TKI WIND OP ZEE
Topsector Energie

© MARIN - Multi-use concept in the Offshore Basin

Risk Mitigation Multi-Use Offshore Wind Farms

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1 Introduction

1.1 Background

In the coming years, offshore wind energy production on the North Sea will be scaled up significantly. Wind farms are currently taking up only 0.2% of the Dutch North Sea, but this is projected to grow with a factor of 100 to 20-25% in 2050. The innovation program 'Multi-Functional Space Use in Offshore Wind Farms' aims at minimising the negative effects of multi-use and find solutions to use the space within wind farms optimally, for example, by combining offshore wind with floating solar energy [1]. Multi-use technology is still under development. In 2019 Deltares carried out a study to explore future multi-use technologies. An overview of possible technologies is given in [4] and Figure 1 depicts some possible multi-use activities.

Figure 1 Multi-Functional space use in wind farms [1]

Although the experience with multi-use technologies is limited, it is obvious that multi-functional space use in offshore wind farms will introduce risks for both the wind farm operators and other stakeholders working in or passing through the wind farm area. These risks could be an obstacle in the development of multi-functional space use.

In order to stimulate multi-use in wind farms, TKI Wind op Zee would like to explore the solutions which can reduce the risks of multi-use and facilitate the development of these solutions. These solutions can be existing technology and solutions but also more innovative solutions. Therefore the overview of risk-mitigating solutions will serve as input for the TKI Wind op Zee research agenda. A second aspect TKI would like to explore is the insurability of multi-use risks; what are the options to insure these risks.

RVO requested MARIN to carry out a study to identify risk-mitigating measures and to explore the insurability of multi-use operations in wind farms.

1.2 Objective and approach

Over the last years, several risk analyses have been carried out to explore the risks of multi-use as well as risk-mitigating measures. However, these studies are more focused on risk identification and less on mitigating measures and the effectiveness of them. The objective of this study is first to create an overview of promising risk-mitigating measures and make recommendations for further research to develop mitigation solutions. The second objective is to describe how risks of multi-use operations can be insured.

To achieve the objective, the study has been carried out in the following steps. First, the available information was collected and reviewed, and the main risks are summaries in a risk table. Second, this risk table was discussed in an expert session, and for each risk mitigation measures were collected. The promising mitigation measures were further elaborated by MARIN's subject matter experts. Third, the main risks and mitigations were discussed with Marsh, an insurance company. Based on this overview, they prepared a memo describing their opinion on the insurability of risks of multi-use operations.

1.3 This document

This document describes the results of the study and includes the following sections:

- Section 2 Risk-mitigating measures
- Section 3 Insurability
- Section 4 Conclusions and recommendations

2 Risk-mitigating measures

2.1 General

This section focuses on the collection of risk-mitigating measures and the selection of the most promising measures. Section 2.2 describes the approach of the expert session. Section 2.3 summarises the main risks of multi-functional space use in offshore wind farms and Section 2.4 summarises the risk-mitigating measures. In Section 2.5 the collected mitigating measures are discussed.

2.2 Expert session

The starting point for this study is the Multi-Use Procedure Risk Register, set up by the Noordzeeboerderij [2]. The Risk Register is a structured overview of risks between Wind Farm Operator (WFO) and Multi-Use Operator (MUO) and quantifies the risk level (high, medium, low) of each risk. The Risk Register gives an overview of risks related to eleven (11) potential hazards:

1. Fixed structures offshore
2. Moored multi-use assets within a wind farm
3. Multi-use area operation
4. Offshore transportation
5. Offshore weather conditions
6. Operation in a complex industrial zone/ area
7. Operation of high voltage facility
8. People passing through the wind farm area
9. Personnel working in multi-use area
10. Personnel working in wind farm area
11. Wind farm operation

This study focuses on the risks as a consequence of multi-use in wind farm areas, Hazard 1, 2 and 8. From these hazards, the risks that are quantified as 'high' were selected for discussion in the expert sessions. Ref. [5]to [11] were used to check if main risks were missing and to collect risk-mitigating measures.

The risk table was then discussed and completed in two expert sessions[1].The following organisations participated in the expert session:

- TKI Wind op Zee;
- North Sea Farmers;
- Nederlandse Wind Energie Associatie (NWEA);

[1] Because of COVID-19 restrictions the expert session was split in two digital meetings instead of one physical meeting.

- Kustwacht Nederland;
- Wageningen Marine Research;
- Rijkswaterstaat Zee en Delta;
- MARIN.

2.3 Main risks of multi-use in wind farms

Appendix 1 - Summary main risk multi-use1 includes an overview of main risks related to multi-use, including the severity and probability rating and the direct and indirect costs.

The main risks of multi-functional space use in offshore wind farms are related to collision between vessels and wind farm assets or multi-use assets. For the risk level, the vessel size and speed should be taken into account. In general, it can be stated that the bigger the vessel or the higher the speed, the higher the severity rating and thus the risk. The same applies to collision with a drifting MU asset, big and heavy structures will result in more damage in case of a collision.

In this case, the vessels concerned are either vessels passing the wind farm area, vessels passing through the wind farm area or vessels working in the area. Most of the vessels working in the wind farm area are relatively small and are sailing at low speed. Vessels passing the wind farm area could be big vessels, sailing at high speed. The vessels passing through the area are in between in terms of size.

The main risks are summarised as follow:

- Collision between vessels working in the multi-use area (for installation, maintenance and e.g. harvesting) and wind farm assets (turbines, infield cables), leading to damage or human fatalities;
- Collision between vessels passing the wind farm area and wind farm assets (turbines, infield cables), either because of navigational error or a technical failure, leading to damage;
- Collision between vessels passing through the wind farm area and wind farm assets (turbines, infield cables), either because of navigational error or a technical failure, leading to damage;
- Collision between vessels working in the wind farm (for installation, maintenance) and multi-use assets, leading to damage;
- Collision between vessels passing the wind farm area and multi-use assets, either because of navigational error or a technical failure, leading to damage;
- Collision between vessels passing through the wind farm area and multi-use assets, either because of navigational error or a technical failure, leading to damage;
- Collision between drifting multi-use asset (because of mooring failure multi-use asset) and vessels in or in the vicinity of the wind farm area.

2.4 risk-mitigating measures

Currently Rijkswaterstaat is developing the Beleids- en afwegingskader Doorvaart en Medegebruik, which include preconditions for safe transit trough and multi-use in wind farms. The main preconditions are:

- Multi-use is only allowed outside the maintenance area of the wind turbines and infield cables. The maintenance area around wind turbines is 500 m radius and infield cables 250 m on both sides of the cable;
- Transit through the wind farm is only allowed through designated corridors;
- Working in the wind farm is only allowed during day time;
- Multi-use installations have to be offshore proof even in severe weather conditions.

These preconditions can be considered as the basic mitigating measures and were taken into account during the expert session.

The results of the expert session are included in Appendix 2, Column 1 to 7 describes the risk, including the original severity and probability rating. Column 8 describes the mitigating measure, and column 9 the corresponding category. The mitigating measures are classified into five categories. The categories are depicted in Figure 2, which also indicates the hierarchy of hazard control. The higher the category level, the more effective the measure is in reducing risks. In order to indicate the effect of a measure, columns 10 and 11 indicates whether a measure effects the severity and or probability: 'no change' (no effect on severity/ probability) or 'reduction' (reduction of severity and or probability).

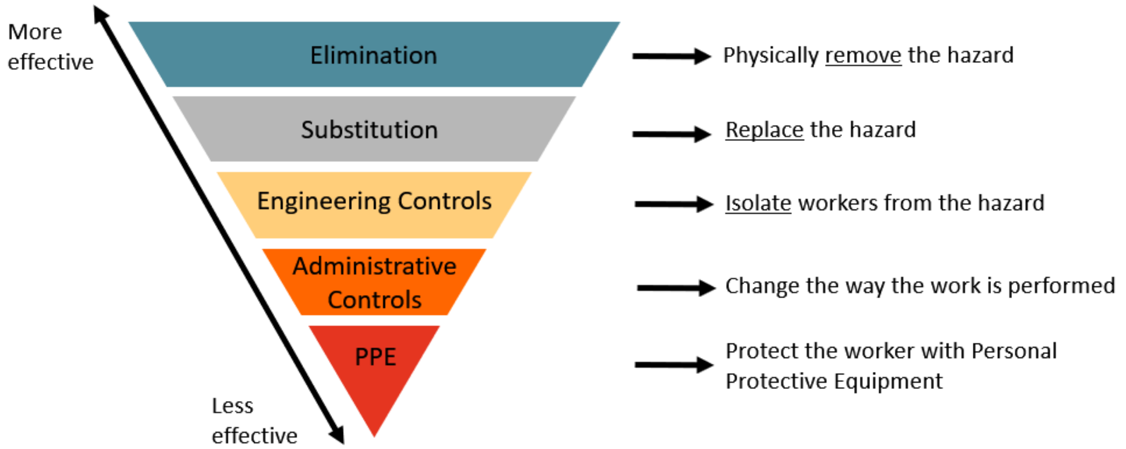

Figure 2 risk-mitigating measures categories

The identified mitigation measure is summarised per category below:

Elimination

- Surveillance related measures: Vessel Traffic Service coverage to the wind farm areas or surveillance by coast guard vessel/ planes. The objective of these measures is to remove the hazard (in this case, vessels which are not supposed to be there) from the wind farm area;

- Automatic anomaly detection. This is a more innovative solution of surveillance. In this case not an operator but an algorithm automatically detects unusual vessel behaviour or vessels entering a prohibited area and alarms an operator. This requires sensors or systems (e.g. radar) to be installed at or in the vicinity of the wind farm area which are able to detect vessels;
- Additional emergency towing vessels to remove the hazard (e.g. drifting vessels with engine or rudder failure) and avoid vessels drifting into the wind farm area.
- Reduction of the number of vessels working in the wind farm or multi-use area by smart materials or design, remote maintenance, smart maintenance planning or by combining maintenance of wind farm and multi-use assets.
- Deployment of autonomous or remote controlled vessels for installation and maintenance.

Substitution

- Deployment of autonomous or remote-controlled vessels. In order to increase safety and thus reduce human severity, autonomous or remote controlled vessels can be applied for maintenance in the wind farm/ multi-use areas. Although the developments of autonomous vessels are rapid, deployment of these vessels requires significant more research.

Engineering

- Robust design of the multi-use installations and mooring constructions and suitable maintenance regime. Currently there is only limited experience with these constructions and how they will behave on longer terms. Also design specifications for these kinds of constructions are not yet available. The design and maintenance of multi-use installations requires significantly more research.
- Design solutions in order to increase the visibility of the assets (intact or drifting after failure), such as navigational aids, radar reflectors and technologies like emergency beacons that will automatically be activated and begins transmitting a radio signal in case of an emergency;
- Detection sensors and radar on the boundary of the windfarm and MU area to alert a vessel (e.g. by a light or sound signal) if it is too close to an asset. The sensors can also be part of an anomaly detection system and alert e.g. an VTS operator (as mentioned above);
- Collision protection of the assets or rock protection of the infield cables in order to reduce the damage in case of a collision.
- Collision avoidance, e.g. design of submersible multi-use asset. In case of a drifting vessel approaching the area, the asset is temporarily submerged in order to avoid damage;
- Development of support systems on-board vessels, such as collision avoidance or object detection systems. These systems could alert the crew on-board and reduce the probability of a collision;

Administrative controls

- Proper information of public, commercial and recreational shipping. This could include accurate and detailed indication of the wind farm and multi-use areas on Electronic Navigational Charts to indicate the go and no-go areas, information campaigns for seagoing commercial and recreational shipping;
- Detailed charts of the multi-use infrastructure for people working in the wind farm or multi-use area. These charts should include not only the floating elements but also submerged structures, such as mooring lines;

- Requirements for stakeholders working in the wind farm, such as adequate training of people working in the wind farm/ multi-use area, working permits, weather restrictions, measures to deal with incidents within a specific timeframe;
- AIS obligation for recreational vessels or even SOLAS 5 obligation;

2.5 Discussion of the results

2.5.1 General

The main risk of multi-functional space use in offshore wind farms is a collision between vessels and assets due to navigational error, a technical failure of a vessel or failure of the MU-asset (resulting in a drifting MU asset). The identified risk mitigation measures reduce the risk of collision either by reducing the probability of a collision/ failure or by reducing the severity after collision. Part of the identified measures are existing solutions, although the effort is required to implement these solutions. Other measures are innovative solutions or new technologies. The latter applies especially to the design of MU assets. For these solutions, additional research is required.

Appendix 3 summarises the mitigating measures and indicates for each measure in column 4 whether it is an existing solution (E) or an innovative solution or new technology (I). Column 5 indicates the effectiveness of each measure, High (H), Medium (M) and low (L).

The identified mitigation measure are discussed per category below.

2.5.2 Elimination measures

The main objective of the elimination measures is early detection of unusual vessel behaviour or vessels entering a prohibited area (the hazard) so that an operator can take action, e.g. to alert the vessel or to send a surveillance or towing vessel. The purpose is to increase the situational awareness of an operator by extensive surveillance. However, surveillance only will not remove the hazard. Still, other measures have to be taken to remove the hazard. E.g. a guard vessel will be informed earlier if extensive surveillance measures are implemented. Also, a guard vessel can cover a larger area because its reaction time will increase due to the extensive surveillance measures.

One option to extend surveillance is VTS coverage of the wind farm areas. In addition, one can think of new and innovative solutions, solutions that support an operator or increase the effectiveness of the existing surveillance tools. In the context of this study, two promising solutions are automatic anomaly detection and the deployment of autonomous guard vessels. Both solutions can be complementary to each other.

The second objective of the identified elimination measures is a reduction of the number of vessels working in the wind farm and multi-use area by developing workboats that can be deployed for both wind farm and multi-use related tasks.

VTS coverage wind farm areas

For the surveillance of the wind farm and MU areas, one can use current VTS stations, the Coastguard or a separated shore control centre. Wind farm areas are currently not part of the

VTS coverage. To extend VTS coverage to offshore wind farms, one can make use of existing systems such as AIS tracking, radar, camera's, lidar. This solution will require the installation of additional radars, VHF equipment, cameras, etc., offshore in the vicinity of the wind farm, e.g. on the substations.

Currently, the Dutch Coastguard is renewing its operational centre. In this new centre also dedicated monitoring positions for offshore wind farms will be included.

Automatic anomaly detection
Surveillance of sea areas requires the analysis of large volumes of data, the interpretation of these data and the evaluation of potential threats. This is a challenging task for a human operator. Automatic anomaly detection comprises the evaluation of sensor data, detection of unusual vessel behaviour and evaluating its threat potential using algorithms. Although steps have been made over the last years, the development of automatic anomaly detection requires significant research and development. Topics to be studied are, e.g. the selection and development of sensors (determine which sensors are required), the fusion of acquired sensor data, the development of algorithms to detect unusual behaviour, the enormous amount of data that has to be analysed and the amount of false alarms.

Other domains (e.g. defence and border patrol) are already doing research into the application of anomaly detection, and also the Dutch Coastguard is also interested in the application of it. It is expected that also for the surveillance of wind farm areas, automatic anomaly detection could be a useful application. Noted that the development of automatic anomaly detection is at a very early stage, and it is expected that it will take quite some time to have a useful and reliable application.

Probably automatic anomaly detection will go together with the development of a digital twin of the multi-use area. A digital twin (or digital model) is a virtual representation of an area and the physical object in the area across its entire lifecycle. It could use digital tools and real-time sensor data to virtually monitor an area, track ship movements, infrastructure, weather, geographic and water data. So for wind farm areas, it could collect all data available from the multi-use assets, vessels inside and around the multi-use assets. The data could be analysed and inform users about anomaly behaviour. The digital twin can also be used to update Electronic Navigational Charts. Over the last years, several ports (e.g. Port of Rotterdam) are setting up a digital twin of their port to optimise the logistic processes and asset management.

Autonomous guard vessels
Over the last years, significant steps have been taken to develop autonomous or remote operated vessels. Especially vessels for so-called "dull, dirty and dangerous" jobs are expected to be the first vessels to operate autonomously. In the context of this study, surveillance is a promising task to be conducted by autonomous vessels. An autonomous vessel could be deployed to collect data of shipping in the vicinity of the wind farm area and thus provide input for an automatic anomaly system. It also could monitor the status of assets and detect drifting assets in case of a failure of the assets.

Although significant steps have been taken, more research and development is required not only to explore the opportunities of such a vessel but also to develop a reliable and safe solution to be deployed offshore in the wind farm area. Research topics are, amongst others, the selection of required sensors onboard the vessel and fusion of sensor data, development of collision avoidance systems, remote monitoring of the vessel and maintenance. Also, more research is needed on endurance, remote energy charging and operations in severe weather. Finally, the application of remote-controlled or autonomous vessels will also introduce new risks. More research is necessary to gain a better understanding of these risks.

Two examples of recent research initiatives on this topic are the development of an Autonomous Guard Vessel and the Windfarm Autonomous Ship Project (WASP). In 2020 a consortium of maritime partners unveiled the concept design of an Autonomous Guard Vessel [12]. Last year also the WASP consortium published a report and roadmap for the introduction of autonomous vessels in support of offshore wind farm operation [13]. It is recommended to examine the possibility to join existing research initiatives.

Figure 3 Offshore Autonomous Guard Vessel [12] and Windfarm Autonomous Ship Project (WASP) [15]

Workboats
The activities in offshore wind farms and multi-use areas require a wide variety of support and maintenance vessels, which need to operate safely in the space in between the wind turbines. The wind turbines themselves require maintenance for which technicians need to be transferred from vessel to wind turbine. A careful approach and a safe transfer of personnel require highly controllable vessels with low impact of waves on the ship motions and with motion-compensated gangways. Good low-speed manoeuvring and dynamic positioning capability are crucial for mitigation of collision risks, and this requirement, besides workability and efficient propulsion, should already be taken into account in the early stages of the design.

This need for controllable vessels is also valid for the workboats supporting the fish and seaweed farms. But also, lifting capacity and deck space are important to ensure good workability. This combination of requirements results in small stable boats with low length to beam ratios. A crane is required for harvesting and other activities at the offshore farm. The use of thrusters as propulsion provides the appropriate controllability and position keeping ability of the vessels.

Fishing near, or even in wind farms, requires, besides good manoeuvrability of the vessel, also good manoeuvrability of the nets. As the nets apply considerable forces on the vessel, the stability needs to be sufficiently high. A proper detection of the position of the nets is also necessary to mitigate the risk of damage to wind turbines and to cables on the seabed. A map with all cables indicated is, in this regard, indispensable.

In order to reduce the number of vessels working in the wind farm area, it is recommended to investigate if the variety of support and maintenance task can be executed by one type of vessel. Therefore more research is required to identify the various tasks and associated equipment and design a good manoeuvrable and stable vessel.

Figure 4 Workboats offshore fish and oyster farms [18] [19]

2.5.3 Substitution measures

The main objective of the proposed substitution measure is to reduce the number of people working offshore. The development of autonomous vessels create opportunities to delegate some tasks to autonomous or remote operated vessels. In addition to surveillance tasks, inspection seems a promising task to be conducted by autonomous vessels. Maybe also more complicated tasks such as installation and harvesting could be done by autonomous vessels.

Inspection comprises both inspections of the parts above water as well as the submerged parts of the assets. Especially for the multi-use assets, the underwater inspection is important and could be a safeguard to prevent failure of the asset. The question is if both types of inspection could be conducted by the same vessel. For the inspection above water, it seems logical to combine this with the vessels used for surveillance, so it is recommended to join existing research initiatives (as mentioned in the previous section) and examine the application of autonomous vessels for inspection and maintenance tasks in wind farms and multi-use areas.

For underwater inspection, Remotely Operated Vehicles (ROVs) are currently quite commonly used. Usually, the ROVs are operated from an offshore mothership. The first step to fully autonomous inspection could be remote operation from a shore station. Over a period of several years, MARIN developed the Modular Autonomous Underwater Vehicle (MAUV) as a platform for research projects on autonomous (underwater) vehicles.

Another recent example is the development of an Unmanned Surface Vehicles (ASV) by Reach Subsea ASA (Reach), dedicated to surveying, inspection, and light repair projects. The USV will serve as mobile power banks, data centres and communication modules for underwater ROVs operated from an onshore control centre [14].

Figure 5 Modular Autonomous Underwater Vehicle (MAUV) and Unmanned Surface Vehicles (ASV) [14]

2.5.4 Engineering measures

The objective of the proposed engineering measures is first to increase the visibility of the assets, second to prevent failure of assets by design and (smart) maintenance and third to make assets collision-proof or minimise the damage in case of a collision or drift off.

Visibility of assets

The visibility of the MU-assets can be increased by using existing means such as buoys and radar reflectors. A promising solution to increase the visibility of a drifting multi-use installation is the installation of beacons that will automatically be activated and transmit a radio signal in case of an emergency, like Emergency Position Indicating Radio Beacons (EPIRB) onboard ships. More research is required to study the application of this technology in offshore wind farm and multi-use areas. Questions to be answered are for example: what are triggers for alarm (deviation of position, failure of a mooring line, etc.), who takes action in case of an alarm.

In order to increase the visibility of MU-assets it is also possible to develop systems onboard vessels to detect (submerged) obstacles and support the bridge crew. However, the implementation of these systems is not in the sphere of influence of the wind farm and multi-use operator. Therefore, in the context of this study, this solution is not further elaborated. The same applies to the development of automatic ENC updates.

Design of MU assets

Preventing a drift off is the preferred engineering solution for reducing the risk of a drifting MU asset colliding with anything. There is a need for rules and regulations regarding the design of MU assets. To do so, it is advised to develop good prediction methods of the loads on the MU asset and the structural integrity of this asset. MU assets will come in many different forms and shapes; therefore, there is not one prediction method that can be advised for all MU assets. For now, the different expected multi-use assets are: floating solar panels, mariculture (seaweed or shellfish), passive fisheries and nature enhancing elements. Of these, the most likely to drift off and cause damage are the floating solar panels and the mariculture.

A difference in the design of an MU assets and more conventional offshore structures such as oil and gas platforms or ships is in the weight per area. For example, a floating solar field will have a low weight and a large area, whereas a ship has a large weight over a small area. This results in a different type of structure. Instead of a rigid structure withstanding waves, it will be more flexible to move with the waves and thus reducing wave loads. The modelling of flexible structures in numerical simulations is being researched; an example is the piecewise flexible floating island in the EU funded programme Space@Sea [16]. Continuously flexible structures are even more complex to model numerically. The design of flexible structures is not yet standardised in rules and regulations. What plays a role is the difference between MU assets and conventional offshore structures with respect to applied redundancy or safety margins. The revenues of conventional offshore structures allows for perhaps an over-dimensioned design (better safe than sorry). Design of MU assets requires more precise insight into the required minimum redundancy or safety margins to become a profitable business case.

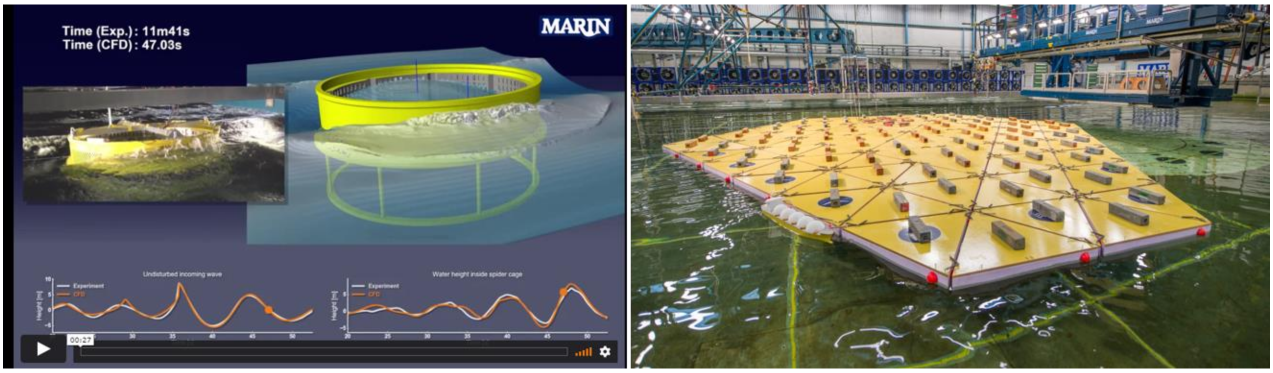

Figure 6 Model tests fish farms and floating islands [16]

Special attention should be given to the organic material growing in mariculture. The influence of this material on the expected loads is not trivial. For example, over the growing period, from brown seaweed, the plant's length changes from a few millimetres to a few metres. The shape of the plant and therefore the drag is influenced by the environmental conditions in which it is grown. Recent publications have attempted to find a drag coefficient for seaweed; however, the results were not conclusive. This example illustrates some of the unknowns in predicting the behaviour of organic material.

Smart maintenance

So far, there is not much experience in the long term behaviour of the assets and the required maintenance. Proper maintenance is a safeguard that prevents the assets from failure. More research is required for a better understanding of the assets behaviour and the development of a smart maintenance strategy. More research is necessary on fault mechanisms, data collection, the application of sensors to monitor the technical status of the assets and the behaviour of the assets in severe weather and data analyses. Remote maintenance and especially smart maintenance are data-driven solutions. This means that for these solutions, specific sensors are needed.

Already in the wind farm industry, a lot of research on data science has been done, which can be used as starting point. Also, the EU funded research program IMPAQT [17] aims to develop and validate a remote, intelligent management system that monitors an aquaculture or sea farm from a distance, using special sensors. The project started in May 2018 and will be finished in April 2021. Through a series of pilot sites across Europe and China, the project develops and tests an intelligent management platform. Although the focus of IMPAQT is on aquaculture aspects and production optimisation (e.g. measurement of nutrient levels) the knowledge and experience gained with an intelligent remote monitoring system can be extended to the monitoring of the technical status of multi-use assets. Dutch participants in IMPAQT are The North Sea Farmers and Deltares.

Minimise damage

Engineering methods to prevent damage in case of a vessel colliding with the MU asset are expected to add complexity and therefore cost, which most MU developers cannot bear. Elimination measures preventing vessels from colliding with the MU asset are expected to be more effective, and the remaining risk of collision should be at an acceptable level.

An effective measure to protect infield cables is rock protection, which is already common practice, so no further research is required.

2.5.5 Administrative measures

The main objective of the proposed administrative measures is to reduce the risk of human error (navigational error) by providing information, training, the extension of regulations and agreement on working procedures between stakeholders. The implementation of these measures could start immediately; no specific research is required. Therefore, in the context of this study, the administrative measures are not further elaborated.

3 Insurability

3.1 Broader insurance market context

Marsh has seen significant changes in the global insurance market place since 2019. There are a number of reasons for this shift, but predominantly these have been due to the effects of large natural catastrophe events in 2017 and 2018, deteriorating loss experiences across various lines of business together with the Lloyd's Performance Review "Decile 10".

The natural catastrophe events of 2017 and 2018 were not significant enough initially to influence the market in isolation; however, Swiss Re (a global insurer and reinsurer) recently announced that for 2017 and 2018 combined, Insurers and Reinsurers paid USD 258,000,000,000 in Natural Catastrophe losses globally – two of the worst combined loss years in history.

The poor profit margins at Lloyd's gave rise to a review to assess the continued operation of certain Syndicates and the sustainability of offering capacity for the worse performing lines of business. Both the power and commercial property classes were identified in the bottom "Decile 10" performing lines (offshore wind sits within Power). Syndicates were required to submit business plans for remedial action to return the businesses to profit. This has led to a number of syndicates ceasing to write certain lines of business, including Managing General Agent's being shut down. The Lloyd's "Decile 10" review has been replicated by many of the markets outside Lloyd's with similar results.

Marsh, therefore, sees a significant change in the market with Insurers and Reinsurers appetite for writing business-changing adversely with the following results:

1. Reduction in capacity offered;
2. Rating, premium and deductible increases;
3. Introduction of cover restrictions.

As a result, both the insurance and reinsurance markets are extremely challenging currently and this is not expected to change in the short term. And if there are additional Natural Catastrophe events in the next year, the market is expected to deteriorate further, with the market only stabilising once profit is achieved.

3.2 General offshore wind insurance market overview

The offshore wind insurance market is one of the areas of the market which has been affected most by the issues detailed above, alongside other factors specific to the offshore wind sector. The offshore wind insurance market over the last 20 years has seen the offshore wind industry grow to become a mainstream generation, and where Insurers were writing 2MW x 30 units close to shore in the early days, these projects now bid at 2GW+ with 10-14MW units. As projects have scaled up, they have been squeezed by cost pressures in order to compete with other energy sources, and unlike oil and gas projects, there has been a huge push to maximise output, minimise cost and construct in the quickest time. All this has put a strain on Insurers as they have paid a high frequency of attritional claims (losses other than those related to major catastrophes or exposures), both in areas of design and installation.

This pressure from the wider insurance market will continue to have an impact: for 20 years, the insurance market has suffered from overcapacity and huge competition for business. This has driven rates down and coverage wider, year on year, and policyholders have all received the benefit of this. However, this road came to an end with the severity of natural catastrophes in 2017, 2018 and 2019, each one far worse than had been seen before. These events marked the turning point in the global insurance market as Insurers of previous years became unsustainable, and boards of directors instigated the change to maintain return on capital for investors. Consequently, there has been increased merger/ acquisition activity as Insurers have fought to maintain position, which in turn has removed capacity from the market. This has resulted in Reinsurers increasing the price and narrowing cover accordingly, which has meant a significant reduction in PD/BI capacity available to direct Insurers.

Then there is COVID-19 which has caused widespread difficulty for Insurers in trying to establish their liability and has served as a major distraction from normal day to day business and could yet be another global catastrophe for the carriers.

3.3 Insurance perspective on risks of multi-use operations

Based on the main risks identified in the previous section, the Insurance perspective on this is as follows:

- Most hazards and consequences occur as a result of a vessel and or floating moored multi-use as-sets. If a party is causing damage to the assets this normally results in liability, and if caused by a vessel, it is a marine liability.
- The damage to the assets in insurance language is called property damage which might result in a business interruption (loss or revenue) as well.
- With regard to the Marine Liability the following, if a vessel is causing damage to fixed structures at sea, this will be due to the marine liability act, and this act (for instance, the Convention on Limitation of Liability for Maritime Claims, 1976) arranges that a vessel owner is liable up to a certain limit. This limitation is depended on the tonnage of the vessel. Thus a small vessel with a limited tonnage has a low liability limit.
- The property damage business interruption insured by the owner of a windfarm normally carries substantial deductibles. For property damage, a minimum would apply of EUR 500.000 and for business interruption 30 days. As mentioned at the beginning, the market is changing, followed by an increase in deductibles up to EUR 1.000.000/ EUR 2.500.000 and 90 days deductible. Therefore most claims (caused by a vessel) will be settled under marine liability insurance because the claims do not exceed the deductibles in current markets.
- At this stage, we have not seen "commercial" multi-use operators in offshore windfarms. We have seen some tests, and for these projects, the liability of the parties is arranged contractually. If this liability is arranged on a so-called "knock for knock" arrangement, both parties WFO and MUO have to arrange insurance for their own assets with no recourse from one to the other. The main question will be if the MUO will be able to insure

its own assets (property damage and business interruption). So far, the latter has not been tested yet in the insurance market.

4 Conclusions and Recommendations

4.1 Risk mitigation measures

Multi-functional space use in offshore wind farms will introduce risks for both the wind farm operators and other stakeholders working in or passing through the wind farm area. The main risk of multi-functional space use in offshore wind farms is a collision between vessels and assets due to navigational error, a technical failure of a vessel or failure of the MU-asset. The latter could result in a drifting MU asset colliding with a vessel of wind farm asset. This study focussed on mitigation of the main risk, the risk of collision.

Rijkswaterstaat is preparing the policy framework "Doorvaart en Medegebruik" which contains preconditions for safe transit and multi-use of offshore wind farms. The main preconditions to reduce risks are: multi-use is only allowed outside the maintenance area of the wind turbines and infield cables, transit through the wind farm is only allowed through designated corridors, working in the wind farm only allowed during day time and offshore proof design of multi-use assets.

In two expert sessions, risk-mitigating measures have been identified. The mitigating measures are divided into five categories which indicate the effectiveness of the measure: elimination, substitution, engineering, administrative and Personal Protective Equipment (PPE). The category indicates the hierarchy of hazard control; the higher the category level, the more effective the measure in reducing risks. The most effective measures are elimination measure, and the lowest level of hazard control are PPE measures.

From the identified mitigating measures, the following measures are promising measures for which further research is recommended:

Elimination measures

The main elimination measure to remove potential hazards is surveillance of the wind farm and multi-use area in combination with other measures to remove the hazard. Early detection of drifting vessels or drifting multi-use assets give more time to respond and take action. It will also support the enforcement to reduce the number of vessels entering prohibited areas. Surveillance wind farm and multi-use areas can be incorporated in the VTS and Coastguard or dedicated control rooms. For surveillance, existing systems such as radar, AIS and cameras can be used.

Two innovative elimination solutions have been identified: automatic anomaly detection and the deployment of remote-controlled or autonomous vessels. It is estimated that the application of remote-controlled/ autonomous vessels is the most promising option. It is expected that research on this option will result in applicable solutions on relatively short notice. There are several consortia working on the development of autonomous vessels for offshore wind farm support. It is recommended to examine the possibility to join existing research initiatives. Further to that, autonomous vessels could not only support in surveillance tasks but also in other tasks such as maintenance and inspection.

In order to reduce the number of vessels working in the wind farm area, it is recommended to investigate if the variety of support and maintenance task can be executed by one type of vessel.

Therefore more research is required to identify the various tasks and associated equipment and design a good manoeuvrable and stable vessel.

Substitution measures

The proposed substitution measure aims to eliminate the personnel risk associated with offshore operations. In addition to surveillance tasks, it is recommended to explore the option of unmanned vessels for maintenance and inspection of multi-use installations. The first step could be the application of remote-controlled vessels operated from a land-based control station. The longer-term goal could be fully autonomous vessels.

Engineering measures

A promising new solution to increase the visibility of multi-use assets is the application of systems like EPIRB. It is recommended to explore the application of these kinds of systems for multi-use installations.

There is a need for rules and regulations to design multi-use assets that are able to withstand (harsh) offshore conditions. Although there is a lot of experience with conventional offshore structures, the knowledge in the area of flexible and low weight multi-use structures is limited. An accurate prediction of the load on the multi-use assets and their behaviour in offshore conditions is an effective measure to prevent the assets from failure. Therefore research on load and on the behaviour of multi-use assets is recommended. Through numerical models, model test campaigns and full-scale experiments, the loading and response of multi-use structures can be determined and provides an adequate input to understand the hydrodynamic and structural viability of a design.

An adequate maintenance strategy could reduce the risk of failure of multi-use assets. Further research is recommended on fault mechanisms, data collection, the application of sensors to monitor the technical status of the assets and the behaviour of the assets in severe weather. This will provide input for an adequate maintenance strategy.

Concluding remarks

This study focuses on the risks as a consequence of multi-use in wind farm areas, Hazard 1, 2 and 8. Apart from the hazards considered in this study, the Risk Register [2] contains risks that were quantified as 'high' for other hazards. However, the proposed measures are also applicable to mitigate the risks related to other hazards or risks quantified as 'medium' or 'low'. Especially for 'Hazard 9 Personnel working in multi-use area', multiple high risks have been identified. The application of remote-controlled vessels operated from a land-based control station or autonomous vessels could reduce these risks significantly.

This study focuses on the technical development of mitigating measures. However, successful implementation of the measures requires cooperation between all stakeholders involved. This will include not only technical cooperation but also agreements about responsibility and working procedures, agreement on liability and legal aspects. Also, the difference in the financial capacity of stakeholders has to be taken into account.

4.2 Insurability

Most hazards and consequences occur as a result of a collision between vessels and or floating or moored multi-use assets. If a vessel is causing damage to fixed structures at sea, this will be due to the marine liability act. The marine liability act arranges that a vessel owner is liable up to a certain limit, depending on the tonnage of the vessel; a small vessel with a limited tonnage has a low liability limit.

At this stage, there is no experience with insurance of commercially operated multi-use installations in offshore wind farms. So far only tests have been setup. For these experiments, the liability of the parties is arranged contractually between the wind farm operator and the multi-use operator. For example, for the WinWind project, the agreement was to insure the assets by a (marine) liability insurance in combination with a Protection & Indemnity (P&I) insurance. A P&I insurance covers property damage and loss of revenue which are not covered in the (marine) liability insurance. Another option is to arrange the liability by a knock-for-knock agreement. In that case, both parties have to arrange insurance for their own assets with no recourse from one to the other. Knock-for-knock agreements are quite common in the offshore oil and gas and towage market.

However, the main uncertainty regarding the insurance of multi-use assets is if the multi-use operator will be able to insure its own assets, both property damage and business interruption. Over the last years, the offshore wind insurance market is changing and the premium increase as well as the deductibles. So it is uncertain if the assets can be insured for an acceptable premium.

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Appendices

Appendix 1 - Summary main risk multi-use

Hazard	Consequences:	Damage category	Affected stakeholder	Severity[3]	Direct cost [€]	INDirect cost [€]	Probability[4]	Risk[5]
Hazard01: Fixed structures offshore	Collision between multi-use vessel and wind farm structure causing damage to the wind farm foundation	Assets	WFO[1]	4	> €1mln	€ 0	4	HIGH
	Collision between multi-use vessel and wind farm structure causing damage to the wind farm infield cables by sinking and/or dropping items on the seabed	Assets	WFO	5	> €1mln	> €1mln	3	HIGH
	Collision between multi-use vessel and wind farm structure causing the vessel to sink leading to human fatalities	Human	WFO	5	< €50k	> €1mln	3	HIGH
	Collision between drifting vessel and wind farm structure causing damage to foundation and infield kabels	Assets	WFO	5	> €1mln	> €1mln	3	HIGH
	Collision between vessel and wind farm structure causing damage to foundation and infield kabels due to navigational error	Assets	WFO	5	> €1mln	> €1mln	3	HIGH
Hazard02: Moored multi-use assets within a wind farm	WFO vessel inadvertently sails through MU Area and collides with MU Assets leading to damage/failure of MU Assets (*Assets & MUO*)	Assets	MUO[2]	5	< €1mln	> €1mln	4	HIGH
	MUPS-Rigid goes adrift due to mooring failure and collides with vessel leading to fatalities (*Human & WFO+MUO)*	Human	Both WFO & MOU	5	< €50k	> €1mln	3	HIGH
	Collision between drifting vessel and MU assets	Assets	MUO	5	< €1mln	> €1mln	4	HIGH
	Collision between vessel and MU assets due to navigational error	Assets	MUO	5	< €1mln	> €1mln	4	HIGH
Hazard08: People passing through the wind farm area	MUMS fails, drifting out of MU Area, leading to collision with third party vessel and causing damage to the vessel (MUPS-Rigid is assumed here as worst case)	Assets	External stakeholder	4	< €250k	< €50k	3	MEDIUM
	Sail-through vessel inadvertently sails through MU Area and collides with MU Assets leading to damage/failure of MU Assets	Assets	MUO	5	< €1mln	> €1mln	4	HIGH
	Sail-through vessel inadvertently sails through WF Area and collides with WF Assets leading to damage/failure of WF Assets	Assets	WFO	5	< €1mln	> €1mln	4	HIGH

Remarks

*1 WFO= Wind Farm Operator

*2 MUO= Multi-Use Operator

*3 Severity rating:

Severity Human
1.Injured + no acute help needed (back in harbour/onshore)
2.Injured + help needed offshore / directly going back to harbour
3.Acute danger to life + help needed offshore / directly going back to harbc
4.Death of one person
5.Death of multiple persons (>1)

Severity Assets
1.Slight damage
2.Minor damage
3.Localised damage
4.Major damage
5.Extensive damage

*4 Probability rating

Probability
1.Extremely unlikely
2.Very unlikely
3.Unlikely
4.Likely
5.Very likely

*5 Risk table

Severity (columns) / **Probality** (rows)

	1	2	3	4	5
0	0	0	0	0	0
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Risk
Low
Medium
High

Appendix 2 – Risk table

1	2	3	4	5	6	7	8	9	10	11
	Consequence	**Damage category**	**Affected stakeholder**	**Severity**	**Probability**	**Risk**	**Mitigation**	**Category**	**Severity**	**Probability**
Hazard01: Fixed structures offshore										
1	Collision between multi-use vessel and wind farm structure causing damage to the wind farm foundation	Assets	WFO	Major damage	Likely	High	Work and wheather restrictions, work permit	Administrative	no change	reduced
							Clear indication of wind farm and multi use areas on ENCs	Administrative	no change	reduced
							Clear indication on the ENC of the go and no-go area within the WF and MU areas	Administrative	no change	reduced
							Reduce the number of maintenance vessels/traffic in general for the area (e.g. by combining maintanance of WF and MU)	Elimination	no change	reduced
							Adequate training of all personnel of the wind farm	Administrative	no change	reduced
							MuO aligns fully with operational procedures of wind farm MCC	Administrative	no change	reduced
							Collision protection wind turbines	Engineering	reduced	reduced
2	Collision between multi-use vessel and wind farm structure causing damage to the wind farm infield cables by sinking and/or dropping items on the seabed	Assets	WFO	Ext. damage	Unlikely	High	Work and wheather restrictions, work permit	Administrative	no change	reduced
							Clear indication of wind farm and multi use areas on ENCs	Administrative	no change	reduced
							Clear indication on the ENC of the go and no-go area within the WF and MU areas	Administrative	no change	reduced
							Reduce the number of maintenance vessels/traffic in general for the area (e.g. by combining maintanance of WF and MU)	Elimination	no change	reduced
							Anchor points for maintenance vessels	Engineering	no change	reduced
							Adequate training of all personnel of the wind farm	Administrative	no change	reduced
							MuO aligns fully with operational procedures of wind farm MCC	Administrative	no change	reduced
							Rock protection cables	Engineering	reduced	no change
3	Collision between multi-use vessel and wind farm structure causing the vessel to sink leading to human fatalities	Human	MUO	Death of mutiple persons	Unlikely	High	Work and wheather restrictions, work permit	Administrative	no change	reduced
							Include wind farm and multi use areas in ENCs	Administrative	no change	reduced
							Clear indication on the ENC of the go and no-go area within the WF and MU areas	Administrative	no change	reduced
							Reduce the number of maintenance vessels/traffic in general for the area (e.g. by combining maintanance of WF and MU)	Elimination	no change	reduced
							Adequate training of all personnel of the wind farm	Administrative	no change	reduced
							Anchor points for maintenance vessels	Engineering	no change	reduced
							MuO aligns fully with operational procedures of wind farm MCC	Administrative	no change	reduced
							Owner should be required to have measures to deal with incidents within specific timeframe	Administrative	reduced	no change
							Autonomous (remote controlled) vessels	Substitution	reduced	no change

	Consequence	Damage category	Affected stakeholder	Severity	Probability	Risk	Mitigation	Category	Severity	Probability
4	Collision between drifting vessel and wind farm structure causing damage to foundation and infield kabels	Assets	WFO	ext. damage	unlikely	high	Collision protection wind turbines	Engineering	reduced	no change
							Rock protection cables	Engineering	reduced	no change
							Emergency towing vessels, additional SAR vessel	Elimination	reduced	reduced
							Automatic anomaly detection	Elimination	no change	reduced
							Vessel Traffic Service coverage wind farm area	Elimination	no change	reduced
5	Collision between vessel and wind farm structure (due to navigational error) causing damage to foundation and infield kabels	Assets	WFO	ext. damage	unlikely	high	Adequate navigational aids systems installed on turbines	Engineering	no change	reduced
							Clear indication of wind farm and multi use areas on ENCs	Administrative	no change	reduced
							Rock protection cables	Engineering	reduced	no change
							Vessel Traffic Service coverage wind farm area	Elimination	no change	reduced
							Emergency towing vessels, additional SAR vessel	Elimination	reduced	reduced
							Surveillance vessels/planes	Elimination	no change	reduced
Hazard02: Moored multi-use assets within a wind farm										
6	WFO vessel inadvertently sails through MU Area and collides with MU Assets leading to damage/failure of MU Assets	Assets	MUO	Ext. damage	Likely	High	Adequate navigational aids systems installed on MU Area and MU Area	Engineering	no change	reduced
							Clear indication of wind farm and multi use areas on ENCs	Administrative	no change	reduced
							Clear indication on the ENC of the go and no-go area within the WF and MU areas, including details of the MU asset structure (e.g. submerged mooring lines)	Administrative	no change	reduced
							Make MU assets resistant to collision	Engineering	reduced	no change
							Work and wheather restrictions, work permit	Administrative	no change	reduced
							Autonomous (remote controlled) vessels	Substitution	reduced	reduced
							Reduce the number of maintenance vessels/traffic in general for the area (e.g. by combining maintanance of WF and MU)	Elimination	no change	reduced
							Adequate training of all personnel of the wind farm	Administrative	no change	reduced
7	MUPS-Rigid goes adrift due to mooring failure and collides with vessel leading to fatalities	Human	WFO MUO	Death of mutiple persons	Unlikely	High	Sensors to indicate mooring failure	Engineering	no change	reduced
							Warning procedure together with coast guard & ship traffic	Administrative	reduced	reduced
							Owner should be required to have measures to deal with incidents within specific timeframe	Administrative	reduced	reduced
							Robust design of the multi-use installations and mooring constructions & suitable maintenance regime	Engineering	no change	reduced
							Object detection onboard vessels, collision warning system	Engineering	no change	reduced
							Install radar reflectors or other identification measures on MUPS such that in case of failure and drifting, the assets will be clearly visible	Engineering	no change	reduced
8	Collision between drifting vessel and MU assets	Assets	WFO	extensive damage	unlikely	High	Collision protection MU assets	Engineering	reduced	no change
							Emergency towing vessels, additional SAR vessel	Elimination	reduced	no change
							Automatic anomaly detection	Elimination	no change	reduced
							Vessel Traffic Service coverage MU area	Elimination	no change	reduced
							Submersible MU asset, temporarily submerge MU assets by apporaching vessel	Engineering	reduced	no change
							Detetction sensors and radar on boundary of windfarm and MU area	Engineering	no change	reduced
							Minimum distance between MU area and traffic routes	Administrative	no change	reduced
9	Collision between vessel and MU assets due	Assets	WFO	extensiv	Unlikely	high	Collision protection MU assets	Engineering	reduced	no change

	Consequence	Damage category	Affected stakeholder	Severity	Probability	Risk	Mitigation	Category	Severity	Probability
	to navigational error			e damage			Clear indication of wind farm and multi use areas on ENCs	Administrative	no change	reduced
							Clear indication on the ENC of the go and no-go area within the WF and MU areas, including details of the MU asset structure (e.g. submerged mooring lines)	Administrative	no change	reduced
							Emergency towing vessels, additional SAR vessel	Elimination	reduced	no change
							Anomaly detection	Elimination	no change	reduced
							Vessel Traffic Service coverage MU area	Elimination	no change	reduced
							Submersible MU asset, temporarily submerge MU assets by apporaching vessel	Engineering	reduced	no change
							Detetction sensors and radar on boundary of windfarm and MU area	Engineering	no change	reduced
							Minimum distance between MU area and traffic routes	Administrative	no change	reduced
							Navigation support systems onboard vessels	Engineering	no change	reduced
							Adequate navigational aids systems installed on MU Area and MU Area	Engineering	no change	reduced
							SOLAS5 obligation for recreational vessels	Administrative	no change	reduced
							Proper information of the public commercial and recreational shipping	Administrative	no change	reduced
							AIS obligation for recreational vessels	Administrative	no change	reduced
							Automatic ENC update (like google maps)	Engineering	no change	reduced
Hazard08: People passing through the wind farm area										
10	MUMS fails, drifting out of MU Area, leading to collision with third party vessel and causing damage to the vessel (MUPS-Rigid is assumed here as worst case)	Assets	external stakeholder	Major damage	Unlikely	High	Sensors to indicate mooring failure	Engineering	no change	reduced
							Warning procedure together with coast guard & ship traffic	Administrative	reduced	no change
							Owner should be required to have measures to deal with incidents within specific timeframe	Administrative	reduced	no change
							Robust mooring installation & suitable maintenance regime	Engineering	no change	reduced
							Object detection onboard vessels, collision warning system	Engineering	no change	reduced
							Install radar reflectors or other identification measures on MUPS such that in case of failure and drifting, the assets will be clearly visible	Engineering	no change	reduced
							Inform stakeholders to be extra cautious during passing of wind farm area that includes MU Areas	Administrative	no change	reduced
							Temporary blockage passage lane (maritime notices, coast guard vessel)	Elimination	no change	reduced
							Code of conduct passage wind farm and MU area (including e.g. risk of passage, what to do in case of drifting asset)	Administrative	no change	reduced
11	Sail-through vessel inadvertently sails through MU Area and collides with MU Assets leading to damage/failure of MU Assets	Assets	MUO	extensive damage	Likely	High	Adequate navigational aids systems installed on MU Area and MU Area	Engineering	no change	reduced
							Clear indication of wind farm and multi use areas on ENCs	Administrative	no change	reduced
							Clear indication on the ENC of the go and no-go area within the WF and MU areas, including details of the MU asset structure (e.g. submerged mooring lines)	Administrative	no change	reduced
							Make MU assets resistant to collision	Engineering	reduced	reduced
							Passage wheather restrictions	Administrative	no change	reduced
							Emergency towing vessels, additional SAR vessel	Elimination	reduced	reduced

	Consequence	Damage category	Affected stakeholder	Severity	Probability	Risk	Mitigation	Category	Severity	Probability
							Vessel Traffic Service coverage MU area	Elimination	no change	reduced
							Navigation support systems onboard vessels	Engineering	no change	reduced
							SOLAS5 obligation for recreational vessels	Administrative	no change	reduced
							Proper information of the public commercial and recreational shipping	Administrative	no change	reduced
							AIS obligation for recreational vessels	Administrative	no change	reduced
							Automatic ENC update (like google maps)	Engineering	no change	reduced
12	Sail-through vessel inadvertently sails through WF Area and collides with WF Assets leading to damage/failure of WF Assets	Assets	wfo	extensive damage	Likely	High	Adequate navigational aids systems installed on wind turbines	Engineering	no change	reduced
							Clear indication of wind farm and multi use areas on ENCs	Administrative	no change	reduced
							Clear indication on the ENC of the go and no-go area within the WF and MU areas, including details of the MU asset structure (e.g. submerged mooring lines)	Administrative	no change	reduced
							Collision protection wind turbines	Engineering	reduced	no change
							Passage wheather restrictions	Administrative	no change	reduced
							Emergency towing vessels, additional SAR vessel	Elimination	reduced	no change
							Vessel Traffic Service coverage MU area	Elimination	no change	reduced
							Navigation support systems onboard vessels	Engineering	no change	reduced
							SOLAS5 obligation for recreational vessels	Administrative	no change	reduced
							Proper information of the public commercial and recreational shipping	Administrative	no change	reduced
							AIS obligation for recreational vessels	Administrative	no change	reduced
							Automatic ENC update (like google maps)	Engineering	no change	reduced
							Surveillance by WFO and incident report procedure	Administrative	no change	reduced

Appendix 3 - Summary mitigating measures

no.	category	description	Status*1	Effectiveness*2
1	Elimination	Automatic anomaly detection	I	H
1	Elimination	Emergency towing vessels, additional SAR vessel	E	H
1	Elimination	Reduce the number of maintenance vessels/traffic in general for the area (e.g. by combining maintanance of WF and MU)	E.I	H
1	Elimination	Surveillance vessels/planes	E	H
1	Elimination	Vessel Traffic Service coverage MU area	E	H
1	Elimination	Vessel Traffic Service coverage wind farm area	E	H
1	Elimination	Autonomous (remote controlled) vessels	I	H
2	Substitution	Autonomous (remote controlled) vessels	I	H/M
3	Engineering	Adequate navigational aids systems installed on MU Area and MU Area	E	M
3	Engineering	Adequate navigational aids systems installed on turbines	E	M
3	Engineering	Automatic ENC update (like google maps)	I,E	M
3	Engineering	Collision protection MU assets	I	M
3	Engineering	Collision protection wind turbines	I,E	M
3	Engineering	Detetction sensors and radar on boundary of windfarm and MU area	I,E	M
3	Engineering	Install radar reflectors or other identification measures on MUPS such that in case of failure and drifting, the assets will be clearly visible	I,E	M
3	Engineering	Make MU assets resistant to collision	I	M
3	Engineering	Navigation support systems onboard vessels	I	M
3	Engineering	Object detection onboard vessels, collision warning system	I	M
3	Engineering	Robust mooring installation & suitable maintenance regime	I	M
3	Engineering	Rock protection cables	E	M
3	Engineering	Sensors to indicate mooring failure	I	M
3	Engineering	Submersible MU asset, temporarily submerge MU assets by apporaching vessel	I	M
4	Administrative	Adequate training of all personnel of the wind farm	E	M/L
4	Administrative	AIS obligation for recreational vessels	E	M/L
4	Administrative	Clear indication of wind farm and multi use areas on ENCs	E	M/L
4	Administrative	Clear indication of wind farm and multi use areas on ENCs	E	M/L
4	Administrative	Clear indication on the ENC of the go and no-go area within the WF and MU areas, including details of the MU asset structure (e.g. submerged mooring lines)	E	M/L
4	Administrative	Include wind farm and multi use areas in ENCs	E	M/L
4	Administrative	Minimum distance between MU area and traffic routes	E	M/L
4	Administrative	MuO aligns fully with operational procedures of wind farm MCC	E	M/L
4	Administrative	Owner should be required to have measures to deal with incidents within specific timeframe	E	M/L
4	Administrative	Proper information of the public commercial and recreational shipping	E	M/L
4	Administrative	SOLAS5 obligation for recreational vessels	E	M/L
4	Administrative	Warning procedure together with coast guard & ship traffic	E	M/L
4	Administrative	Work and wheather restrictions, work permit	E	M/L

Remarks

*1 = Innovative solution (I) of existing solution (E)

*2 = High (H), Medium (M), Low (L)

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