Journal of Environmental Management 279 (2021) 111762

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Research article

Fishing within offshore wind farms in the North Sea: Stakeholder perspectives for multi-use from Scotland and Germany

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ARTICLE INFO

Keywords:
Commercial fisheries
Offshore wind
Co-existence
Stakeholders
Co-management
Marine spatial planning

ABSTRACT

Offshore wind power generation requires large areas of sea to accommodate its activities, with increasing claims for exclusive access. As a result, pressure is placed on other established maritime uses, such as commercial fisheries. The latter sector has often been taking a back seat in the thrust to move energy production offshore, thus leading to disagreements and conflicts among the different stakeholder groups. In recognition of the latter, there has been a growing international interest in exploring the combination of multiple maritime activities in the same area (multi-use; MU), including the re-instatement of fishing activities within, or in close proximity to, offshore wind farms (OWFs). We summarise local stakeholder perspectives from two sub-national case studies (East coast of Scotland and Germany's North Sea EEZ) to scope the feasibility of combining multiple uses of the sea, such as offshore wind farms and commercial fisheries. We combined a desk-based review with 15 semi-structured qualitative interviews with key knowledge holders from both industries, regulators, and academia to aggregate key results. Drivers, barriers and resulting effects (positive and negative) for potential multi-use of fisheries and OWFs are listed and ranked (57 factors in total). Factors are of economic, social, policy, legal, and technical nature. To date, in both case study areas, the offshore wind industry has shown little interest in multi-use solutions, unless clear added value is demonstrated and no risks to their operations are involved. In contrast, the commercial fishing sector is proactive towards multi-use projects and acts as a driving force for MU developments. We provide a range of management recommendations, based on stakeholder input, to support progress towards robust decision making in relation to multi-use solutions, including required policy and regulatory framework improvements, good practice guidance, empirical studies, capacity building of stakeholders and improvements of the consultation process. Our findings represent a comprehensive depiction of the current state and key stakeholder aspirations for multi-use solutions combining fisheries and OWFs. We believe that the pathways towards robust decision making in relation to multi-use solutions suggested here are transferable to other international locations.

1. Introduction

Global energy demand has been rising and, although the biggest proportion of this demand has been met by conventional energy sources (oil, gas and coal), the share of renewable power generation has been growing steadily. Renewables saw a growth rate of 4% in 2018, accelerating to their fastest growth rate this decade and providing 45% of the world's electricity generation growth (IEA, 2019). Wind energy (onshore and offshore) is currently the most competitive source of renewable power and already meets 10.4% of Europe's power demand (WindEurope, 2018). Offshore wind is now a mainstream energy source and has been steadily growing since the early 2000s with a cumulative total installed capacity of 15.8 GW in Europe. Most European offshore wind installations (71%) are situated in the North Sea (Fig. 1). Future

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https://doi.org/10.1016/j.jenvman.2020.111762
Received 8 June 2020; Received in revised form 22 November 2020; Accepted 26 November 2020
Available online 17 December 2020

growth of the European offshore wind market is predicted to concentrate mainly in UK and German waters. Combined, they are predicted to host over half of Europe's 70 GW offshore wind power cumulative capacity by 2030 (WindEurope, 2018).

Offshore wind energy generation requires large surface areas to accommodate the sector's activities at sea. It already occupies considerable areas of both the UK's and Germany's Exclusive Economic Zones (EEZ), specifically 6504 km^2 and 1129 km^2 respectively (4Coffshore, 2020). The North Sea is notable for its dense coastal populations, heavy industrialisation, and intense use of the sea (Emeis et al., 2014). Thus, the current and future predicted expansion of offshore wind energy in UK and German waters creates an interesting dynamic with other established maritime users. Similar required space characteristics (e.g. shallow water, specific depth ranges, sediment types, proximity to coast, etc.) often lead users to compete for access to the same locations (Holm et al., 2017). Increased claims for exclusive use of marine space from OWFs results in significant competition among stakeholders (Buck et al., 2004; Douvere and Ehler, 2009; Jentoft and Knol, 2014; Pomeroy and Douvere, 2008; Smith and Brennan, 2012). Other established and traditional maritime users, such as capture fisheries, often find themselves primarily concerned about exclusion from historically open fishing grounds and the resultant damage to their interests and livelihoods (Hooper et al., 2017; Roach et al., 2018).

More specifically, the concept of Multi-Use (MU) or the "the joint use of resources in close geographic proximity by either a single user or multiple users" (Schupp et al., 2019, p. 4), has received a lot of attention over the past few years (Brennan and Kolios, 2014; Buck and Langan, 2017; European Commission, 2018a; 2018b; Krause et al., 2011; MARIBE, 2016; Quevedo et al., 2013; van den Burg et al., 2016; Wageningen, 2018) and is forecast to play an integral role in future OWF development (Wind Guard, 2019).

The dynamic and wide-ranging distribution of commercial fisheries makes them ideal candidates for studying user interactions and the potential of multi-use solutions to mitigate spatial use conflicts. OWFs impede the movement of fishing vessels, constrain crossing or circumnavigation of fishing vessels, as well as excluding any fishing operations during their construction and (in many cases) operational phase, effectively acting as area closures (FLOWW, 2015; Gray et al., 2016; Kafas et al., 2018a; SeaPlan, 2015; Vries et al., 2015).

Excluding fisheries from OWFs has a range of negative direct and indirect economic, social and environmental effects on individual fishers, the fishing industry, fishery-dependant coastal communities and wider society (Kafas et al., 2018a). There is growing international pressure by the fisheries sector to change the *status quo* and encourage the re-instatement of fishing activities within offshore wind farms (Burdon et al., 2018; Christie et al., 2014; Fayram and de Risi, 2007; Hall and Lazarus, 2015; Hoagland et al., 2015; Jongbloed et al., 2014; Reilly et al., 2015; White et al., 2012; Yates et al., 2015; Zhang et al., 2017). More specifically, the argument has reached the public and academic discourse in several occasions in the UK (Ashley et al., 2014; Blyth--Skyrme, 2011, 2010; FLOWW, 2015; Gray et al., 2005; Groot et al., 2014; Hooper et al., 2017; Hooper and Austen, 2014; James and Slaski, 2006) and Germany (Berkenhagen et al., 2010; Griffin et al., 2015; Michler-Cieluch and Krause, 2008; Nicolai and Wetzel, 2017; Stelzenmüller et al, 2013, 2016; Wever et al., 2015). These initiatives are in line with Europe-wide efforts on scoping for potential combinations of multiple maritime activities in the same area, promoting a fundamental change to current thinking away from exclusive use of ocean space.

Comparing experiences from the two leading countries in the field of offshore wind energy (UK and Germany) can help to put scenarios for multi-use development into perspective. In this study, we take a stakeholder-focused mixed-method case study (CS) approach in two subnational cases, one focused on the East coast of Scotland and the other on Germany's North Sea EEZ (Fig. 1). Using this approach we aim to:

(i) Identify the current barriers to establishing this MU combination,
(ii) Capture the opportunities and drivers for MU combination,
(iii) Evaluate the resulting economic, environmental, and social effects, and ultimately
(iv) Present management recommendations to support progress in developing the decision-making process based on stakeholder perspectives from the two countries.

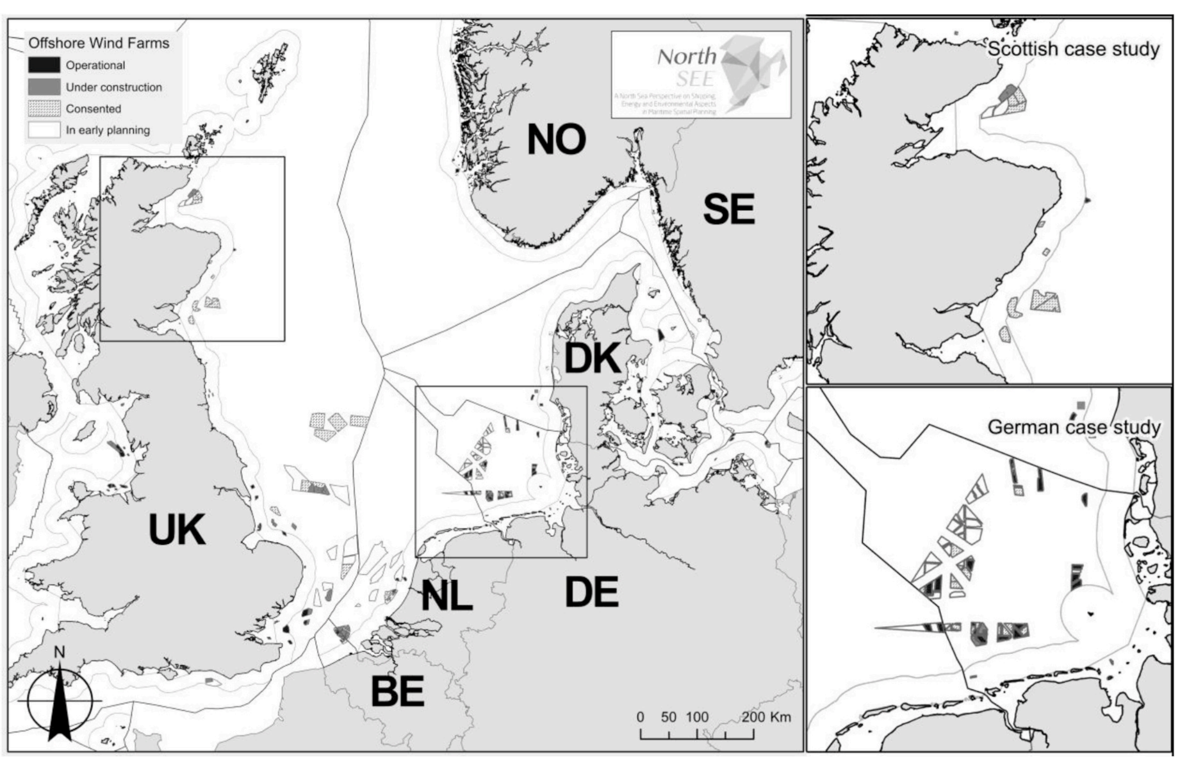

Fig. 1. Map of offshore wind farms in the North Sea and the two case studies (adapted from Kafas et al., 2018).

2. Case study description

The two case study areas chosen in this study are the German North Sea EEZ and the East coast of Scotland as depicted in Fig. 1. Fishing has a significant, millennia-long presence in the North Sea and is deeply rooted in society, especially in the coastal regions of the UK and Germany (Engelhard et al., 2014; Fock et al., 2014).

2.1. Fishery characteristics

The UK fishing sector landed 698,000 tonnes of sea fish (including shellfish) into the UK and abroad in 2018 using a fleet of 6036 vessels (MMO, 2019), with roughly 60% of the total catch being landed by Scottish vessels (Scottish Government, 2017). The German fishing sector is smaller than the UK's, following a drastic decline in the second half of the 20th century when states declared EEZs and limited access to international fishing vessels. German fisheries now land 261,000 tonnes annually with a fleet comprised of 1330 vessels in 2018 (BLE, 2019).

2.2. Offshore wind energy characteristics

The UK and Germany lead the European offshore wind market with 43.3% and 33.9%, respectively, of all installed offshore wind capacity in Europe in 2018. Both CS areas contain many OWFs at various stages, which occupy large areas of ocean space (30–400 km^2 per OWF), as well as future offshore wind planning areas (called Plan Options in Scotland and Offshore Wind Clusters in Germany). Utility-scale offshore wind developments are predominantly bottom-fixed and situated in relatively shallow waters (27.5 m on average), and comparatively close to shore (41 km on average; Wind Europe, 2018). However, the offshore energy industry is constantly evolving with new advancements in technology, such as floating wind farms (Scottish Government, 2015a), allowing larger developments of bigger and more powerful wind turbines to be built further offshore.

The Scottish CS hosts both fixed-foundation and prototype floating offshore wind farms, which made it an ideal UK candidate to explore perceptions of OWF developers. The German North Sea EEZ contains most of the country's installed OWFs and was thus chosen as the second focal point of this study to contrast Scotland.

2.3. Multi-use policies

MU policies within the CS areas are distinctly divergent. The UK and Scottish policy regimes (UK Parliament, 2011; Scottish Government, 2015b, Marine (Scotland) Act 2010, UK Electricity Act 2004) support commercial fishing activities within Scottish offshore wind farms (both offshore development areas and along the offshore export cable corridor). During the construction phase, a safety zone of 500 m around major construction vessels excluding fishing is put in place on a 'rolling' basis (covering only those areas of the total site in which such activities are physically taking place at a given time). During operation, installed infrastructure can be protected by safety zones of 50 m around fixed structures (or an appropriate size to incorporate its full size). Under these conditions, it is often assumed that fishing activities can resume to some degree. However, the ultimate decision to fish within an operational wind farm is down to the individual vessel skippers, who have been reported to avoid resuming fishing operations within constructed UK OWFs (Gray et al., 2016).

In Germany, different uses are assigned "priority areas" under the German Marine Spatial Plan (MSP) (BMVBS, 2009a; 2009b, 1997). "Priority areas" assign a maritime user priority over other user groups. Uses that are not compatible with the priority use are not permitted within this area. In the case of offshore wind, priority areas for OWFs adhere to strict safety regulations and, for the most part, constitute exclusion zones to any other users, including commercial fisheries. Fisheries do not have assigned priority areas due to the high spatial variability of their fishing grounds and a management system controlled primarily by the EU Common Fisheries Policy (European Commission, 2013). Instead, they are awarded special considerations in the priority areas of other uses, but no legal rights (BMVBS, 2009a). These special considerations must be considered by users and permitting authorities alike during the permitting process of offshore wind farms according to the ordinance on offshore installations (BMVBS, 2009a, 1997). However, this provision, although legally binding, does not yet result in MU combinations. Current opinion considers fisheries capable of hindering or endangering construction, operation or maintenance of the OWF (BMVBS, 2009a). This has led to a state where fishing operations, whether mobile or static, are *de facto* not permitted inside the security zone of OWFs (500 m; BMVBS, 2009b). The approach adopted is contradictory to a series of German studies since 2000 (see Buck et al., 2017 for a review) which offer solutions for multi-use concepts with respect to technologies and designs for the MU of OWF areas with aquaculture and fisheries.

3. Materials and methods

3.1. Stakeholder mapping and identification of interviewees

A stakeholder mapping exercise identified key stakeholders on the meta-level for each CS. These comprised industry stakeholders from offshore wind and commercial fisheries sectors (both companies and cognate cluster associations), with active business interests within the locality of the two case studies, National regulators, marine planners, and academics of relevance to the case studies were also included as candidate stakeholders and approached where available (see Supplementary Material 1, Table 1 for Scotland and Table 2 for Germany). Available interviewer resources were targeted at representatives of wide cluster associations or industry leaders rather than individual companies, where possible. We assumed that industry associations, having close ties to and personal experiences in the industry, would represent their respective sector accurately and objectively. In cases where associations could not be reached, a random selection of remaining stakeholders was interviewed while keeping the balance between offshore wind and fisheries interests. It is assumed that this approach was best suited to reaching saturation and allowed the collection of a comprehensive catalogue of factors indicative of the wider stakeholder communities' current understanding of the multi-use scenario.

Energy interests included both the national renewable energy industry bodies, and individual energy companies who had submitted a consent application to the respective marine licencing authority (BSH, 2017; Marine Scotland, 2017). Commercial fisheries interests included national federations, and individual local associations who had responded to the respective statutory consultations. Additional candidates, comprising domestic and international experts, were included to share their relevant experiences. Eventually, 26 candidate stakeholders were identified for the Scottish CS and 19 for the German CS. Not all candidate stakeholders were responsive or available for an interview. Out of the available interviewees, a total of 10 semi-structured stakeholder interviews (n) were undertaken for the Scottish CS and 5 for the German CS while keeping a balance between both sectoral interests and including regulator and academic viewpoints. Participating in the Scottish CS were three representatives from the offshore wind sector, four from the fisheries sector, two from academia and one key regulator. Participating in the German CS were two representatives from the offshore wind sector, and one key presentative each from fisheries, the regulatory agency and academia.

Interviews took place between July 2017 and October 2017. Where possible, face-to-face interviews were conducted in a personal setting. In some cases, interviews were undertaken via videoconferencing facilities. Interviews lasted 2 h on average. All interviewees agreed for their information to be included in the study. Some stakeholders wished to remain anonymous at an individual or organisational level.

3.2. Desk-based review and interview methodology

A desk-based review was complemented and validated using semi-structured qualitative. The review established the national policy and legal *status quo* contexts with respect to MU combination in Scotland (with links to UK policy where relevant) and Germany. Semi-structured interviews, following the methodological guidelines set out by Bernard (2006), with key stakeholders from the two sub-national case studies, East coast of Scotland and German North Sea EEZ, documented industry perceptions at a local level. The study followed the methodology described in Zaucha et al. (2017) and Bocci et al. (2019).

The review assessed the state-of-the-art literature regarding the opportunities and obstacles of multi-use solutions in Scotland and Germany, prior to engaging any stakeholders. *Grey* literature included national marine plans, sectoral plans, marine management legislation, as well as other associated strategic policy documents and sectoral reports. Scientific literature targeted references to the MU combination, based on a combination of key words, including: "offshore wind AND fisheries", "co-location", "co-existence", "co-management", "co-production", "multi-use", "multi-resource use", "secondary use", "symbiotic use", and "multiple ocean uses". The aim was to collect evidence of factors that (i) support the MU combination (drivers), (ii) hinder the MU combination (barriers), as well as (iii) result in positive effects and (iv) negative effects. Here, positive effects relate to the benefits received by a stakeholder group or society when implementing multi-use concepts. Negative effects comprise detriments i.e. damage to stakeholders' or society's interests by the MU combination coming into being. A catalogue of all four components (drivers, barriers, positive and negative effects) was compiled and became available for review and scoring by stakeholders during the semi-structured interviews.

The semi-structured interviews followed two steps. Before the start of the interview, stakeholders were asked to read and sign a consent form, which committed authors to high ethical standards and to safeguarding the data privacy of the interviewees. The first part of the interview was guided using a range of open-ended questions regarding MU development (see Supplementary Material 2 – Table 3), in order to guide the interview and centre the topic firmly on multi-use, rather than sector specific, issues. These questions prompted them to share their local experiences by identifying policy, industry, and other drivers that, in their opinion, facilitate or encourage the MU combination. Similarly, they were asked to identify any barriers to MU with regard to their current status of information. Their views on the stated positive and negative effects of the MU combination were also collected. Stakeholders were invited to comment on the potential for MU extensions (innovative ways to enhance MU extending beyond the two named sectors, resulting in further benefits), and to identify any management interventions needed to overcome barriers or enhance MU.

Building on this first section, individual stakeholders were asked to review and score the initial catalogue of factors compiled from the literature review based on their understanding of the multi-use scenario. Any new issues identified during interviews were included in the revision of the catalogue and stakeholders were given a chance to score all additional factors in their respective case study after the initial interviews. A semi-quantitative scoring system for factors was applied with 4 levels based on their perceived influence on the MU combination (0 – no strength, 1 – low, 2 – medium, 3 – high); as per Bocci et al. (2019). The scoring system allowed arithmetic averages to be calculated. Drivers and positive effects were scored positively (between 0 and + 3), while barriers and negative effects were scored negatively (between 0 and -3). When a stakeholder did not agree with a factor or had no knowledge about it, the factor received no score (NA). Scoring of factors by stakeholders in this manner allowed the calculation and comparison of average category scores in order to derive common priorities in addressing challenges and capitalising on synergies. Interviews were not recorded and transcribed due to data privacy concerns raised by the stakeholders. Relevant key points during the interview were instead noted by the interviewer and immediately reread to the interviewee in order to reaffirm that they accurately represent the intended meaning.

Finally, after completion of the interview stage, factors included in the final catalogue (collected via desk research and validated, refined and complemented by interviews) were grouped thematically into five categories: economic, social, policy and legal, technological and environmental.

Results from both CS were combined into a single integrated catalogue for analysis. Average scores for the integrated factors and categories were calculated by averaging the scores of all factors in each category from all interviews. In addition, summary tables listing sector-specific factors include separate average scores for Scottish and German stakeholders to allow for initial comparison of country differences. The results of the interviews were collated and the identified management recommendations for the MU combination set into the context of national and international parallel developments. All analysis and production of figures was undertaken in the R statistical environment (R Development Core Team, 2008).

4. Results

All factors collected via desk research and their verification via the semi-structured interviews in both countries were merged in a single integrated catalogue for analysis. A summary of all factors in the catalogue and respective average scores from all stakeholders is provided in Fig. 2. A total of 57 unique factors (*f*) were identified and scored by stakeholders, including 16 Drivers, 16 Barriers, 18 positive effects and 7 negative effects. There was a large diversity in scoring applied by interviewees. Not all stakeholders scored all available factors. No factor was unanimously scored by all stakeholders. In all cases, factors were scored by a subset of stakeholders (approx. 58% of stakeholders on average). Overview tables explaining the factors along with scores for the offshore wind sector (Table 4), commercial fishing sector (Table 5), and government (Table 6) are provided in Supplementary 3. Average factor scores are shown for Scottish (SCOT; $n = 10$), German (DE; $n = 5$), and all stakeholders together (ALL, $n = 15$). Fig. 3 presents average scores for all categories of factors. The category of drivers which received the highest average stakeholder score were economic drivers. Stakeholders scored the categories of barriers roughly equal with the policy and legal category ranking last. Category scores for positive effects had very small score differences. The categories of negative effects were scored, in descending order of strength, as social, economic, and environmental. Finally, stakeholders proposed management measures based on their experience. Recommendations addressed the removal of barriers or enhancement of drivers for the MU combination. Stakeholders' recommendations jointly resulting from all interviews were collated and edited by authors and summarised in Table 7T.

5. Discussion

Building on international stakeholder consultation processes in relation to multi-use of space by offshore wind farms and fisheries, we identify industry-wide factors and derive management recommendations to progress the decision process of the MU combination. Integrated results encourage mutual learning between the case studies and allow for wider applicability of the management recommendations outside the case study areas. We found that the offshore wind industry shows a low interest in multi-use of any kind, unless clear added value is demonstrated, and no risks are involved. Fulfilling legal requirements, avoiding potential costs from delays and maintaining a good company reputation are the strongest drivers for the wind sector. In contrast, the commercial fishing sector is proactive towards multi-use projects and acts as a positive driving force for MU developments, since it, along with structurally weaker coastal regions, stands to be impacted most if MU is not implemented. Perceptions around safety of operations, and issues with data

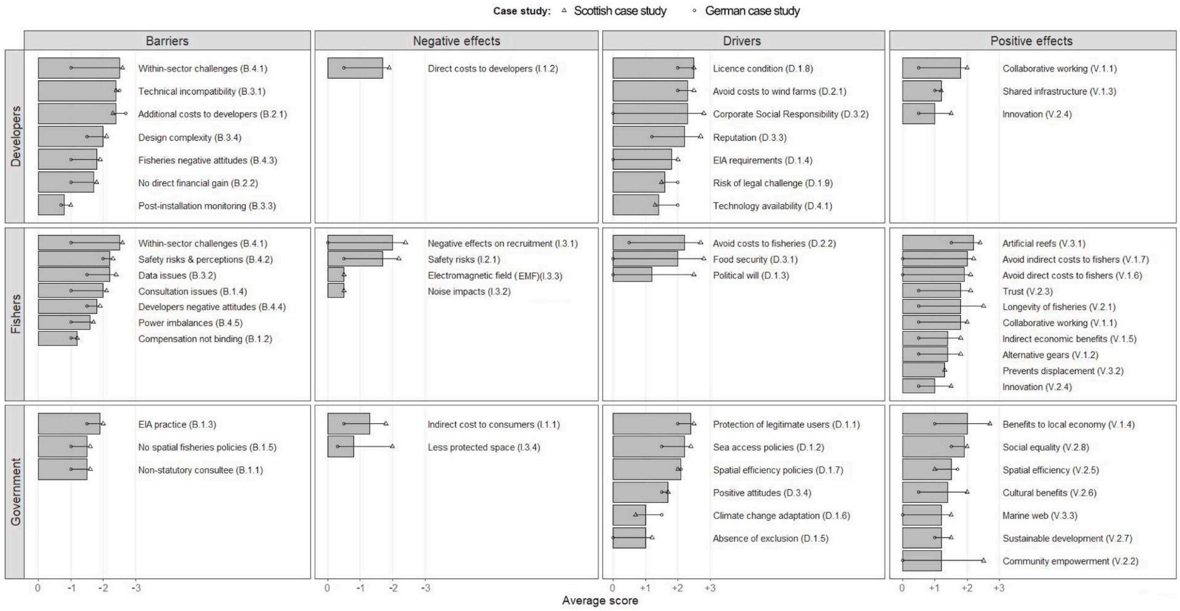

Fig. 2. Integrated catalogue including all factors by stakeholder group. Factors are ranked in each panel based on stated importance (average score). Bars show average factor scores for all stakeholders, while points show scores separately for each case study. For more detailed definition of factors please see the catalogue of factors in Tables 4 (developers), 5 (Fishers) and 6 (Government).

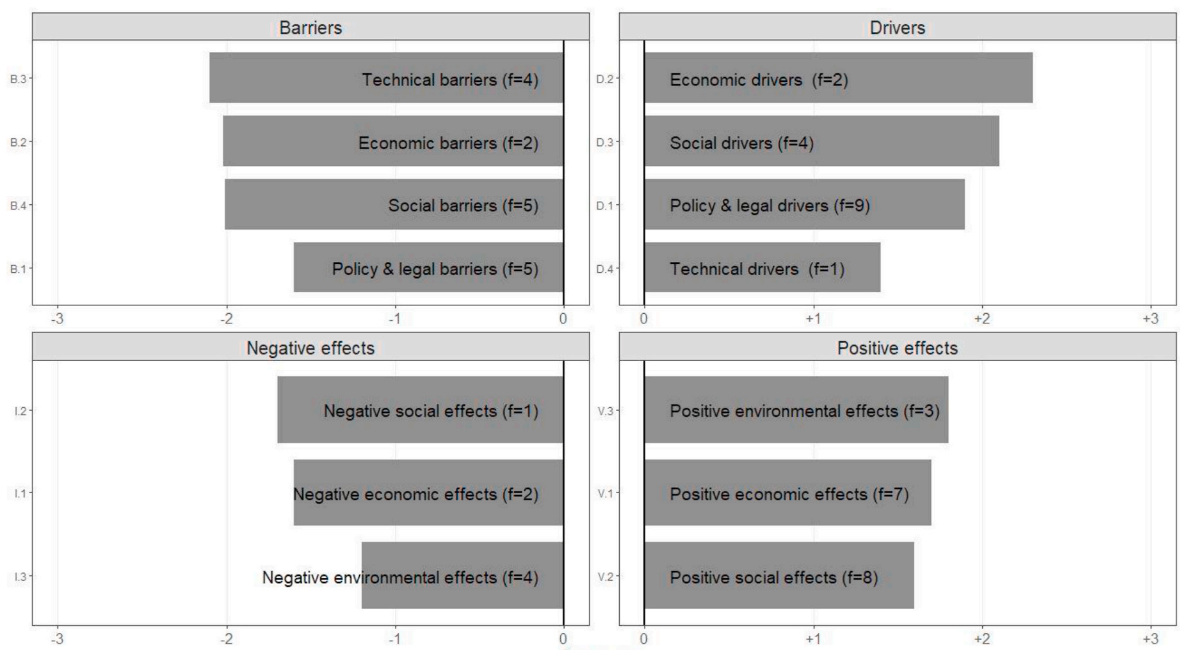

Fig. 3. Categories of factors in the integrated catalogue ranked by average score.

and consultations are the strongest barriers faced by the fishing sector. An interesting dichotomy appears in the negative effects perceived or feared by representatives of the fisheries sector. Fig. 2 shows a perceived negative impact of the MU combination on recruitment of target fin fish species. This factor was only raised by representatives in the Scottish CS and potentially shows an awareness of fishermen of environmental spill over effects of OWFs.

There are big differences in average factor scores between the two case studies (see Fig. 2). It is likely that this, in part, reflects the policy framework in regards to the MU combination in each country. Despite the limited geographic scope of the study on the global scale, the two countries represent the extremes of the range of current European policy attitudes towards this MU combination within a similar policy and natural environment, one allowing (Scotland/UK) and the other “in essence” prohibiting (Germany) fishing activities within operational domestic offshore wind farms.

Our approach allows the lessons learned to be easily transferred to other multi-use locations around the North Sea, where management styles within the same spectrum are adopted (e.g. Belgium, Denmark, and the Netherlands; Stelzenmüller et al., 2013) or abroad. Transferring results to other cases like the USA or South Korea, where conflicts between fishery representatives and OWF developers are taking centre stage in the development of offshore renewables (Kim et al., 2018; ten Brink and Dalton, 2018), will require a detailed stock-taking of the respective stakeholder landscapes, power dynamics, policy and regulatory frameworks and goals.

It also needs to be noted that the factor scores presented here only provide a baseline of stakeholders' subjective perceptions of the MU combination. Readers should treat individual scoring, overall ranking of factors (f=57), and score differences between CS as qualitative indicators of the knowledge and perceptions of the involved stakeholder groups.

A larger sample of stakeholders is needed in order to provide a quantitative assessment of all perceptions surrounding the MU combination. Due to this, no statistical comparison between countries was undertaken. Instead, CS scores are presented separately along with narrative text, where relevant. Repeating the analysis and including a larger sample size might potentially skew the results of the factors catalogue and scoring. The combination of a desk-based review of previous relevant research outcomes and grey literature with stakeholder engagement might serve to minimize any potential impact of a larger sample size. Similarly, the use of qualitative data from interviews harbours problems in that it is, by design, highly subjective. The data obtained in this way will invariably be coloured, based on the normative and professional backgrounds of the study's participants, by survey response bias. A different factor which could possibly influence the results of future studies would be the inclusion of other actors such as environmental interest groups or other special interest groups.

These limitations of the methodology need to be considered when evaluating the gathered data. Single sector viewpoints could otherwise dominate the discourse while divergent but equally valid opinions could go uncaptured. However, careful stakeholder selection and balancing, as well as the use of semi-structured interviews to guide the discussion, try to maintain the applicability of the gathered data.

5.1. Management recommendations

The results presented here demonstrate that stakeholders have high expectations for the range of benefits and positive effects from the MU of OWFs and commercial fisheries. However, the MU combination also faces several barriers and has been associated with negative effects. Stakeholder perceptions seem to mirror this, as shown by the wide range of barriers and negative effects perceived. Drivers can only have an effect in the absence of barriers, which require proactive management for their removal. Stakeholders were therefore invited to offer management recommendations to overcome those barriers and enhance the MU combination (Table 1).

Table 1
Management recommendations to remove barriers or enhance drivers for the MU combination.

	Management recommendations	Most relevant factors addressed
Policy framework improvements		
1	Undertake "MU opportunity" mapping - encourage overlap between the two industries and demonstrate the potential benefits of coexistence.	D.1.1, D.1.7
2	Provide financial incentives for the MU combination (e.g. via state subsidy contracts).	D.2.2, D.3.4, B.2.1, B.2.2
3	Encourage innovation by reducing the scope of full-scale assessments for small-scale MU pilots.	D.2.1, B.2.1, B.3.1, B.3.4
Regulatory framework improvements		
4	Further improvements in assessment methodologies as part of the EIA and CIA processes.	D.1.8, D.1.9, B.1.3, B.3.2
5	Establish mutually-agreed co-existence plan between the two industries as part of the marine licencing process.	D.1.4, D.1.8, D.1.9, D.3.2, D.3.3, B.1.1, B.1.4, B.4.4, B.4.5
Good practice guidance		
6	Develop good practice technical guidance on co-design of OWFs to accommodate multiple uses, including commercial fisheries	D.1.2, B.2.1, B.3.4, B.4.4
Empirical studies		
7	Fund and/or encourage in situ gear trials and Research and Development projects (R&D)	D.1.1, D.1.4, D.1.8, D.3.2, B.4.2
Consultation and capacity building		
8	Reinforce and formalise direct stakeholder dialogue to exchange best available information and technology on all aspects of the MU combination	D.1.4, D.3.3, D.4.1, B.1.4, B.3.2, B.4.2, B.4.3, B.4.4, B.4.5
9	Increase stakeholder's knowledge and financial capacity via educational resources and community funding, respectively.	B.4.3, B.4.4

5.1.1. Policy framework

It was noteworthy that stakeholders in both countries advocated for more explicit references to MU within the policy framework. This calls for policy transformations, as it requires governments to adapt their management-style from reactive to proactive in relation to the MU combination. More specifically, some stakeholders stated that there are certain fleet segments that will be less compatible (e.g. mobile gears) within offshore wind farms than others. They assumed that this may present an opportunity for alternative fleet segments operating more compatible gears (e.g. pots) to benefit. In cases where new segments have a smaller environmental footprint than the previous ones, establishing OWFs in carefully selected areas can contribute to fisheries management initiatives (e.g. reduction of a fleet segment in certain areas; promotion of sustainable fishing practices) and to wider marine conservation efforts (links to *de facto* Marine Protected Areas; Inger et al., 2009; Tien and van der Hammen, 2015; Vries et al., 2015; Rouse et al., 2017). They referred to this concept as "MU opportunity mapping", where overlap between the two industries in a certain area is targeted rather than avoided. This is converse to traditional "constraints mapping" approaches often adopted in sectoral planning initiatives (e.g. Scottish Government, 2013; Scottish Government, 2018) and is expected to be of particular relevance to floating wind developments which bring additional challenges to the fishing industry due to the presences of cables throughout the water column (NERC, 2016).

Furthermore, most stakeholders suggested the provision of clear incentives for the MU combination. One form of incentives (financial) target existing state mechanisms for renewable energy supply contracts (e.g. UK Contracts for Difference). Assessment criteria can favour developments that maximise the sea use potential and enhance MU with other sea users, such as commercial fisheries. Evidence for co-location opportunities with fisheries can be provided via a supply chain plan (e.g. by listing employment opportunities for local fishing vessels), and commitment to fund gear trials to test the safety of available equipment and develop new gear adapted to operating inside OWFs. Another form of incentive (cost savings) targeted innovation. Innovation can be encouraged by reducing the scope of full-scale assessments for small-scale pilots demonstrating the MU combination (similar to the Scottish Survey, Deploy, and Monitor Policy applied primarily to small-scale ocean energy developments; Scottish Government, 2016).

5.1.2. Regulatory framework

Recommendations by stakeholders also extended to overcoming pitfalls of the current regulatory framework and associated assessments, including Environmental Impact Assessment (EIA) and Cumulative Impact Assessment (CIA) processes as echoed by Stelzenmüller et al. (2020). For example, definitions of the level of significant effects on fisheries are not harmonised across EIAs, and assessment of some effects, such as fisheries displacement, have previously been discounted due to a lack of relevant assessment tools or not easy-to-use decision-support tools (Pınarbaşı et al., 2017). Collectively these oversights may undermine the true cumulative impact on fishers (Berkenhagen et al., 2010; Campbell, 2015). Additional focus should be given to assessment frameworks, including the cumulative impacts or benefits of MU scenarios, and quantifying the resulting socio-economic effects, in order to support decision making. Regulatory frameworks in both cases are also missing requirements on multi-use insurance models. This causes steep premiums for indemnity policies for activities potentially dangerous to the OWF infrastructure or operations. Both actors need to be provided comprehensive insurance to protect the other actor from potential harm in such a multi-use situation. Making sure the insurance burden on the smaller actor is not disproportionate might require regulatory intervention and assurance from the regulators and policy makers.

In the German CS, it was suggested that the relevant German licensing authorities on the federal level could develop the MU decision making process by requesting a mutually-agreed co-existence plan between the two industries, prior to the submission of a licence application. The plan would detail OWF design variables, and installation methods adopted. This is similar to the Commercial Fisheries Mitigation Strategy (CFMS) for proposed OWFs adopted in Scotland (e.g. BOWL, 2015). An alternative recommendation included use of a "Statement of Common Ground" (SCG) between developers and impacted fishermen (mostly an English practice e.g. SMartWind, 2018), which can be a good starting point towards a full CFMS. No direct equivalent of CFMS or SCG exists in Germany. The implementation of CFMS in Scotland would benefit from an earlier adoption, prior to the submission of a marine licence application. Earlier agreement on the mitigation strategy (prior to securing a marine licence) will aid with stakeholder power imbalances. Currently, most of the mitigation options are examined, and agreed post-consent, by which point the perception is that developers already have the upper hand.

5.1.3. Good practice guidance

Stakeholders from both countries encouraged the idea of developing a good practice technical guidance on co-design of OWFs to accommodate multiple uses. In relation to commercial fisheries, the guidance could propose a protocol for better integration and interpretation of fisheries distribution data layers within EIAs, set gear specification for safe operation within OWFs, suggest design adjustments (e.g. turbine spacing, cable burial depths, specifications of cable protection measures, scour protection etc.), propose business models for data sharing agreements and protocols between industries (e.g. for sharing ROV footage and bathymetric survey data by developers to demonstrate to fishers that fishing can take place safely within the wind farms), offer information about alternative employment opportunities (e.g. Gwynt y Mor OWF; Hattam et al., 2015) and, very importantly, make a business case for the benefits to developers when adopting such recommendations. Demonstrating benefits towards corporate social responsibility, company reputation, faster and smoother licensing are all expected to be favourable to developers.

Such guidance needs to be developed by or under the oversight of the regulatory authority in order to prevent power imbalances between actors to impede development progress. Existing best practices on consultation processes may serve to develop effective methods of co-designing socially sustainable frameworks.

5.1.4. Empirical studies

It was suggested by many stakeholders that empirical studies exploring the compatibility between OWFs and commercial fisheries can drive insurance costs down, boost fishing industry confidence to return to fishing grounds (if communicated effectively) and can have financial benefits to both parties. Both industries will need to be directly involved to ensure scientific results propagate fully into practice. Hence, a new mode of knowledge production is called for that centres around co-production, allowing potential direct uptake by practitioners. Funding for trials and R&D modifications in gear technology can be sourced, depending on the size the necessary investment, from local community funds, government funds, or directly from developers. Large utility-scale developers may be able to absorb the risks introduced by the novel nature of trials. Hence, they may be tasked to facilitate initial trials as part of licensing conditions. From this, findings may spread within the industry and attaining funding is expected to become successively easier. Recommendations took the form of in situ gear trials and Research and Development projects (R&D).

In situ gear trials can alleviate safety concerns by fishers (e.g. in relation to dropped objects, mud berms residue from construction vessels, and rock protection profiles). It can also alleviate concerns by OWF operators and build a larger knowledge base for insurers and drive down premiums. A similar practice has been adopted by the UK Oil and Gas sector where over-trawlability surveys were undertaken by fishing bodies who then issued an unobstructed seabed certificate (SFF, 2017). Such surveys within development areas will reinforce fishers' confidence to operate within OWFs and overcome safety objections.

R&D studies should focus on better mapping of navigational hazards (e.g. dropped objects during construction), gear technology and modifications (e.g. minimising seabed penetration of scallop dredge gears; Catherall and Kaiser, 2014), fishing-friendly mooring types (e.g. tension legs), cable installation and protection methods (with guaranteed burial depths, minimal sediment suspension and post-installation obstructions), and real-time monitoring of installed cables for detection of exposed sections (e.g. distributed fibre-optic temperature sensing systems; Selker et al., 2006). Stakeholders also mentioned R&D studies to further enhance the artificial reef effects of OWF by engineering turbine foundations or cable rock armouring to provide cryptic spaces that would benefit crustacean fisheries (primarily lobster; e.g. Stenberg et al., 2010; Lengkeek et al., 2017) and establishing alternative fishing practices (e.g. targeting a new species) within offshore wind farms (e.g. Stelzenmüller et al., 2016).

5.1.5. Consultation and capacity building

The most frequently mentioned recommendation related to the need for further strengthening of dialogue opportunities between relevant stakeholders. *Ad hoc* opportunities are currently channelled through informal professional networks and research projects. Most stakeholders highlighted the need for reinforcing these opportunities through a formal government-led forum (e.g. FLOWW, 2015). There is a clear need to establish an open and direct dialogue between key stakeholders (i.e. users, regulators, and certifying companies) to exchange the best available information and technology on all aspects of the MU combination. This will serve to alleviate safety concerns and showcase added value for all stakeholders involved. Cross-border exchanges between German regulators and other countries, where this combination exists already (e.g. UK or Denmark), to find commonalities and streamline management approaches will also benefit the MU combination.

Lastly, many of the consultation issues mentioned relate to the fishers' capacity to get involved and developers' understanding of the nature of fishing. Fishers' capacity limitations relate to available resources (time, financial, and human) and understanding of the planning and licensing processes. Developer's limited understanding relates to knowledge of fishing practices, seasonality, and gear specifications. Further educational resources to increase the capacity of stakeholders will help mitigate the issues currently faced. The format could be similar to current industry-run courses on commercial fishing facilitation (e.g. fishing awareness seminars; SFF, 2018). Limitations related to financial capacity of the fishing industry, could be addressed via fishing community funds. These can cover industry-wide costs e.g. certification/labelling of sustainable fishing practices in the vicinity of OWFs, new safety equipment for interacting fleets, electrifying energy-intensive processing plants (also referred to as corporate renewable power purchase agreement; Richter, 2012), and providing electricity to fishing vessels (linked to a long term vision of electric or hydrogen-fuelled transportation).

6. Conclusions

As the demand for ocean space increases, a fundamental change to current thinking away from exclusive use of ocean space is critical. Therefore, in the North Sea, fishing within or around offshore wind farms is increasingly and will continue to be a major topic in stakeholder debates.

Satisfying legal requirements, avoiding costs, and having a positive effect on reputation are the strongest drivers for the offshore wind sector. Avoiding interferences and minimising threats to livelihoods drive the fishing sector. Both sectors face sector-specific challenges that inhibit the general uptake of the MU concept as well as barriers related to additional costs, technical issues, perceptions and negative outlooks.

Based on the findings of this study, the offshore wind industry in either country has demonstrated a low interest in multi-use, unless clear added value could be demonstrated, and no risks for the respective businesses were involved. On the other hand, the commercial fishing sector is proactive towards multi-use projects and is a positive driving force for MU developments.

The comparative CS approach taken in this study has highlighted several important differences as well as similarities between the situation of the offshore wind energy and fisheries MU combination in the UK and Germany. Providing an integrated cross-country catalogue of drivers, barriers, positive and negative effects from both countries showcases the *status quo* on a trans-boundary level. It allows both preliminary comparisons and the formulation of industry-wide management recommendations to promote the development of the MU combination. However, the integrated factor catalogue presented here represents a snapshot of a fast evolving situation that is expected to change as the public and academic discourse on multi-use evolves in both case study areas. Future assessments will need to regularly take stock of the key factors governing this development.

Lastly, and maybe most importantly, if multi-use of ocean space is to become a potential sustainable solution for reducing conflict in MSP, a clear commitment is needed from policy makers towards this end. We argue that this requires a regulatory framework that guides the process of weighing multi-use options by considering both environmental and socio-economic impacts. Ultimately, MSP objectives and respective regulations are driving the implementation of spatial management measures.

Author contributions

Maximilian Felix Schupp: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review and editing, Project administration. Andronikos Kafas: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review and editing, Project administration. Bela H. Buck: Writing – original draft, Supervision. Gesche Krause: Writing – original draft, Supervision. Vincent Onyango: Writing – original draft, Supervision. Vanessa Stelzenmüller: Writing – original draft. Ian Davies: Writing – original draft, Writing – review and editing, Supervision. Beth E. Scot: Writing – original draft, Writing – review and editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Financial support for the conduct of the research, collection and analysis of data, as well as preparation of the article has been received by the European Union's Horizon 2020 research and innovation programme, under the MUSES project grant agreement No 727451. The authors would like to thank all stakeholder participants involved in the research and all project partners involved in the MUSES project. We acknowledge support by the Open Access Publication Funds of Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2020.111762.

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