the North Sea	Ecological limitations not included, such as bird migration routes, etc.	Gusatu *et al.* (2020)

Assessment output	**Management scenario analysis**	**Gaps identified (by the authors)**	**Reference**
Model-based output. 'If all six interventions are implemented, we demonstrate that global warming, acidification, eutrophication, land occupation, freshwater use, and fossil energy use could be reduced by between 28% and 49% per unit of fish'	Yes. 'Shortlist of possible interventions and innovations for more sustainable farming practices to meet Indonesian 2030 production targets	Some innovations could not be included in this study	Henriksson *et al.* (2019)
It is shown how the potential displacement of commercial fishing could affect the fishing industry directly, and the consequent regional multiplier effects on economic impacts, value added, local tax revenues, and employment are estimated	No	The likely behaviour of commercial fishermen who would be displaced by the windfarm has been ignored	Hoagland *et al.* (2015)
Model based on Lagrangian particle technique to model Jellyfish drift along Danish, German and Polish coasts	No	More detailed info on Polyp spatio-temporal distributions is needed to improve results	Janßen *et al.* (2013)
Maps and level of impact due to varying prioritizations/weighting of OWF priorities	Yes	Assigning monetary value to fisheries not possible due to lack of data	Jongbloed *et al.* (2014)
Map habitat sensitivity (score 0-1) to disturbance based on changes in benthic functioning	No	Functional responses of the larger, more mobile epifaunal invertebrates (e.g. crabs, bottom-living fish) not included	Kenny *et al.* (2018)
Based on the mapped Vulnerability scores (Vh), Swept per recovery time (Spr) scores and conflict scores, risk evaluation is carried out and priority areas for MSP are identified.	Yes, related to upcoming blue growth industries (AQ and OWF) that can double the conflict potential, especially in coastal waters where MPAs, trawling, AQ and extraction coincide. Future installation of OWF enters in conflict with offshore shipping and	No	Muñoz *et al.* (2018)

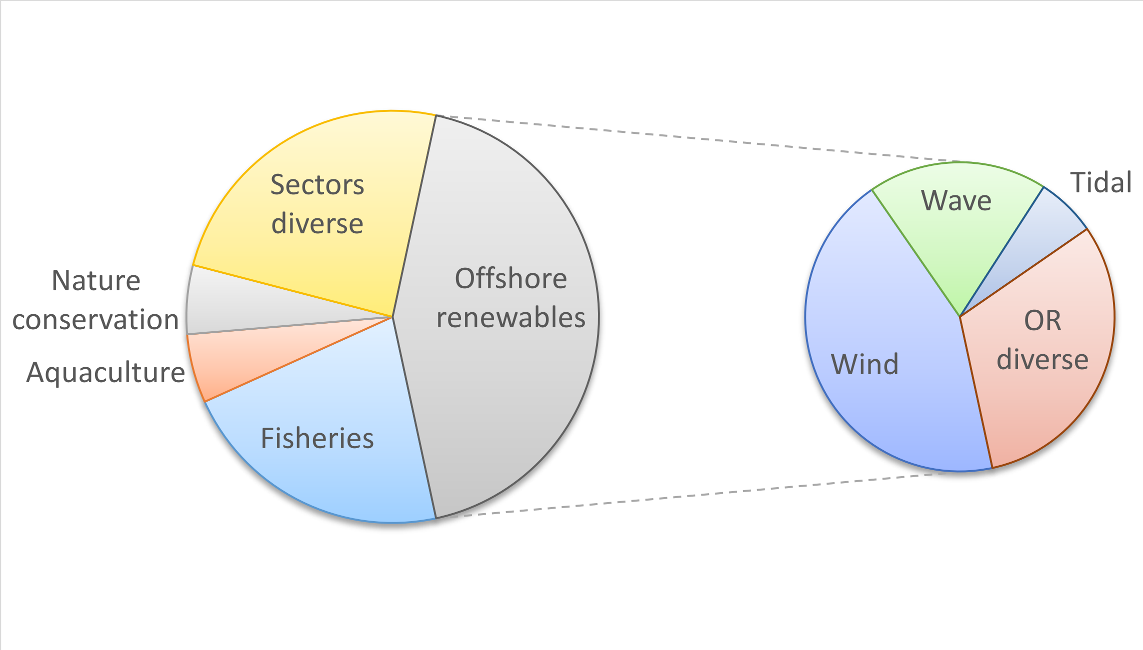
Assessment output	Management scenario analysis	Gaps identified (by the authors)	Reference
	migration corridors of great pelagic predators		
Map of conflict hot spots, more optimal wave farms sites tended to occur in areas with more marine uses	Yes, CS is a scenario -no real case	More in-depth analysis of conflicts for better assessments of economic consequences and trade-offs needed	Plummer & Feist (2016)
Maps: spatial distribution and magnitude of activity for each region's diverse commercial fisheries and on regulatory closed areas	No	No	Pomeroy *et al.* (2015)
No	No	No	Shumchenia, *et al.* (2012)
3 D graphs of economic values for each sector combination, shape of curves allows to define the strength of trade-offs	Yes, CS scenarios for different management strategies	No	White *et al.* (2012)
If all interaction between fish schools was to be avoided, the loss of operational time for tidal kites would be 6%. This information could also be used in planning the operating depths of OR devices to avoid or minimize overlap with fish schools and their predators by developers, and for environmental licencing and management authorities to gauge potential ecological impacts of different OR device designs and operating characteristics	No	Several, incl. possible avoidance behaviour of fish schools (proportion calculated is a 'worst case scenario'). The presence of demersal fish schools may be underestimated at dawn and dusk	Whitton *et al.* (2020)
Trade-off curves based on defined cost functions	YES, various zoning options were compared with a given set of conservation, development and fisheries targets	Costs for offshore energy development per unit area, revenues of energy sector per unit area	Yates *et al.* (2015)

Assessment output	Management scenario analysis	Gaps identified (by the authors)	Reference
Possible actions of combination of MSP and offshore wind power, e.g. guidance programme for cooperation between offshore wind power and fishery based on UK and US experience	No	No	Zhang *et al.* (2017)

Source: Author based on data derived from a literature review

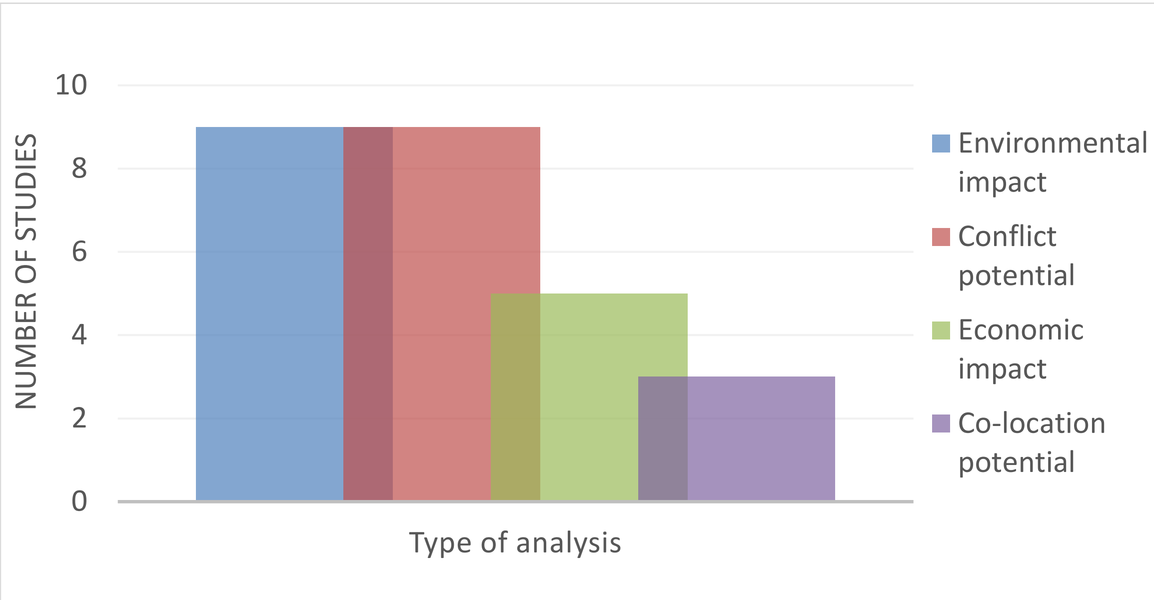
Note: The assessment output describes the type of output generated, e.g. maps or model output; the management scenario analysis indicates if a future management scenario has been assessed (if yes, which methods have been applied); and the gaps identified present the factors mentioned in the study that describe uncertainty. MSP = marine spatial planning, OR = offshore renewables, OWF = offshore wind farm

Figure 22: Sectors focused on during case study-specific effect assessment



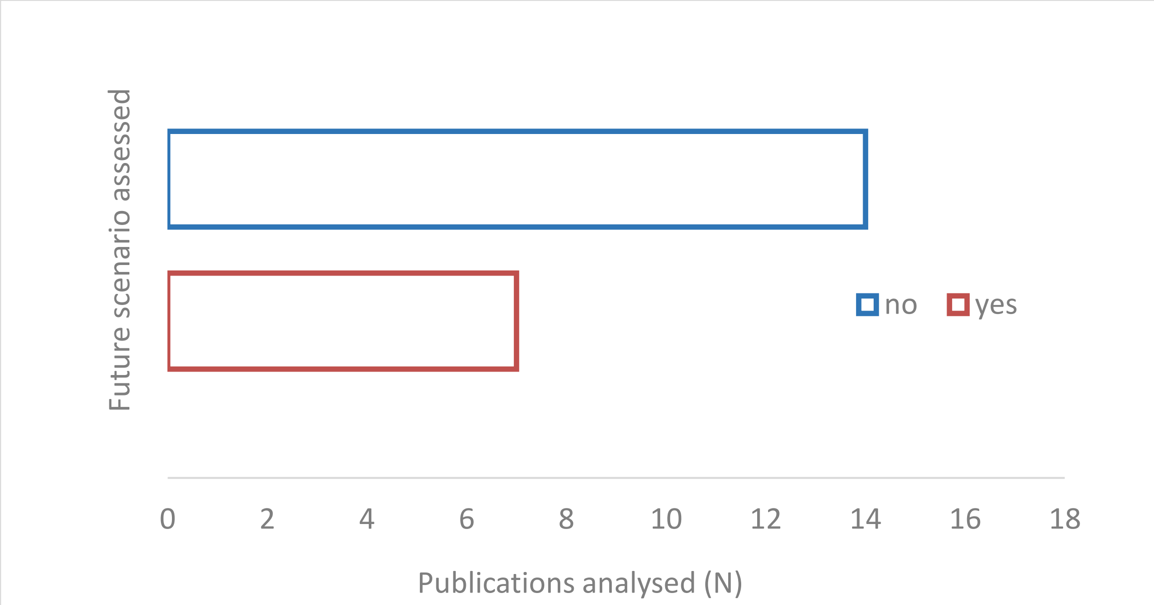
Source: Author based on data derived from a literature review

Figure 23: Type and aim of conducted effect assessment



Source: Author based on data derived from a literature review

Figure 24: Future scenario included (yes or no)



Source: Author based on data derived from a literature review

References

- Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Åstrand Capetillo, N. and Wilhelmsson, D. (2014). *Effects of offshore wind farms on marine wildlife—a generalized impact assessment*. Environmental Research Letters, 9, (3), https://doi.org/10.1088/1748-9326/9/3/034012.
- Berkenhagen, J., Döring, R., Fock, H. O., Kloppmann, M. H. F., Pedersen, S. A. and Schulze, T. (2010). *Decision bias in marine spatial planning of offshore wind farms: Problems of singular versus cumulative assessments of economic impacts on fisheries*. Marine Policy, 34, (3), 733-736. https://doi.org/10.1016/j.marpol.2009.12.004.
- Calado, H., Papaioannou, E. A., Caña-Varona, M., Onyango, V., Zaucha, J., Przedrzymirska, J., Roberts, T., Sangiuliano, S. J. and Vergílio, M. (2019). *Multi-uses in the Eastern Atlantic: Building bridges in maritime space*. Ocean & Coastal Management, 174, 131-143. https://doi.org/10.1016/j.ocecoaman.2019.03.004.
- Campbell, M. S., Stehfest, K. M., Votier, S. C. and Hall-Spencer, J. M. (2014). *Mapping fisheries for marine spatial planning: Gear-specific vessel monitoring system (VMS), marine conservation and offshore renewable energy*. Marine Policy, 45, 293-300. https://doi.org/10.1016/j.marpol.2013.09.015.
- Christie, N., Smyth, K., Barnes, R. and Elliott, M. (2014). *Co-location of activities and designations: A means of solving or creating problems in marine spatial planning?* Marine Policy, 43, 254-263. https://doi.org/10.1016/j.marpol.2013.06.002i.
- Cronin, M. A. (2011). *The conservation of seals in Irish waters: How research informs policy*. Marine Policy, 35, (6), 748-755. https://doi.org/10.1016/j.marpol.2011.01.006.
- Flocard, F., Ierodiaconou, D. and Coghlan, I. R. (2016). *Multi-criteria evaluation of wave energy projects on the south-east Australian coast.* Renewable Energy, 99, 80-94. https://doi.org/10.1016/j.renene.2016.06.036.

- Gusatu, Yamu, Zuidema and Faaij. (2020). *A Spatial Analysis of the Potentials for Offshore Wind Farm Locations in the North Sea Region: Challenges and Opportunities*. ISPRS International Journal of Geo-Information, 9, (2), https://doi.org/10.3390/ijgi9020096.
- Henriksson, P. J. G., Banks, L. K., Suri, S. K., Pratiwi, T. Y., Fatan, N. A. and Troell, M. (2019). *Indonesian aquaculture futures—identifying interventions for reducing environmental impacts*. Environmental Research Letters, 14, (12), https://doi.org/10.1088/1748-9326/ab4b79.
- Hoagland, P., Dalton, T. M., Jin, D. and Dwyer, J. B. (2015). *An approach for analyzing the spatial welfare and distributional effects of ocean wind power siting: The Rhode Island/Massachusetts area of mutual interest*. Marine Policy, 58, 51-59. https://doi.org/10.1016/j.marpol.2015.04.010.
- Janßen, H., Augustin, C. B., Hinrichsen, H. H. and Kube, S. (2013). *Impact of secondary hard substrate on the distribution and abundance of Aurelia aurita in the western Baltic Sea*. Mar Pollut Bull, 75, (1-2), 224-234. https://doi.org/10.1016/j.marpolbul.2013.07.027.
- Jongbloed, R. H., van der Wal, J. T. and Lindeboom, H. J. (2014). *Identifying space for offshore wind energy in the North Sea. Consequences of scenario calculations for interactions with other marine uses*. Energy Policy, 68, 320-333. https://doi.org/10.1016/j.enpol.2014.01.042.
- Kenny, A. J., Jenkins, C., Wood, D., Bolam, S. G., Mitchell, P., Scougal, C., Judd, A. and Degraer, S. (2018). *Assessing cumulative human activities, pressures, and impacts on North Sea benthic habitats using a biological traits approach*. ICES Journal of Marine Science, 75, (3), 1080-1092. https://doi.org/10.1093/icesjms/fsx205.
- Munoz, M., Reul, A., Gil de Sola, L., Lauerburg, R. A. M., Tello, O., Gimpel, A. and Stelzenmüller, V. (2018). *A spatial risk approach towards integrated marine spatial planning: A case study on European hake nursery areas in the North Alboran Sea*. Mar Environ Res, 142, 190-207. https://doi.org/10.1016/j.marenvres.2018.10.008.
- Plummer, M. L. and Feist, B. E. (2016). *Capturing Energy from the Motion of the Ocean in a Crowded Sea*. Coastal Management, 44, (5), 464-485. https://doi.org/10.1080/08920753.2016.1208877.
- Pomeroy, C., Hall-Arber, M. and Conway, F. (2015). *Power and perspective: Fisheries and the ocean commons beset by demands of development*. Marine Policy, 61, 339-346. https://doi.org/10.1016/j.marpol.2014.11.016.
- Shumchenia, E. J., Smith, S. L., McCann, J., Carnevale, M., Fugate, G., Kenney, R. D., King, J. W., Paton, P., Schwartz, M., Spaulding, M. and Winiarski, K. J. (2012). *An adaptive framework for selecting environmental monitoring protocols to support ocean renewable energy development*. ScientificWorldJournal, 2012, 450685. https://doi.org/10.1100/2012/450685.
- White, C., Halpern, B. S. and Kappel, C. V. (2012). *Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses*. PNAS, 109, (12), 4696–4701.
- Whitton, T. A., Jackson, S. E., Hiddink, J. G., Scoulding, B., Bowers, D., Powell, B., D'Urban Jackson, T., Gimenez, L., Davies, A. G. and Heino, J. (2020). *Vertical migrations of fish schools determine overlap with a mobile tidal stream marine renewable energy device*. Journal of Applied Ecology, 57, (4), 729-741. https://doi.org/10.1111/1365-2664.13582.
- Yates, K. L., Schoeman, D. S. and Klein, C. J. (2015). *Ocean zoning for conservation, fisheries and marine renewable energy: assessing trade-offs and co-location opportunities*. J Environ Manage, 152, 201-9. https://doi.org/10.1016/j.jenvman.2015.01.045.

- Zhang, Y., Zhang, C., Chang, Y.-C., Liu, W.-H. and Zhang, Y. (2017). *Offshore wind farm in marine spatial planning and the stakeholders engagement: Opportunities and challenges for Taiwan*. Ocean & Coastal Management, 149, 69-80. https://doi.org/10.1016/j.ocecoaman.2017.09.014.

The study provides an overview of general impacts of the development of offshore wind farms and other marine renewables on the European fishing sector. It further highlights pathways for possible co-existence solutions of both sectors, a description of best practice examples and lessons learnt, the identification of research gaps and last but not least the presentation of policy recommendations.

PE 652.212
IP/B/PECH/IC/2020-048

Print ISBN 978-92-846-7310-0 | doi:10.2861/410289 | QA-04-20-605-EN-C
PDF ISBN 978-92-846-7311-7 | doi:10.2861/617655 | QA-04-20-605-EN-N