North SEE

A North Sea Perspective on Shipping, Energy and Environmental Aspects in Maritime Spatial Planning

Improving the co-existence of Offshore Energy Installations & Shipping

Report on Work-package 4.4 of the NorthSEE Project

Interreg
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Contents

Preface

The Interaction between Offshore Renewable Energy Installations (OREIs) & Maritime Activities

As the harsh realities of climate change become ever more apparent, there is a noticeable shift towards increased renewable energy generation. One of the most popular renewable energy sources is wind power. Significant technological advancements – as well as improved installation, maintenance and decommissioning strategies (Maegaard et al. 2013a; b; Mehdi et al. 2016) – have particularly boosted the reliability of offshore wind farms (OWFs) and driven down the associated levelized cost of energy (LCOE) (Siemens 2014; GWEC 2016). This, along with widespread social acceptance, has also contributed to the increasing popularity of OWFs.

According to recent reports, Europe – the region leading the world in terms of the number of OWFs – has about 3.5k offshore wind turbines (OWTs) with a total installed capacity of 12.6 GW as of 2016 (WindEurope 2017). An additional 4.8 GW worth of offshore wind projects are currently under construction, 24.2 GW have been consented, 7 GW are pending approval, and a staggering 65.6 GW more projects are planned – in just Europe. These projects will result in a *six-fold increase* in the number of OWTs and OWFs, in a region where marine areas are already quite crowded by shipping traffic and other marine uses such as fisheries, leisure activities, military activities, and protected areas – not to mention test sites for other marine renewable energy developments, including wave and tidal generators.

Industry predictions also forecast that OWTs will get larger and more complex (e.g. larger rotors, floating turbines, vertical axis turbines), and OWFs will continue to grow in size and number over the upcoming years. There are also strong indications that OWFs continue to move further away from shore towards deeper water to better exploit wind resource (WindEurope 2017; GWEC 2016). Other offshore renewable energy installations (OREI) are expected to evolve and grow as well over the coming years.

Despite its many advantages, however, offshore renewable energy generation is also plagued with a plethora of challenges. For instance, there are still some lingering concerns about the technical challenges, reliability and cost-effectiveness facing OWFs (Ostachowicz et al. 2016). As such, there have been several studies on the lifecycle economic (e.g. Blanco 2009; Snyder & Kaiser 2009) and environmental impacts (e.g Weinzettel et al. 2009; Wang & Sun 2012) of OWFs to address some of the aforementioned concerns.

In addition to the technical and cost-related challenges, further barriers to the continued growth of the offshore wind industry ironically stem from the *environmental* impact of OWFs. Marine biologists, for instance, carefully scrutinize the impact of OWFs on marine life (e.g. Köller et al. 2006; Degraer & Brabant 2009; Andersson 2011; Bailey et al. 2014; Verfuss et al. 2016). Similarly, ornithologists are often concerned that OWFs may negatively affect the migration and breeding patterns of various avian species (e.g. Desholm & Kahlert 2005; Dierschke et al. 2006; Hüppop et al. 2006; Degraer & Brabant 2009; Beiersdorf & Radecke 2014; New et al. 2015). Furthermore, there are also other environmental and societal impacts of OWFs – such as the perceptions of coastal communities – that can also be viewed as potential barriers; these topics are covered in works such as those of Devine-Wright (2005), Lacroix & Pioch (2011), Ladenburg (2011) and Chen et al. (2015).

A crucial topic often discussed in the context of environmental impacts is the interaction between OWFs and maritime activities[1]. This multi-dimensional interaction is often viewed as a marine spatial conflict, with both industries vying for adequate space in marine areas that may be already over-crowded with other multiple uses. Consequently, this interaction between OWFs and maritime operations is the subject of a vast body of both academic and non-academic literature. For instance, Chircop & L'Esperance (2016) have discussed the legal aspects of this interaction, whilst there have also been some interesting investigations regarding vessel re-routeing to reduce the costs associated with OWFs by authors such as Samoteskul et al. (2014).

Perhaps the most widely explored topic under the broader thematic area of spatial OREI-maritime interactions is the effect of OREIs on maritime navigational safety. There is consensus amongst stakeholders acknowledging that OREIs can pose risks to maritime operations in terms of reduced navigational safety (Wright et al. 2016; Mehdi & Schröder-Hinrichs 2016). The presence of an OWF, for instance, means that there more obstacles in the water which ships have to avoid. OWFs may also restrict the navigable space available to ships, leading to increased traffic density, and an increased risk of collision. It is also well established that OWTs may interfere with ships' on-board navigation equipment such as radar and other radio-frequency devices (MARIC0 2007; de la Vega et al. 2013; MCA 2016). All these factors, and more, can be detrimental to navigational safety.

Of all the different impacts related to OREIs, the navigational safety risks are perhaps the most concerning for stakeholders. Maritime accidents can be very expensive for all parties involved, and in the absolute worst cases, such accidents can lead to human casualties or serious environmental damage. This is the core reason why authorities who are involved in the consenting and approval of marine projects tend to pay special attention to the maritime risks associated with OREIs. In most coastal states, there are stringent processes requiring OWF owners/developers to demonstrate that they have thoroughly assessed the maritime risks and implemented adequate risk management measures (BSH 2015; MCA 2013). Traditionally, however, this focus on maritime risk assessment/management has been much more pronounced during the licensing and approval stages of OWF projects, than during the planning or MSP process. This, thus, has led to problems where marine-areas-*as-planned* are often not the same as marine-*areas-as- approved*[2]. Consequently, there have even been cases where coastal states have had to alter shipping routes or modify OWF layouts either retroactively, leading to ire from stakeholders and ineffective 'cramming' of sea-space.

As the offshore renewables sector continues to grow and evolve, addressing the mutual risk between OREIs and maritime activities is becoming a pressing issue for stakeholders across the spectrum. Technical developments such as floating turbines further away from shore, as well as socio-political developments such as the European Energy Grid, and transboundary MSP have now added a new hue of urgency to this quest for solutions. Of particular interest are solutions which can help to close the gap between planners and approval authorities, to ensure that limited marine space is effectively utilized and that disruptions to the different sectors are kept at a minimal level throughout project lifecycles. Within the scope of the NorthSEE project, a further aim is to also ensure that these solutions contribute to improved, coherent *trans-boundary* marine plans.

The analysis of Safety Distances and NRAs in the present work serves as an interface between work-packages 4 and 5, which deal with the development of transnationally coherent shipping routes and transnationally coherent energy infrastructure respectively.

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[1] A maritime activity can be defined as any human activity which occurs adjacent to a marine area (e.g. on-board a ship)

[2] A case in point is Belgium, where OWFs are as planned had to be 'trimmed' around the corners during the approval stages, to ensure safety of navigation for shipping traffic.

Part I

Defining the Spatial Conflict between OREIs & Maritime Activities: A Focus on Safety Distances

1. Introduction to Safety Distances (SDs)

In order to ensure that the mutual risks between OREIs and maritime activities is as low as possible, coastal states often implement 'risk-control measures' during the planning or approval stages of the OREI projects. Examples of risk-control measures include optimal lighting and marking of structures, remote monitoring of congested traffic areas through VTS or shore-control centres, and even patrol boats around the installation boundaries. Some states also choose to route or reroute vessel traffic near OREIs to mitigate navigational risks to an acceptable limit. All these risk-control measures are designed to ensure that there is adequate room for vessel traffic in both routine and emergency scenarios. Consequently, these risk-control measures often have a direct or indirect 'spatial cost'.

This spatial cost is best embodied by 'Safety Distances', 'Safety Zones' or 'Safe Passing Distances'. While there is no universally accepted definition of these distances, they can all perhaps be best described as '*spatial buffers between OREIs and shipping traffic which have been implemented in order to mitigate the risk of navigational accidents, and to provide adequate manoeuvring room for vessels*'. A differentiation between these terms is provided in the Annex. Of these, Safety Distances (henceforth abbreviated as SDs) are the one of most interest to spatial planners. SDs are specifically defined as the '*total distance from edge of vessel fairway to an offshore installation, implemented to ensure navigational safety*'. It is important to highlight that increasing SDs does not necessarily increase safety of navigation: for example, there have been studies which demonstrated that increasing SDs in certain cases compressed the fairway width, leading to less space for vessels to manoeuvre and an increased risk of collisions. It is therefore quite important to understand factors influencing navigational safety before implementing SDs.

Nonetheless, SDs are crucial in determining the net space available for different marine uses. By extension, SDs have a direct influence on the efficiency of both OREIs and maritime operations. *Over-designing* SDs in terms of safety can lead to scenarios where limited sea-space is not used effectively for energy generation (e.g. having to reduce a row of wind turbines from a wind farm) or where vessels have to be rerouted inefficiently. On the other hand, *under-designing* SDs may increase the risk of maritime accidents and lead to accidents which would have been otherwise avoidable.

The quantification, implementation and enforcement of SDs varies between coastal states – and these mechanisms are ultimately governed by a combination of national law and policy, as well as international legislation. This approach means that coastal states (often following advice from stakeholders) have the flexibility to implement SDs as and when they see fit. A downside, however, is that there is no harmonized approach to SDs on a regional or international level. The lack of harmonization is particularly problematic for neighbouring countries with OREIs from both an operational and marine-planning perspective. With North Sea countries looking to adapt trans-national marine plans, this problem is exacerbated even further.

The obvious solution to this problem is to determine which country has the 'best' approach to SDs, and to recommend other nations to follow the same approach. This, however, is easier said than done. Although countries in the same geographical location may share physical environmental similarities, the underlying decisions behind SDs are often driven by complex underlying factors. For instance, countries which have not met their quotas for international climate change targets may aggressively promote OREIs over shipping, whereas nations with major ports or shipping interests may opt for a more conservative approach to favour maritime activities. As another example, countries with major ports may be influenced by stakeholder groups such as ship-owners to promote maritime interests over energy generations. Thus social, political, technical, and economical factors can (and often do) directly influence how SDs are quantified, implemented and enforced – and countries may be unwilling to deviate to a harmonized approach due to perceived or actual differences in circumstances. Subsequently, it is difficult and imprudent to determine a single 'best' approach to SDs. Nevertheless it *is* possible to provide a qualitative evaluation of the different approaches to SDs. Indeed, such evaluations can serve as the vital first step towards any further discussions on harmonized approaches to SDs.

2. Evaluating Approaches to Safety Distances (SDs)

In order to evaluate the approaches to SDs, participants from 7 different countries – UK, Germany, Denmark, the Netherlands, Belgium, Sweden, and the US (as a test case) – were surveyed. The raw data sheets with handwritten notes are included in Appendix 1.

2.1 Legal Context

From a legal perspective, the spatial conflict between OREIs and maritime activities can be quite complex, as evident in the recent work of Chircop & L'Esperance (2016) which provides an excellent in-depth analysis on the subject.

In essence, the United Nations Convention on the Law of the Sea (UNCLOS) gives coastal states the right to exploit their marine areas for various purposes including energy generation. At the same time, coastal states are also obliged to comply with rules on Freedom of Navigation and ensure adequate provisions for the safe, unhindered passage of ships in their waters. Coastal states must also ensure that their exploitation activities do not hinder internationally established shipping routes. As a result, the establishment of SDs and safety-zones is well-enshrined in international law.

UNCLOS Article 60, which allows coastal states to create 'safety-zones' of up to 500m around OREIs in the EEZ, and makes it mandatory for ships to respect these safety-zones. Article 60 also states that the establishment of these zones may not interfere with 'recognized sea lanes essential to international navigation' – a statement that can be subject to different interpretations. If coastal states want to establish safety-zones or SDs larger than 500m, they must obtain authorization from the competent international organization – i.e. the International Maritime Organization (IMO).

The IMO, in turn, has further international instruments which must be considered during the establishment of SDs. For instance regulations in SOLAS Chapter V and in the General Provisions on Ships' Routeing (GPSR – Res. A.572 (14) as amended) clearly state the responsibilities of coastal states when establishing or modifying routeing schemes. The regulations are a particularly important consideration if proposed SDs have an influence on existing shipping lanes and routes.

The IMO has also passed Res. A.671 (16) (as amended), which lays-out the responsibilities of the coastal state in establishing safety-zones, as well as the responsibilities of the vessels operating in the vicinity. The document also sets out the responsibilities of the operators of offshore installations in taking adequate measures to prevent infringement of safety zones.

When submitting proposals for routeing or SDs, coastal states are encouraged to follow the risk-based Formal Safety Assessment (FSA) framework of the IMO. During the FSA, coastal states should demonstrate a consideration of all socio-technical factors including static and dynamic environmental conditions (weather, bathymetry, waves, current, tides, seascape, etc.), ship traffic characteristics, existing aids to navigation and implemented routeing measures. In considering ship traffic, other instruments such as the International Regulations for Preventing Collisions at Sea (COLREGS) and Standards for Ship Manoeuvrability (MSC. 137(16)) should also be considered. The guidelines from PIANC on waterway design are also an important consideration from a legal perspective.

The international regulations have helped to ensure that there is already a harmonized *legal* approach for the establishment of SDs. As a result, it is difficult to evaluate and establish a ‘best’ approach from a legal standpoint. This then leaves the technical, implementation and enforcement aspects of SDs as potential areas of improvement in the context of transboundary planning.

2.2 Technical Context

While international regulations provide a harmonized *legal* framework for SDs, the *technical* approaches to quantifying SDs do vary amongst the different member states. It is important to highlight here that the *list* of factors (e.g. static and dynamic environmental conditions, ship traffic characteristics, existing aids to navigation, etc.) which are considered when establishing SDs does not significantly vary between different countries; rather, it is the *values* of these factors, and the *quantitative or qualitative process* by which these factors are considered that are different. In essence, the ‘calculation method’ of SDs is one area where coastal states differ.

Belgian authorities for instance, have no fixed formula for determining SDs, but consider a whole array of socio-technical factors when making decisions in this regard. Aside from the typical environmental and ship traffic data, Belgian authorities are also very conscious about their already-crowded marine areas and are of the opinion that anything greater than the UNCLOS mandated 500m maximum would be unfeasible.

A similar list of environmental and technical factors is also present in guidance documents from the Netherlands (e.g. ‘*Reglementen, voorschriften en verkeersregels voor scheepvaart die relevant zijn voor veilige afstanden*’). In contrast to their Belgian neighbours however, the Dutch *do* rely on quantitative equations to determine SDs. The Dutch method is based on traffic density, ship size, and manoeuvrability characteristics – and allows authorities to determine the minimum SD between OREIs and shipping lanes, as well as the width of shipping lanes near OREIs as shown in **Fig. 1**.

The UK – and more recently, Denmark – have also started opting for an approach similar to the Netherlands in quantifying SDs based on physical ship sizes and manoeuvrability characteristics. Both these countries also consider similar factors when quantifying SDs, as evident through guidance documents such as the MCA’s (Maritime & Coastguard Agency UK) MGN 543.

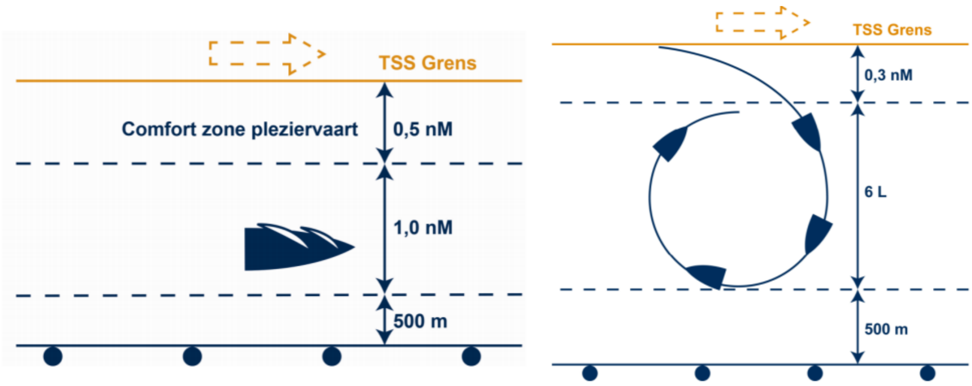

Fig. 1 Example of SDs based on the Dutch approach, which considers PIANC guidelines for minimum waterway widths, as well as ship lengths, numbers and manoeuvrability characteristics.

Other countries such as Germany and Sweden have traditionally based their SD estimations on more qualitative approaches and expert judgements – albeit considering similar socio-technical factors as the Netherlands, UK, Denmark or Belgium. In Germany, the results of these qualitative approaches have resulted in a generic minimum SD of 500m around all OREIs, plus an additional buffer 'reserve area' for future shipping or OREI needs. On the other hand, the Swedish authorities opt for a case-by-case approach rather than a general and/or equation-based approach. The reasoning of the Swedish authorities is that a general formula or a generic minimum SD may not be adequately compensate for the differences between marine areas – and could thus lead to ineffective spatial use in certain scenarios.

Qualitative approaches rely on continual stakeholder feedback and consultation – particularly if the SDs are estimated on a case-by-case basis. Thus one disadvantage of such qualitative approaches (aside from potentially higher costs) is that harmonization of SDs is made more difficult, especially in transboundary planning. On the other hand, qualitative approaches may be necessary to ensure the best possible use of space in an increasingly crowded sea-scape where spatial plans need to be lean – and where generic formulae may be deemed too crude. Furthermore, qualitative approaches may be necessary in countries like Belgium where there is simply no space to implement the recommendations of a quantitative approach.

It is also important to highlight that SDs are very rarely – if ever – quantified in isolation. Irrespective of whether a coastal state opts for a qualitative 'rule-of-thumb' approach or a more quantitative approach using empirical formulae, a navigational risk assessment (NRA) is usually conducted before the SD can be formally established and implemented. NRAs help stakeholders to holistically understand the effect of any proposed SD, and also ensure that the proposed SD does what it supposed to do (i.e. mitigate the navigational risk around OREIs). NRAs can also be used by coastal states for any FSA submissions to IMO in case routeing measures need to implemented or modified in order to accommodate the SD. Despite the critical role of NRAs, the methods, tools and models used in the processes can also vary significantly between coastal states as discussed in Part II of this report.

Both the estimation of SDs and NRA methods thus remain a potential area of improvement in the context of transboundary MSP.

2.3 Implementation

The implementation of SDs also varies between different coastal states. In some countries (e.g. the UK) it is *encouraged* but not necessary to implement SDs; it is only deemed necessary if the outcome an NRA shows it to be, or until specifically advised to do so by the relevant authorities. In the UK, an OREI owner/operator who is concerned about maritime risks may also approach the authorities with a request for a SD around the installations; such requests then require the approval of IMO if the proposed SD is larger than 500m and/or requires routeing measures. This approach towards SDs differs from that of Belgium and the Netherlands, for instance, where a minimum SD *must* be implemented around OREIs.

Before the EU MSP directive came into force, it was unusual for SDs to be implemented at the planning stage. Most coastal states did, however, ensure compliance with UNCLOS where feasible – and ensured that OREIs were approved at some arbitrary distance away from established shipping routes. Now, under the binding influence of the directive, SDs around OREIs (if any) are being increasingly included in the spatial plans created by member states. These plans are an important step towards improved coexistence of marine uses, as they provide a holistic overview of the spatial scenarios well in advance.

However, there is often a mismatch between planners (i.e. those who plan marine areas) and approval authorities (i.e. those who approve or consent the project) and SDs as planned are not necessarily SDs as approved. There have been cases, for instance, in Belgium and the Netherlands where either OWFs have been curbed or shipping lanes rerouted because the planned SD was not adequate after a NRA was conducted during the approval stages. Such situations are not ideal because OREI owners bid on very specific energy farm designs and any ‘last-minute’ changes can have a significant impact on operational efficiency and cost to consumers. To overcome this problem, Belgium and the Netherlands now also conduct NRAs during the *planning* stages to ensure that there is minimal change at the approval stage and to ascertain that SDs are approved and implemented as they were planned.

SDs may also be implemented *after* an OREI project has been approved, or even during specific lifecycle phases of OREIs (e.g. installation, O&M, decommissioning). This is done if new information comes to light – e.g. complaints from stakeholders, or an increase in accidents around the area which cannot be solved by other means. In such cases, shipping lanes may need to be rerouted, which would then require submissions to the IMO such as lighting, markings, monitoring, etc. It goes without saying that these scenarios are far from ideal, as they can hinder shipping traffic, and thus cause substantial economic and efficiency problems. An example of retroactive implementation of SDs is the Hook of Holland case, where new routeing measures were introduced to mitigate the navigational risk due to OWFs.

Although most North Sea member states now consider SDs during the planning stages, there are some concerns that these considerations are crude and therefore likely to be modified at the approval stage; the exception is countries like Belgium and the Netherlands who actually conduct NRAs during both the planning and approval stages. In the context of transboundary MSP, further improvements to the implementation of SDs are therefore still needed in some member states.

2.4 Enforcement

SDs are also enforced differently amongst the various coastal states in the North Sea. In Belgium and Germany for instance, laws *prohibit* passing ships from trespassing into the 500m safety zone around OREIs. By contrast, other countries such as the UK generally give ships more freedom of navigation – and only *recommend* maintaining a SD or *caution* against entering any safety zones; in the latter cases, there are no penalties for trespassing into a SD but mariners may be warned or questioned about their activities. It is noteworthy that countries where it is *not necessary* to implement a SD (e.g. UK) often do not have mandatory SDs.

In order to enforce mandatory SDs in practice, coastal states may impose financial penalties, or rely on the help of through coast-guard/water-police interventions and shore-based monitoring. Regardless of whether a SD is mandatory or recommended, proper notice must be given to mariners under IMO guidelines, and nautical charts also need to be updated accordingly.

Countries that choose *recommended* rather than *mandatory* SDs have experienced that seafarers generally respect and follow their advice. Recommended rather than mandatory SDs also give seafarers more flexibility to navigate as they feel comfortable. For instance, recent simulator studies demonstrated that seafarers would prefer to pass closer to OREIs than to other ships in heavy traffic scenarios (Mehdi et al. 2017b); this would not necessarily be possible with mandatory SDs, and vessel traffic would be more compressed than normal thereby increasing the risk of collision between vessels.

The different enforcement regimes are a problem from both an operational and a planning viewpoint. In the former context, differing enforcement practices between neighbouring countries can cause disruptions in traffic flow – unless both countries agree on routeing measures. Belgium and the Netherlands have done so by submitting a joint proposal of routeing measures to IMO, and thus set a good example for other coastal states to follow. Enforcement policies may also have a direct influence on ship emissions in an operational context. In the latter context of planning, differing enforcement policies may make it more difficult for sea space to be used efficiently as possible. Factors such as grid connections between countries can be affected if enforcement policies are not harmonized.

3. Improving SDs in a Transboundary MSP Context

It is fairly clear that the legal framework, as well the factors considered when determining SDs are quite similar across the different North Sea countries. There are, however, differences in terms of the technical methods used, and in an implementation, enforcement and transboundary contexts – as shown in Table 1.

The findings in Table 1 indicate that is imprudent to focus on improving the *legal* aspects of SDs as the international guidelines available are already quite comprehensive. Instead, it appears to be more worthwhile to focus on improving the technical, implementation, and enforcements aspects.

	Legal Context	Considerations	Technical Method	Implementation	Enforcement	Transboundary Co-op	
BE	Right to implement SDs governed by UNCLOS on international level; SDs larger than 500m subject to approval from IMO (IMO approval subject to compliance with IMO Instruments)	Static/ dynamic environmental conditions, vessel traffic (present & future), vessel characteristics, social, political, economic factors	None; qualitative discussions with stakeholders. NRA used to validate SDs/ modify plan if risk is unacceptable.	Fixed minimum of 500m. Implemented during planning. Example of retroactive implementation/ modification also present through re-routeing measures or curbing of OREI areas following NRA results	Strictly enforced as safety zone by Royal Decree: Strictly enforced as safety zone. Penalties on ships for trespassing.	Good cooperation with neighbouring NL, evident through joint routeing submissions to IMO	**BE**
DE			None; qualitative discussions with stakeholders	Fixed minimum of 500m. Implemented during planning.	Strictly enforced as safety zone. Penalties on ships for trespassing.	No examples of transboundary cooperation on SDs	**DE**
DK			*(Recommended)* Quantitative equation based on ship size, traffic, manoeuvrability to determine SD & width	Not mandatory. Case-by-case basis, can be requested by OREI operator/ developer/owner. Can be implemented	Not enforced. Recommended SDs may be provided to seafarers.	No examples of transboundary cooperation on SDs	**DK**

			of shipping lanes	before, during or after installation, O&M, decommissioning			
NL			*(Mandatory)* Quantitative equation based on ship size, traffic, manoeuvrability to determine SD & width of shipping lanes. NRA used to validate SDs/ modify plan if risk is unacceptable.	Fixed minimum of based on quantitative equations of ship size, traffic, manoeuvrability. Implemented during planning. Example of retroactive implementation/ modification also present through re-routeing measures or curbing of OREI areas following NRA results	Not enforced. Recommended SDs may be provided to seafarers.	Good cooperation with neighbouring BE, evident through joint routeing submissions to IMO	**NL**
SE			None; qualitative discussions with stakeholders	Not mandatory. Case-by-case basis, can be requested by OREI operator/ developer/owner. Can be implemented before, during or after installation, O&M, decommissioning	Not enforced. Recommended SDs may be provided to seafarers.	No examples of transboundary cooperation on SDs	**SE**
UK			*(Recommended)* Quantitative equation based on ship size, traffic, manoeuvrability to determine SD & width of shipping lanes	Not mandatory. Case-by-case basis, can be requested by OREI operator/ developer/owner. Can be implemented before, during or after installation, O&M, decommissioning	Not enforced. Recommended SDs may be provided to seafarers.	Indirect involvement in joint submission of NL/BE to IMO	**UK**

From a technical standpoint, there are two main approaches of determining the extent of SDs – a quantitative formula-based approach such as that used in the Netherlands and recommended by the UK and Denmark, or a qualitative approach as used by Germany, Sweden and Belgium. Both approaches have their advantages and drawbacks as discussed in section 2.2. The main argument against using a quantitative formula is that such an approach not necessarily account for the differences in marine areas and scenarios – and may thus lead to an over- or under-design for safety. Nevertheless, the only way forward for transboundary planning of SDs is through harmonization – which in turn requires a certain degree of quantification. The logical solution then is to improve the quantitative formulae which are used in order to better address a broader range of scenarios. Such a formula could include social and even economic factors in addition to purely technical factors – and would thus help to alleviate some of the concerns that certain coastal states presently have.

With regards to implementation of SDs, the problem lies *within* member states rather than *between* member states, and the fundamental question is to understand how the gap between planners and approval authorities can be reduced. Once this question is answered, harmonization between member states for transboundary MSP may be a lot closer. A feasible solution to this problem is for member states to adopt the approach of Belgium and the Netherlands – i.e. conduct NRAs such as those used approval stages during the planning stages as well. This would help to mitigate the risk of major surprises down the line at or after the approval stages. NRAs can also be combined with comprehensive cost-benefit analyses and energy efficiency calculators to enhance decision making. If this approach is adopted, then a harmonization of NRA processes (in terms of tools, methods and models) would certainly be needed for transnational MSP. Coastal states can also advocate an increased use of maritime simulators; such an approach has been used in the Netherlands, and has so far proven to be hugely beneficial for both planning and approval processes. The use of simulators is also encouraged by the UK – and given the decreasing cost of improving simulators, it is quite feasible for other coastal states to follow suit. Simulators have also been shown to elicit better stakeholder participation, as well as more informed insights from seafarers (Mehdi et al. 2017b) both of which can be very valuable for the planning process – and help planners to better understand the viewpoints of approval authorities.

In terms of the enforcement of SDs, the problem is differing status of SDs between neighbouring coastal states. This problem can lead to operational inefficiencies and cause undue burden on seafarers. Coastal states must unanimously decide on whether SDs need to be mandatory or recommended. Given that seafarers generally abide by the recommendations, it seems unnecessary to have mandatory measures, which can restrict the options of vessels in heavy-traffic scenarios.

Part II

Resolving Spatial Conflicts between OREIs & Maritime Activities: Risk-Based Approaches & NRAs

1. Introduction to Navigational Risk Assessments (NRAs)

Unquestionably, the burden on marine spatial planners, and approval and consenting authorities is immense. In the context of the OREI-maritime interaction, these stakeholders have to ensure that OREIs have a minimal impact on the safety and efficiency of shipping operations – whilst simultaneously maximizing renewable energy generation potential and finding optimal locations for such installations. And in balancing the needs of the OREI and maritime industries, the leeway for over- or under-design for safety and efficiency is minimal to none – particularly in already-crowded marine areas.

For planning of marine areas, MSP guidance documents advocate for an ecosystem based approach (EBA). While this approach is thorough and robust, it considers the interaction between different marine uses from a purely environmental/ecological perspective. As a result, it does not adequately capture the safety risks and energy efficiency concerns which arise due to spatial conflicts.

Generally speaking, there is agreement amongst stakeholders that a risk-based approach is needed in order to improve the coexistence of maritime activities and OREIs. IALA, for example, have recently published guidelines consolidating the risk management process with the MSP process – and in doing so, have set the groundwork for a harmonized risk-based approach (IALA 2017). IMO also recommend a risk-based approach through methods such as the FSA.

The good news is that risk-based approaches focussing on the spatial conflict between OREIs and maritime activities already exist in the form of navigational risk assessments (NRAs). A NRA is a process which is conducted by OREI developers to get approval for their projects. Through this process, developers can demonstrate to approval authorities that their projects do not pose unacceptably high risk to maritime activities. Thus approval authorities tend to be more familiar with NRAs than planners. If NRAs were also adopted to be a part of the planning process, however, it could substantially help to close the gap between marine-areas-as-planned, marine-areas-as-approved, and operational scenarios. In fact, this approach is already being in some states, and planners in Belgium and the Netherlands have started using NRA tools during their MSP processes as well. NRAs can be used for entire sea-areas as well as for specific OREI sites, and this flexibility in the scope is a further advantage for stakeholders across the spectrum. NRAs can in fact be viewed as the maritime alternative for EBA within the MSP process; EBAs consider the conflict between marine users in an ecological/environmental context, whereas NRAs consider the same conflicts in terms of impact on navigational safety and efficiency.

In order to ensure that every bit of the available marine space is used as safely and efficiently as possible, NRAs need to be quite robust. An NRA that is overly conservative may lead to inefficiency: ships may have to be unreasonably re-routed, or OREI layouts may have to be curbed unnecessarily due to over-estimation of navigational risks. A poorly-conducted NRA may alternatively lead to reduced safety: an under-estimation of the maritime risks could mean that appropriate risk-control measures are not implemented, potentially increasing the probability and consequences of accidents even further. Therefore, a NRA – like everything in the age-old fable of Goldilocks, or the Swedish concept of '*lagom*' – needs to be "just-right".

This leads us to question – are current NRA processes robust enough to deal with an increasingly complex and crowded seascape? And if not, what are the shortcomings that need to be addressed to improve the situation?

To answer these questions, the authors surveyed stakeholders from 6 North Sea member states, as well as the US as a test-case. The participants were first asked to describe the NRA process in their countries (section II-2). Following this, they were asked to rate their agreement with 10 statements (section II-3); each statement was derived through a literature review exploring the shortcomings of existing NRA processes. By understanding why participants agree and/or disagree with each statement, the authors were able to produce a list of recommendations to improve NRA processes further (section II-4).

2. Evaluating Existing NRA Processes

The core premise of the NRA process is to assess the probability and consequences of maritime accidents[3] in the vicinity of OREIs, through the use of various methods, models, tools, and even stakeholder feedback. By conducting a NRA, it is possible to evaluate whether or not the presence of an OREI will *significantly* increase navigational risk, beyond an unacceptable level. OREI developers are thus *required* to conduct NRAs (either qualitative or quantitative) before their projects can get final approval from coastal-state authorities. Coastal state authorities may also conduct their own NRAs for planning rather than approval purposes, as demonstrated by Belgium and the Netherlands.

As the challenges associated with maritime operations in the vicinity of OREIs are fairly comparable in different areas, one can expect to find quite of lot of *similarities* in the NRA processes of various countries. At the same time, the different stages of offshore wind industry development in various countries is a reason to believe that there may also be *differences* in these NRA processes. A literature review – such as the one conducted by Ellis et al. (2008) or Mehdi & Schröder-Hinrichs (2016) – points towards both similarities and dissimilarities amongst the NRA frameworks, models, methods and tools used by different countries, but is inconclusive in proving whether there are *more* differences than similarities in the actual NRA processes. Thus, this survey of stakeholders seeks to fulfil comparative clarifications on national NRA processes.

2.1 United Kingdom

When it comes to energy generation from *offshore* wind, the undisputed leader is the UK. With 1,472 OWTs currently installed, the UK has the greatest Cumulative Offshore Wind Capacity (COWC) – 5156 MW – of all the countries with OWFs. The UK also boasts the largest OWF in the world – London Array, a 630 MW OWF with 175 installed turbines. As mentioned earlier, the world's first and largest floating OWF – due to be completed in 2017 – is also in the UK, just off the coast of Scotland.

A marine license is necessary for all OREIs in the UK, and it is granted by the various devolved authorities – such as the MMO in England, or Marine Scotland in Scotland. In order to obtain a marine license, OREI developers need to conduct a NRA. The purpose of the NRA in the UK, like elsewhere, is quite simple: to evaluate the risk to shipping without ('base-case') and with ('future-case') the proposed OREI – and to demonstrate that the proposed OREI will not lead to unacceptably-high navigational risks. The devolved authorities consult the Maritime and Coastguard Agency (MCA), as well as other relevant stakeholders, to ensure that a NRA conducted by an OREI developer is valid and adequate.

[3] *All* countries considered in the present study require developers to assess the risk of all the following navigational accidents: powered and drifting contact (vessel-turbine) accidents, powered collision (vessel-vessel) accidents, and, powered and drifting grounding accidents.

The UK's significant NRA experience is well-reflected in comprehensive guidance documents, which are developed for OREI developers by authorities such as the MCA. These documents include the well-known '*Methodology for assessing the marine navigational safety and emergency response risks of offshore renewable energy installations*' (MCA 2013) and '*MGN 543 (M+F) Safety of Navigation: Offshore Renewable Energy Installations - UK Navigational Practice, Safety and Emergency Response*' (MCA 2016). Both these documents provide a comprehensive list of factors (e.g. vessel traffic, types of vessels, traffic characteristics, location of routes, routeing measures, bathymetry, waves, winds, currents, OREI layout, OWT marking and lightings, effect of turbines on navigational equipment, etc.) – as well as non-exhaustive list of stakeholders (e.g. RNLI, lighthouse authorities, Chamber of Shipping, recreational shipping, local fishermen, ship-owners and operators, etc.) that need to be considered during a NRA. These factors and stakeholders were also mentioned by the respondent during their interview.

The maritime operations that are considered during a NRA in the UK include passing shipping traffic, wind farm support vessel (WSV) operations, OREI installation operations and emergency operations such as search and rescue (SAR). Decommissioning operations are not explicitly covered, nor are operations in ports and harbours, the latter of which are dealt separately with by harbour authorities. The NRA also does not cover the decommissioning *phase* of an OREI's lifecycle[4].

The guidance documents from the UK recommend that developers follow the five-step Formal Safety Assessment (FSA) methodology (IMO 2002). FSA – which has also been adapted by the International Maritime Organization (IMO) – allows decisions makers to evaluate the risks, costs and benefits of a proposed activity or system, and to propose adequate risk control options, making it ideally suited for a process such as NRA.

Within the FSA methodology, users are free to choose which models and tools they want to use for probability and consequence calculations. In the UK, there are *no minimum requirements* as to whether these models or tools should be qualitative, quantitative, numerical, empirical, probabilistic, deterministic, etc. Thus, even though the two guidance documents cited above (MCA 2013; 2016) mention possible use of numerical models and simulations, OREI developers are *not* obliged to use any adhere to these specifically – and are free to use any *models* or *tools* for probability or consequence calculations that they deem fit.

A quick look on the National Infrastructure Planning Portal (NIP 2017), which contains Environmental Impact Assessment (EIA) and NRA studies for various UK-based OREIs indicates that developers have a *preference* for the COLLRISK model from Anatec UK Ltd (Anatec 2017). This quantitative, probabilistic model primarily relies on vessel traffic data to estimate the difference in risk of navigational accidents in an area before and after an OREI is constructed. The COLLRISK model also uses estimates of impact energy (using kinetic energy formulae), as well as past accident statistics, to predict the probability and level of consequences, such as loss of life, injuries or environmental damage.

Nevertheless, the adequacy of a NRA, in the UK, is determined on a strictly case-by-case basis. Therefore, developers should be able to demonstrate that they have considered all listed factors thoroughly, whilst giving reasonable justification for the methods, models and tools that they have used.

Furthermore, each OREI in the UK is also approved on a case-by-case basis, which means that there are no specific limits on how *low* the probability and/or consequences of OREI-related navigational accidents

[4] It is important to distinguish between 'operations' and 'lifecycle phases'. For instance, it is possible for a NRA to cover the decommissioning 'phase' but not decommissioning 'operations'. This would essentially mean that the NRA is *not* conducted from the perspective of decommissioning vessels, but *does* cover the decommissioning phase from the perspective of *other* operations (e.g. passing vessels).

should be. In other words, the 'acceptable' risk limits for of each OREI can be different – and whether an OREI gets the go ahead is decided on the results of the NRA, as well as Hazard Identification (HAZID) workshops and stakeholder consultations.

2.2 Germany

Germany has the second-largest COWC after the UK, with 947 installed OWTs as of 2016. There has been a flurry of OWF-related activities in Germany over the last two years in particular: of the 4108 MW total COWC, 2282 MW worth of turbines were installed in 2015 alone – with a further 813 MW installed in 2016.

In Germany, the licensing of all OREIs in the Exclusive Economic Zone (EEZ) is done by the Federal Maritime and Hydrographic Agency of Germany (Bundesamt für Seeschifffahrt und Hydrographie, or BSH). The NRA is a part of the licensing process, and is checked by the Directorate-General for Waterways and Navigation[5] (Generaldirektion Wasserstraßen und Schifffahrt, or GDWS).

Some of the early (and already quite comprehensive) documents for OREI NRA were developed by the class-society Germanischer Lloyd more than 15 years ago (GL 2002) and updated nearly a decade ago (GL 2008). Subsequently, some of the early NRA studies used models developed by GL such as COLWT (GL 2002; 2008; Ellis et al. 2008). In more recent years, updated NRA guidance documents have been produced by federal authorities in Germany. The BSH, for instance, has developed a construction standard for OWFs – '*Minimum requirements concerning the constructive design of offshore structures within the Exclusive Economic Zone'* (BSH 2015) – which provides an overview of the risk assessment process, as well as details about accident-consequence estimation. This document is used in combination with '*AG-Richtwerte*' – a document developed by GDWS which provides guidelines for probability assessment (in German). Other relevant documents[6] containing guidance on NRA include: an implementing directive on marine impacts of OWFs (BMVI 2014a); a safety framework for OWFs (BMVI 2014b); a framework to ensure the proper implementation of traffic regulations in the vicinity of OREIs, including guidance on marking of offshore turbines (GDWS 2014a); and a directive to ensure the safety and security of ship-traffic in the vicinity of OREIs (GDWS 2014b). These documents list the factors that need to be considered during NRAs (e.g. vessel traffic, OREI location and layout, environmental conditions including wind, weather, ice, fog, bathymetry, effect on navigational equipment, etc.) – and also identify important stakeholders that should be consulted during the process (e.g. GDWS, German Sailing Association, fisheries associations, etc.). The factors and the stakeholders which are considered during a NRA are similar in both the UK and Germany, and were confirmed by the German respondents in their survey responses during the present study.

The focus of the NRA, in Germany, is primarily on assessing and managing the impact of OREIs on *passing shipping traffic*. WSV operations, installation & decommissioning operations, emergency response operations and operations in ports and harbours are not explicitly dealt-with during the NRA process. A NRA in Germany covers all phases of an OREI's lifecycle, including installation and cable-laying, operation, and decommissioning[7].

[5] GDWS itself has 39 waterways and shipping offices, as well as 7 waterway construction offices. Both the BSH and GDWS are a part of the Waterways & Shipping Administrations of the Federal Government (Wasserstraßen- und Schifffahrtsverwaltung des Bundes, or WSV). The WSV is one of 9 directorates of the Federal Ministry of Transport & Digital Infrastructure (Bundesministeriums für Verkehr und digitale Infrastruktur, or BMVI).

[6] The other aforementioned documents are available in German only.

[7] See footnote 2.

The guidance documents by BSH clearly state that *'the method of risk classification and analysis shall be based on the German Hazardous Incident Ordinance (Störfallverordnung), the British Safety Case Regulations for offshore installations and the IMO regulations*' (BSH 2015).

In Germany, the *probability* of navigational accidents *must* be calculated numerically whilst accounting for factors such as ship type, size, speed, weather conditions, location and layout of OREI, etc.; the GDWS provides inputs on which ship types and sizes need to be considered. Once the probability of a navigational accident is calculated, it can be categorized within a qualitative band (Frequent, Occasionally, Rare, Extremely Rare) as per the guidance of BSH (2015). The emphasis in Germany is *more* on vessel-turbine collisions than on vessel-vessel collisions or vessel groundings which may also be caused due to an OREI restricting navigable space. A BMVI working group has deemed that there should not be more than *one* OREI-related navigational accident every 100 years; any frequency higher than this is considered unacceptable. This is a very different approach than that of the UK, where the so-called return-period of vessel-turbine accidents (i.e. minimum the number of years between accidents) is determined on a *case-by-case* basis rather than a fixed, generic value. It is also interesting to note the *requirement* for a numerical probability calculation – which is again in stark contrast with the UK where there are no *minimum* model- or tool-related obligations on developers.

Furthermore, the focus on *consequence* assessment is also more detailed and explicit in Germany than in the UK and most other countries. Developers are *required* to use finite-element (FE) simulation programmes to model an accident between a turbine and a reference vessel(s). Developers are, however, free to choose their preferred software package and modelling tools for the FE-calculations. Examples of FE analyses of ship-turbine collisions can be found in the works of Biehl & Lehmann (2006), Le Sourne et al. (2015) and Bela et al. (2017) amongst many others as listed by Mehdi & Schröder-Hinrichs (2016) and Deeb et al. (2017).

The purpose of the FE-calculations is to understand the behaviour of turbine collapse, and to *ensure* that the support structure of an OWT is 'collision-friendly' – i.e. 'if an offshore wind turbine, as a consequence of collision, does not fall onto the ship, the ship remains floatable and there is no leakage of pollutants' (BSH 2015). In other words, a turbine *must not* rupture the hull of a ship under specified conditions; the conditions are specified by the BMVI and assume that a reference-ship, of a given type and structural configuration, drifts into the turbine at a speed of 2 m/s. The BSH (2015) guidance lists further specific criteria that must be met during the FE-calculation stages, including a list of acceptable assumptions for the model.

Ideally, several different scenarios should be modelled using FE-calculations. Following the FE-calculations, experts assign *qualitative* consequence-levels (Catastrophic, Serious, Significant, Insignificant) to each scenario based on the expected condition of the OWT, the expected damage to the ship, the expected environmental damage, and/or the expected casualties and fatalities. Developers are then required to use a risk-matrix to 'combine' the consequence and probability levels into a given risk value for each scenario. The combined risk-value for each scenario must be below a certain threshold to be acceptable, as specified by BSH (2015).

Compared to other countries, Germany has opted for a more rigid approach to NRA. The lack of flexibility, however, *does* offer certain apparent advantages in terms of standardization, transparency, and harmonization. Whether this approach is more or less effective than that of other countries, of course, remains to be seen.

2.3 Denmark

Denmark is truly a pioneering country when it comes to offshore wind energy. The first-ever OWF, Vindeby, was commissioned near Lolland in Denmark, in 1991. And after producing 243 GWh of energy over 25 years, Vindeby is finally being decommissioned. The legacy of offshore wind, however, remains strong in Denmark, where there are currently 517 installed OWTs, with a COWC of 1271 MW. This year, the Danish Energy Agency (DEA) produced a report detailing the Danish experiences of OWFs (DEA 2017).

The licensing of OREIs is handled by the DEA. Developers are required to conduct an EIA for each OREI, and a crucial part of this EIA is the NRA. The NRA is checked and validated by the Danish Maritime Authority (DMA).

While the DMA has internal guidelines on NRA, there are no specific *public* documents providing guidance on the topic. Nevertheless, the in-depth interview with the Danish authorities provided a thorough insight into the NRA process. The factors and stakeholders that are considered in Denmark are very similar to those that are considered in UK or Germany. The factors that are considered during a NRA include vessel traffic data, ship-routes, OREI-related data, effect of turbines on navigational equipment, and static and dynamic environmental conditions, as well as the presence of existing risk-control options such as Vessel Traffic Service (VTS) or Traffic Separation Schemes (TSS). The Danish authorities explicitly listed pilots, VTS operators, local port authorities, fishermen, leisure boat owners and operators as well as leisure ports as important stakeholders. The list of both factors and stakeholders is, of course, non-exhaustive, as stated by the interview respondents.

In Denmark, the NRA covers all maritime operations, including passing vessels, WSV operations, OREI installation and decommissioning operations, emergency response operations and even operations in ports and harbours that deal with OREI activities. The NRA also covers all phases of an OREI's lifecycle, including installation and cable-laying, operation, and decommissioning.

The DMA – like the MCA – strongly recommends the use of FSA as the overarching method for NRA. Developers *can* opt for a different method with reasonable justification, but generally comply with DMA's recommendation. As in the UK, developers are free to choose which *models* and *tools* they use for probability and consequence assessment stages within the FSA. There are *no minimum requirements* as to whether probability and/or consequence assessments need to be qualitative, quantitative, numerical, probabilistic, etc.

Generally, however the starting point of a NRA in Denmark is the consideration of current and predicted[8] AIS data to quantitatively estimate the probability of navigational accidents for different vessel types in the vicinity of OREIs. This estimation should account for the various factors listed above, such as vessel traffic, OREI location and layout, configuration of shipping routes, and environmental conditions. If the return-period is found to be too low, then developers need to demonstrate that they will implement adequate risk-control measures – particularly to mitigate the consequences of navigational accidents. This discussion is usually a part of HAZID workshops.

There are no strict demands in terms of consequence assessment either – and certainly no *requirements* for FE-calculations like in Germany. That being said, the turbines *do* need be collision-friendly, but this is something that is generally addressed *qualitatively* during discussions in HAZID workshops.

In previous years, OREI developers in Denmark have often made use of Det Norske Veritas' (DNV's) '*Marine Accident Risk Calculation System*' (MARCS) model (Ellis et al. 2008). This model combines AIS data with OREI location and layout to assess the frequency of accidents before and after an OREI is

[8] There are several ways of 'predicting' changes in vessel traffic. One could, for instance, use simulator exercises to come up with corrective factors for existing AIS data. Another way is to reconfigure the waypoints around an imaginary OREI site. This is done by both iWRAP (IALA) and SAMSON (MARIN) as well as other tools. In fact all NRAs compare 'base-case' with 'future-case' scenarios – and this requires predictions to changes in AIS data. Predicted AIS data may also incorporate changes in ship types and ship traffic volumes.

installed. The model also has the capability to estimate the probability and level of consequences, and can provide a rough assessment of environmental damage through probabilistic damage calculations. Of course, this detail of consequence assessment may not be needed for qualitative discussions, but it is nevertheless a good option to have. In more recent years, companies such as COWI and Rambøll have also conducted NRAs for OREIs in Denmark.

Each OREI in Denmark is approved on a case-by-case basis – and thus there are no *generic* requirements about how low the probability or consequences need to be. If the accident return-period is too low, then the approval of a OREI may hinge on adequate risk-control options being implemented; these measures may seek to reduce to probability, or more often, the consequences of navigational accidents associated with OREIs.

Overall, the approach of Denmark towards NRA follows more closely with the approach of the UK rather than that of Germany. That being said, the requirement for turbines to be collision-friendly is an idea championed by Germany more so than the UK.

2.4 The Netherlands

The Netherlands are another pioneering country when it comes to wind energy. The very mention of the nation evokes images of quaint, centuries-old windmills in fields of tulips. It is therefore apt to see that the Netherlands has a strong OWF sector as well. As of 2016, there are 365 OWTs with a COWC of 1118 MW in the Netherlands[9].

The licensing of OWFs in the Netherlands falls under the '*Kavelbesluiten*' (Part of the Act on offshore wind energy), and also relates to the Water Act. The Water Act also provides the general rules for all OWFs within the EEZ. The authority responsible for the licensing of OWFs is the Ministry of Economic Affairs and Climate Policy (MEACP), which makes decisions in liaison with other federal authorities such as the Ministry of Infrastructure and Water Management (MIW)[10]; the Netherlands Enterprise Agency (RVO.nl) executes the SDE+ (in Dutch: Stimulering Duurzame Energieproductie) operating grant, offshore wind energy subsidy and permit tenders on behalf of MEACP.

The Dutch government itself is responsible for producing an EIA, called a marine environmental effects report (MER), as well as the NRA. The MER and NRA are then passed on to the developers, along with specific design requirements for potential OWFs. Rijkswaterstaat, the part of the Ministry of Infrastructure and Water Management (MIW) that is responsible for the design, construction, management and maintenance of the main infrastructure facilities, is responsible for conducting the NRA, and verifying that developers comply with the NRA findings. The approach of the Dutch authorities towards the NRA thus differs from other coastal states covered in this study. While the other coastal states require the OWF developers to conduct NRAs and EIAs, these process are led and conducted by the governmental authorities in the Netherlands. This means that in other coastal states, the NRA is generally a part of the

[9] These numbers, cited by WindEurope, differ to the official Dutch figures of 289 offshore turbines and 957 MW COWC. The discrepancy is because WindEurope include the turbines at Lake Ijsselmeer, whereas the Dutch authorities do not. For the purposes of this report, the Dutch figures are more accurate as 'offshore' turbines are those beyond the defined marine baseline of a country, where the baseline is defined as per UNCLOS. For reasons of consistency however, the figures from WindEurope are cited in text.

[10] Following the Dutch General Elections in March 2017, the ministry of Infrastructure and the Environment (MIE) is now called the Ministry of Infrastructure and Water Management (MIW). The spatial department of the old ministry of Infrastructure and the Environment is now part of the Ministry of the Interior and Kingdom Relations.

The old ministry of Economic Affairs is now called the Ministry of Economic Affairs and Climate Policy. Note that the former ministry of Economic Affairs was also responsible for MPA policy and fisheries. These task are now in our new Ministry of Agriculture, Nature and Food quality.

approval and licensing stages only – whereas in the Netherlands, the NRA is the same across the planning, approval and licensing stages. This has the added advantage of ensuring that there are minimal differences between OWFs-as-planned and OWFs-as-approved.

There are publicly available guidelines pertaining to safe navigation around OWFs. Most of the documents[11], however, are in Dutch. This includes the important '*Bijlage 4: Reglementen, voorschriften en verkeersregels voor scheepvaart die*' – an appendix which deals with rules and regulations of shipping traffic, with a particular focus on safe-passing distances to OWFs. An equivalent and comprehensive document is also available in English (MIE & MEA 2014). The latter document lists the factors and stakeholders that are taken into consideration when discussing safety of navigation. Factors which are taken into account include vessel traffic characteristics, ship speed, sizes and manoeuvrability, static and dynamic environmental conditions, and OWF layout and location. Important stakeholders for NRA – as listed by the interview respondent – include, but are not limited to, the OWF sector, commercial and recreational shipping, fishermen, harbour authorities and various governmental departments. It is apparent that the factors and stakeholders considered during a NRA in the Netherlands are similar to those considered during NRAs in other countries such as the UK, Germany and Denmark.

In the Netherlands, a NRA should cover all maritime operations, including passing vessels, WSV operations, OWF installation and decommissioning operations, emergency operations, as well as operations in ports and harbours that deal with OWF activities. The NRA also covers all *phases* of an OWF's lifecycle from installation, through operation, to decommissioning.

A NRA in the Netherlands can be conducted for two purposes related to OWFs. The first purpose is proposal of risk control measures (e.g. new routeing measures) around *existing* OWFs. For this purpose, the NRA is conducted by the Dutch authorities and submitted to the IMO. The IMO-recommended FSA methodology (IMO 2012) is followed for such submissions – and authorities prefer to use the quantitative '*Safety Assessment Models for Shipping and Offshore in the North Sea*' (SAMSON) model (van der Tak 2010; Ellis et al. 2008), developed by the Marine Research Institute of the Netherlands (MARIN), for the probability and consequence calculation stages in the FSA. When proposing routeing measures, the Dutch authorities follow the guidelines of World Association for Waterborne Transport Infrastructure (PIANC) with regards to minimum waterway width, and also rely on the results from the research institute MARIN which have determined how much space is needed between waterways and OWF boundaries. Using an NRA to re-route shipping lanes around existing OWFs is an unprecedented action that was taken by the Netherlands, as normally, in other coastal states, shipping lanes are re-routed before OWFs have been built, in anticipation, often during planning and/or scoping stages. Nevertheless, it is a positive step to ensure navigational safety, and set a good example for other coastal states to follow, in case they ever recognize the need to retroactively adopt their risk control measures, due to changes in shipping traffic and/or environmental conditions for instance.

The second purpose for an NRA is the *approval* of OWFs (which is common across the other coastal states). In this case, a NRA is used to compare base-case with future-case scenarios, and is conducted by MIW and Rijkswaterstaat. As mentioned earlier, the results of the NRA (as well the overarching MER) are presented to developers, along with specific design specifications for potential wind farms. The federal authorities (i.e. MIW and Rijkswaterstaat) are then responsible for ensuring that developers adhere to the guidelines during the approval and licensing phase. The Dutch authorities prefer to follow the FSA

[11] Available from www.noordzeeloket.nl

methodology, and favour the use of MARIN's quantitative SAMSON model for probability and consequence calculations[12] for OWF-approval NRAs as well.

SAMSON, like most other commercial models, relies on AIS data to calculate the risk of navigational accidents in the vicinity of OWFs. It can be used to calculate and compare the probability and consequences of navigational accidents for various base-case (i.e. no OWF) and future case (i.e. OWFs in different layouts/locations) scenarios. When calculating the probability of drifting or powered accidents near OWFs, SAMSON can account for various specific factors such as ship types, sizes and speeds, effect of OWTs on ships' navigational equipment, as well as static and dynamic environmental factors – not to mention risk-control options such as VTS, TSS, availability of tugs in an area, etc. SAMSON also performs quantitative consequence assessment, and can be used to predict the damage to turbines and ships, environmental damage in terms of oil spills or human casualties through the use of complex semi-analytical/empirical formulae. Furthermore, SAMSON is also able to assess the economic- and efficiency-cost of various risk control options (e.g. re-routeing), which makes it a good tool for cost-benefit analyses – and an ideal complement to the FSA methodology. Despite all the positives, however, SAMSON is a commercial tool, which means that certain elements within it may not be entirely transparent to the general public.

It is important to reiterate that the use of SAMSON is highly recommended, but not obligatory. Whilst most OWF developers – and the Dutch authorities themselves – use SAMSON, it is possible to employ other models and tools for OWF NRA, with reasonable justification.

Like in Denmark, or the UK, OWFs in the Netherlands are approved on a case-by-case basis. Each individual NRA is generally discussed with operational end-users (including seafarers, fishermen, recreational sailors) and nautical policy experts before being presented to OWF developers, and before licenses can be granted.

The Dutch approach to NRA is quite comprehensive and well-established. In terms of flexibility, it is not quite as flexible as that of the UK, but is certainly more on par with Germany's approach. Aside from 'traditional' NRAs, the consideration of ship manoeuvrability and minimum waterway width are factors which the Dutch have pursued more vigorously than other countries, in order to ensure that their sea-space is used as safely and efficiently as possible. This is certainly an approach that can certainly be better integrated within NRA processes in other coastal states.

2.5 Belgium

Bordering two OREI 'giants' – the UK to the West, and the Netherlands to the North – Belgium also has some serious ambitions of its own when it comes to offshore wind. Despite only having a coastline of approximately 67 km, Belgium has a COWC of 712 MW, which places it at the 6th rank *globally*. Currently, 182 OWTs are installed off the coast of Belgium – and the Belgium government has given approval for four more OREIs to be built in the future.

OREIs in Belgium need an environmental license which is granted by the Ministry of Public Health and Environment. The NRA is a part of this environmental license, and is conducted by the OREI developer. The NRA is checked by Directorate-General Shipping, which is a part of the Federal Ministry of Transport –

[12] Whilst Denmark and UK also advocate the use of the FSA methodology for NRA, they do not have any particular recommendations as to which *models* should be used for probability and consequences calculations within the FSA.

as well as by the Agency for Maritime and Coastal Affairs from the Flemish Region, who are responsible for pilotage and VTS in the whole of Belgium.

The factors and stakeholders which are considered during a NRA in Belgium are very similar to those that are considered in other countries. There are particular similarities between the NRA process in Belgium and the Netherlands. Factors which are taken into consideration during a NRA in Belgium include, but are not limited to, vessel traffic, static and dynamic environmental conditions, and OREI-related information such as the location and layout of OWTs. Stakeholders who are consulted during a NRA in Belgium include seafarers and pilots, port and harbour authorities, ship-owners, VTS operators, and end-users involved in emergency maritime operations, such as search and rescue (SAR).

A NRA in Belgium covers most maritime operations, including passing shipping traffic, WSV operations, installation and decommissioning operations, and emergency operations including SAR. Operations in ports and harbours that deal with OREI activities, however, are not covered as part of the NRA. The NRA only covers the installation and operation phases of an OREI, and not the decommissioning phase[13].

Belgian authorities do not *require* OREI developers to follow any specific methods for the NRA. They do however *recommend* the use of MARIN's SAMSON model – although developers can opt for other models and tools with reasonable justification as well[14]. Regardless of which model they use, at the very minimum, OREI developers should be able to demonstrate that they have assessed the probability of navigational accidents *quantitatively*. This requires a comparison of base-case and future-case scenarios, with and without an OREI, whilst accounting for factors such as vessel traffic, shipping routes, effect of OWTs on navigational equipment, weather conditions, hydrographic features, existing risk-control options and OREI layouts. Belgian authorities are particularly interested in the frequency of accidents before and after a OREI is installed, and base their decision heavily on this parameter, which is why they recommend a model like SAMSON.

There are no specific *requirements* with regards to consequence assessment in Belgium either – but it is strongly recommended that developers conduct *quantitative* probabilistic assessments which can estimate the likelihood and level of consequences in terms such as potential ship damage, expected OREI downtime, potential environmental damage and possible human casualties. Such quantitative consequence assessment can be conducted through SAMSON, if that model is being used.

Each OREI has its own specific impact on navigation, and subsequently each NRA is judged on a case-by-case basis. There are no generic guidelines on how low the probability and/or consequences of navigational accidents need to be, and the acceptability criteria are determined on the back of the NRA and stakeholder consultations. A crucial factor driving the acceptability of the risk is the volume of vessel traffic near an OREI; if two OREIs have the same return-period of 1000 vessel movements, but one OREI has 1000 times more vessel movements in its vicinity, it is obvious that that one will pose much higher risk to navigational safety.

The Belgian approach to NRA is quite similar to the Dutch approach, which – given their shared borders, and close proximity of OREIs – works out very well. Like their Dutch counterparts, Belgian planners have also used SAMSON to conduct NRAs during their MSP process. Recently, Belgium and the Netherlands also submitted a joint FSA to the IMO to implement certain joint routeing measures that would mitigate the risk of navigational accidents in the vicinity of OREIs. Despite the fact that Belgian authorities opt for 500 m safety distance between their shipping lanes and OREIs, whilst the Dutch opt for *at least* 1.87 NM, the joint

[13] See footnote 2.

[14] Early NRA studies in Belgium have utilized models from DNV (MARCS) and GL (COLWT).

proposal was quite a success. Although they may have different views of how 'safe' a system is, or what the acceptable distance between a shipping lane and an OREI should be, they nonetheless have very similar, compatible NRA processes. Their joint approach is thus a perfect example that if countries wish to harmonize their NRAs, they can do so – and still have different opinions and acceptability criteria when it comes to navigational risk.

2.6 Sweden

Sweden can be classified as an 'emerging' nation when it comes to offshore wind energy generation. With just 86 installed OWTs, the Sweden has a COWC of 202 MW. Nevertheless, Sweden has ambitions to generate around 10 TWh of energy from offshore wind by the year 2020.

A NRA is necessary for OREIs in Sweden (BalticMaster 2007), where the licensing for such installations is carried out by the Environmental Court. The NRA is normally then checked by Swedish Maritime Administration (*Sjöfartsverket*, or SMA for short) as well as the Swedish Transport Agency (*Transportstyrelsen*, or STA for short).

Despite being an 'emerging' nation in terms of offshore wind, Sweden has produced several comprehensive documents related to OREI NRA. The work of Ellis et al. (2008), for instance, was conducted to provide input for the Swedish NRA process. Following this work, a brief guidance document was produced by the governmental authorities (SMA & STA 2009). More recently, the Swedish Energy Agency (*Energimyndigheten*, or SEA for short), together with other relevant stakeholders such as SMA and STA produced guidelines on health and safety issues related to OREIs (SEA 2014). Part of this guidance refers to safe navigation of vessels in the vicinity of OREIs. The factors and stakeholders which are considered during a NRA in Sweden are similar to those considered in other countries. The aforementioned documents identify vessel traffic, dynamic and static environmental conditions, OREI layout and location, and existing risk control options including VTS, TSS, etc. as some of the factors that need to be considered during a NRA. When asked about the stakeholders, the interview respondents listed SMA, STA, the Environmental Court, *Länsstyrelserna* (County Administrative Boards), *Havs- och Vattenmyndigheten* (Swedish Agency for Marine and Water Management – SwAM), and various environmental organizations as some of the parties that need to be consulted during a NRA.

A NRA in Sweden should ideally assess the risk to *all* maritime operations including the risk to passing shipping traffic, the risk during WSV operations, the risk during OREI installation and decommissioning operations, the risk during emergency operations such as SAR in the vicinity of OREIs, and even the risk during port and harbour operations related to OREIs. Subsequently a NRA should also be valid for the all phases for an OREI's lifecycle – from installation, through operation, to decommissioning.

In Sweden, OREI developers are *not required* to use any specific models or methods for OREI NRA. That being said, the guidance document produced by SEA (2014) mentions the tool iWRAP-MK-II, which was developed by the International Association of Lighthouse Authorities (IALA). Traditionally, however, tools and models developed by the maritime consultancy SSPA (Ellis et al. 2008) are more commonly used for OREI NRA in Sweden than iWRAP; this is unsurprising considering that SSPA has played a major role in developing some of the guidelines related to OREI NRA in Sweden. SSPA's model for NRA is very similar to those developed by DNV, GL, or MARIN – and also relies primarily on AIS data. Amongst other factors, the SSPA model takes into account vessel sizes and speeds, condition of vessel (powered or drifting), layout of shipping routes, static and dynamic environmental conditions, OREI location and layout, and availability of risk control options such as VTS, TSS or tugs, etc. Through this information, the model can quantitatively predict the probability of various navigational accidents in a given sea area both before and after an OREI is built. This information can also be combined with accident statistics to empirically quantify the probability and level of consequences.

Although it may not yet be a major OREI player, the existing NRA processes in Sweden reflect the country's ambitions for the future. Truly, Sweden is taking a proactive stance towards safety of navigation around OREIs.

2.7 United States of America [Comparative Case]

The last country considered in the present study is the US. The US, like Sweden, can be classified as an 'emerging' nation in terms of offshore wind energy generation. As of 2016, there is only one commercial OREI in the US – the 5-turbine Block Island Wind Farm – giving the US a COWC of 30 MW. Yet, the US has great potential for OREI given their enormous coast lines along the Atlantic and Pacific seaboards, the Gulf Coast, the coast of Alaska, in the Hawaii archipelago, and along the coasts of many of their outlying territories.

The Bureau of Ocean Energy Management (BOEM) is responsible for the licensing of all offshore renewable energy installations (OREIs) beyond 3 NM state waters; within the 3 NM limit, licensing of OREIs and OREIs falls under the mandate of US Army Corps of Engineers. A NRA is not required by law in either regime, but is generally included as part of the broader Environmental Review. The United States Coast Guard (USCG) are normally asked to weigh-in on the NRA submissions.

Despite their late-entry into the offshore wind sector, the US also have comprehensive documents with regards to NRA. In particular, the USCG has developed a thorough and comprehensive document pertaining to OREI NRA (USCG 2007). The document lists various factors – such as vessel traffic, ship types and sizes, waterway characteristics, static and dynamic environmental conditions including wind, waves, current and ice – that should, amongst others, be accounted for during a NRA. The document also lists various stakeholders that need to be consulted during the NRA process. On a personal level, the interview respondent identified commercial seafarers, fishermen, recreational boaters, tug and barge operators, and various commercial shipping companies as important stakeholders to consider during the NRA. It is quite obvious that the factors and stakeholders considered during a NRA in the US are similar to those considered in other countries.

Developers in the US are encouraged to produce NRAs that assess the risk to all types of maritime operations – from passing vessel operations, to WVS and installation and decommissioning vessel operations, as well as emergency maritime operations, and operations in ports and harbours that deal with OREI activities. The NRA should cover the installation and operation phases of an OREI's lifecycle, but there is no specific requirement for a NRA to also cover the decommissioning phase.

As in several other countries, developers are not obliged or required to use any specific method, model or tool for NRA. Even though the guidance developed by the USCG mentions 'what-if analysis' as a tool, for example, it is simply a recommendation and not a requirement. Whilst there is no requirement to use any specific tools, it is important for OREI developers to demonstrate that they have considered all factors listed in the guidance document, some of which are mentioned above. Developers are also required to demonstrate the effect that their installation can have on the *probability* and *consequences* of navigational accidents, whilst accounting for each of the listed factors. In other words, developers are required to compare the base-case with possible future-case scenarios – a practice which is common in all of the countries considered in the present study.

Each OREI in the US is approved on a case-by-case basis, and as such, there are no generic guidelines about the probability or consequences being below a certain threshold. Generally, a stakeholder consultation may discuss the NRA results, and decide whether the estimated risks are acceptable or not.

It is encouraging to note that even the US, who only have 30 MW COWC, are proactively addressing the navigational risk aspect of OREIs and OREIs. Having comprehensive and thorough guidelines in place, and learning lessons from evolving and established countries, is a path that should be followed by all emerging nations who have ambitious offshore energy plans.

2.7 Norway

Norway is also a coastal state in the North Sea region, and a partner on the NorthSEE project. Despite the fact that Norway is heavily involved in offshore wind projects, the state currently does not have any offshore wind turbines installed (with the exception of a demonstration project for a 2.3MW floating turbine). For this reason, Norway was excluded from the current study, as it aims to list the lessons learnt from countries with existing offshore wind projects.

3. Gaps in Existing NRA Processes

After describing the NRA process in their respective countries, the respondents were asked to indicate their agreement with ten statements, as shown in **Table 2**. The statements directly and/or indirectly reflect the *apparent* weaknesses of current NRA process, as identified by the authors through a literature review. By asking the respondents to rate these statements in an interview setting, the goal was to establish whether or not NRA experts perceive these weaknesses as well – and, furthermore, to elicit their opinions on how they might wish to address these shortcomings.

Table 2. Agreement ratings assigned to different statements by the respondents. Key: SA = Strongly Agree; A = Agree; NAD = Neither Agree or Disagree; D = Disagree; SD = Strongly Disagree.

		5156 MW	4108 MW	1271 MW	1118 MW	712 MW	202 MW	30 MW
		UK	**DE**	**DK**	**NL**	**BE**	**SE**	**US**
1.	*The planning/approval of OREIs (especially trans-national OREIs) can be improved by harmonizing the steps of the NRA process in different countries*	A	A	A	SA	SA	A	A
2.	*All countries should have the same NRA process for offshore wind farms (OREIs)*	A	A	A	A	A	NAD	NAD
3.	*A step-by-step best practice guide for OREI NRA should be produced by an intergovernmental organization (such as the IMO) to ensure a harmonized NRA process across different countries*	A	NAD	NAD	A	A	A	NAD
4.	*There is a need to improve the transparency of the NRA process in terms of the models and data that are used*	D	NAD	A	A	A	A	D
5.	*There is a need to improve the input data that is used in NRA frameworks, methods and models*	NAD	NAD	NAD	A	NAD	A	NAD
6.	*There is a need to improve the models that are used during the NRA process*	D	NAD	NAD	A	D	A	NAD
7.	*There is a need to improve the way through which stakeholder feedback is incorporated in the NRA process*	D	NAD	D	NAD	NAD	A	D
8.	*The is a need to improve the communication between maritime and offshore energy stakeholders during the NRA process*	D	NAD	NAD	D	NAD	A	A

9.	*There is a need to improve the communication of NRA results to seafarers*	D	NAD	D	D	SA	NAD	A
10.	*Seafarers that operate near OREIs should be provided with risk-based decision support systems that allow them to assess navigational risk operationally*	A	NAD	D	D	A	NAD	NAD

3.1 Statements 1, 2 & 3 – Harmonization of NRA Processes

One of the shortcomings identified by the literature review is a lack of harmonization between the NRA processes of different countries. Statements 1, 2 and 3 in **Table 2** relate to this particular concern. It is obvious from both the literature review, and the descriptions provided by the respondents themselves, that NRA processes are *not* the same in different countries. The differences within the NRA processes of various countries, however, are quite subtle for the most part; in fact, it is evident that there are more *similarities* in the way that certain countries conduct NRAs. Belgium and the Netherlands, for instance, both recommend the same model for probability and consequence assessment; the UK, Denmark and the Netherlands all advocate the use of the FSA methodology; and the factors and stakeholders which are consulted during a NRA are identical across *all* the countries in the present study. Even the different commercial models used for probability and consequence assessment have some similarities in terms of calculation methods and input data – but subtle differences do exist, and may lead to significantly different NRA results.

The similarities are nonetheless quite good news, because the respondents unanimously agree (or strongly agree) with statement 1 – i.e. that the planning and approval of OREIs can be improved by harmonizing the steps of the NRA process. In particular, several of the respondents explicitly stated that having similar (or even the same) *probability* and *consequence calculation process* would be immensely useful – especially when it comes to transnational OREIs. This would help to avoid unexpected situations wherein the probability and consequences of navigational accidents are calculated differently for the same OREI, as was the case with Krieger's Flak – which is an OREI that jointly lies in the EEZs of Sweden, Denmark and Germany (Ellis et al. 2008).

It should be mentioned that the two countries that 'Strongly Agree' with **statement 1** – BE and NL – already have a very harmonized process: they recommend the same process and the use of the same model for probability and consequence calculations (SAMSON) – and consider very similar factors and consult very similar stakeholders during the NRA. These two countries have also made joint submissions to the IMO for routeing measures near their shared OREI boundaries. At the same time, they have different views of *risk-acceptability* – e.g. how much safe distance should be maintained between an OREI boundary and a shipping route. Nonetheless, their experience of harmonization seems very positive and mutually beneficial. As mentioned earlier, this case clearly shows that harmonization can be achieved while still having different opinions and risk-acceptance criteria.

This brings us to **statement 2**, which does not garner the same unanimity as statement 1 from the respondents of the two emerging OREI nations: while the respondents of the US and Sweden agree with the need to harmonize steps within the NRA process, they are unsure about whether *all* countries should have the exact same NRA process. Their primary concern is the *implementation challenge* of such a measure. This is understandable from their point of view: they do not currently have as much stake in offshore wind as other countries, and for them, the bureaucratic burden of revamping their entire process to match the others far outweighs the potential benefits; the Swedish respondents particularly view having the same process as a generally unfeasible endeavour. These respondents also feel that *regional* approaches might be better rather than *international* harmonization. Nevertheless, the respondent from the US mentioned the potential benefits of having 'international guidance' that can *augment* the NRA process in the country.

This ties in with Statement 3, which was designed to ask respondents about who should take the lead for the harmonization of the NRA process – and whether it should be a top-down initiative led by the IMO, for instance, or if a more bottom-up approach led by various member states would be more preferable. The responses indicate a preference for the top-down approach – with 4 of the 7 respondents agreeing and 3 indicating neutrality.

The respondents with a neutral stance on **statement 3** have reservations about the practicality of a top-down approach, and/or the *ability* of organizations like IMO to push through such standards in a reasonable time. These reservations are not entirely unfound either[15]: while IMO has pushed through globally-accepted regulations, it is undeniably true that this process can take a very long time; a good recent example of this is the Ballast Water Management Convention – which took 14 years to just being adopted in 2004, and another 13 years to finally enter into force in 2017. Furthermore, there are many technical guidelines – e.g. on ship manoeuvrability standards, which are still not ratified by all member states. Despite these shortcomings, IMO[16] should strive to work together with member states that have experience with OREIs, to publish guidance documents on NRA. If done right, this would surely be welcomed by *other* member states, as it could help to provide clarity and coherence in an age where seascapes are increasingly cluttered.

Instead of going international through IMO, an alternative approach to statement 3 would be if member states with OREIs formed *regional* agreements to harmonize their NRA processes. In fact, North Sea countries – who incidentally have the most experience with OREIs – have just recently signed a political declaration[17] that includes harmonization as of its core objectives. This provides a precedent for other countries to undertake similar measures at a regional level.

3.2 Statements 4, 5 & 6 – Transparency & Adequacy of Models & Input Data

The second main shortcoming of NRA processes, as identified through the literature review, is the apparent lack of transparency when it comes to the models and input data that are used in these processes. The agreement ratings assigned to statements 4, 5 and 6 indicate a very split view of this *perceived* shortcoming. Unlike the harmonization concern – where there was near unanimity – agreement towards

[15] When the IMO started its work in 1958, initially, it was forced to develop international legal instruments following a number of maritime accidents that occured at that time. As a result, the early work of IMO has often been portrayed as more reactive in its nature. After almost 65 years of successful work allowing the international legal instruments developed in IMO to demonstrate their positive effects, it is clear that this approach has changed and IMO has adopted a more pro-active approach in respect to maritime safety.

[16] The perceived 'role' of IMO is quite interesting when it comes to OWFs. A study by Gibson & Howsam (2010), which plotted various stakeholders on an interest-influence graph placed IMO in the bottom-left quadrant – i.e. IMO is perceived to have a low interest, and low influence in matters related to the approval of OWFs.

[17] Political Declaration on energy cooperation between the North Seas Countries. Text available online via https://ec.europa.eu/energy/

this second shortcoming seems to be influenced much more by the personal perceptions and opinions of the individual respondents.

When asked whether there is a *need* to improve the *transparency* of models and input data (**statement 4**), respondents from both the UK and US disagreed, the respondents from Germany indicated neutrality, whilst the respondents from the other 4 countries agreed. Respondents from the UK and the US believe that their NRA process is transparent enough – and that the models and input data which are used by the respondents are openly available for scrutiny. Therefore, they do not see the *need* to improve further – but nevertheless mention that they are open to suggestions for further improvements. The transparency of the NRA process – in the UK particularly – is undeniably exemplar: it is, for instance, quite easy to find correspondence between the MCA (or other stakeholders) in the UK and the consultative bodies that perform NRAs on behalf of OREI developers asking for clarification with certain aspects of the models, input data, or assumptions (NIP 2017).

It is also very encouraging to see that DK, NL, BE, and SE themselves see the need to improve the accessibility of their already-quite-transparent NRA processes. While these other countries *also* strive for transparency, they are evidently not yet at the level of the UK in this matter. Part of this may be due to the language 'barrier': NRA studies, and even guidance documents, or documents describing the models and input data from these countries are not always available in English, which means that third-party interested stakeholders may have a harder time accessing and evaluating these documents. This is *not* to say that all countries should conduct NRAs in English – but rather a request to the authorities to ensure that at least the core documents are accessible by all stakeholders. Shipping is truly a global industry, and while OREIs may be 'locally' placed, they can have an influence on a much broader spectrum of stakeholders than just local folks. Most countries already issue 'notices to mariners' in English, and it would be very helpful if documents describing NRA models were also made available in such a manner.

Statement 5 asked respondents if there is a need to *improve the input data* that is used during the NRA process. While NL and SE indicated their agreement, 5 of 7 the respondents indicated a neutral stance to statement 5. This statement is clearly very hard to judge. As mentioned in the literature review section, OREIs are still a 'new' development – and a lot of the input data used for OREI NRA is merely derivative from navigational risk studies for oil platforms, bridges, quays, piers, and other offshore installations. Even though, OREIs *have* now been around for almost a quarter of a century, and our understanding of the navigational risks associated with such installation is much improved, there are still gaps in specific knowledge. The input data used so far has been quite effective in helping to avert navigational accidents. At the same time, as the respondents from Sweden highlighted, a lot of the data used in NRA processes stem from accidents statistics – but there haven't been enough accidents to create a reliable dataset. This means it is still too early to say if our present knowledge, assumptions and data is *good enough*, especially when considering the predicted evolution of the offshore wind sector over the coming years and the possible increased impact that this might have on navigational safety.

Due to this cyclical development, the respondents with a neutral outlook to statement 5 appear to have opted for a cautious 'time-will-tell' attitude. Naturally, as the offshore wind sector evolves, more and more data will also become available – which will hopefully lead to an improved understanding of navigational risks associated with OREIs. One can question, however, whether a 'wait-and-see' approach is prudent. Powerful modelling tools and simulators – which incidentally are recommended, and even used as part of the NRA process in the UK, and NL – are becoming increasingly common and feasible. Simulators can allow users to create 'future-case' scenarios and explore navigational behaviour and challenges in a more proactive manner – giving access to scenario-specific data and allowing the validity of assumptions to be thoroughly tested (Mehdi et al. 2017b). Approval authorities may thus benefit greatly by advocating further use of such technology.

This leads us to **statement 6** – which asked respondents whether there is a *need to improve the models* that are used to calculate the probability and consequences of navigational accidents within the NRA processes. Statement 6 had quite polarized responses – with NL and SE agreeing, UK and BE disagreeing, and the other three countries opting for a neutral stance. The respondents who disagree with, or rate this statement neutrally, are of the opinion that there is no *need* to improve the models further, as the existing ones have done an adequate job at preventing navigational accidents around OREIs; these respondents nevertheless indicated their openness to new innovations, and stated that they would gladly adapt new models and tools, if they were demonstrably better than the existing ones. Respondents from NL and SE opt for a more proactive approach, and clearly state that they would like to continually improve the models that they use during their NRAs – irrespective of whether or not there is a need.

The authors see the merit in both viewpoints. It is undoubtedly more effective and efficient for all involved stakeholders to stick with the tried-and-tested models. At the same time, the current and predicted evolution of the offshore wind sector serves as an ominous reminder against complacency, and highlights the need to be proactive with NRA models: it isn't enough to have models that help to prevent accidents for *now*; NRA models should be robust enough to allow for the safe and efficient planning of increasingly complex and crowded marine areas in the *future*.

When discussing **statement 6**, it is also important to highlight that researchers have developed, applied, and validated some excellent tools and models (Deeb et al. 2017; Mehdi & Schröder-Hinrichs 2016) – which definitely are on par, if not better, than some commercially available tools. Unfortunately, many of the research models are under-used in real-world applications. This is certainly *not* the fault of any particular stakeholder group – approval authorities, for example, are very open to developers using new tools and models as long as they are valid, and comply with recommendations or guidelines; academics are eager to promote their work; and commercial organizations are happy to work with research organizations in improving their own models or collaboratively developing new ones. Why then, is it, that the maritime industry always appears to be slow in adapting these state-of-the-art tools? In all honestly, there isn't a definitive answer, but respondents indicated that two factors may play a major role: comfort, and lack of awareness. Most OREI developers and consultative agencies are *comfortable* using the most convenient and popular models – even if they do not perform at a level of more complex models; it is also a hassle to continually use new models instead of sticking with a 'trusted' one, which is also an understandable issue. The lack of awareness, meanwhile, stems from the issue that sometimes researchers often fail to show the *value* of their work (language barriers, publication barriers, poor communication, etc.). Together, these two factors may be a reason why some cutting-edge navigational models haven't seen much use in industry yet. Given the progressively crowded seascape, and a lower tolerance for over- and under-design for safety, it is vital for research models to be bought to the forefront for the mutual benefit of both the OREI and maritime industries. And this is a task that the OREI and maritime industries – as well as researchers – should address jointly.

3.3 Statements 7, 8, 9 & 10 – Stakeholder Communication within the NRA Process

The last possible shortcoming in existing NRA process, as identified by the literature review, pertains to stakeholder communication. **Statement 7**, therefore, directly asked the respondents if there is a *need to improve the way in which stakeholder feedback is incorporated in the NRA process*. Respondents from the UK, DK, and US disagreed, whilst the respondents from DE, NL and BE indicated their neutrality. Only the respondents from SE agreed with this statement. The respondents who disagreed with this statement were of the opinion that stakeholder consultations in their countries are already quite robust, and pointed towards ample communication loops and workshops, wherein stakeholders are encouraged to express their viewpoints. It was also pointed out that it may be impossible to please all stakeholders – which might be why there are occasional complaints about feedback not being taken into account. In reality, the comments from each stakeholder *are* well-documented and thoroughly considered by the approval authorities, and efforts are made to find the best possible compromise where necessary.

It is also quite interesting that the respondents from SE agree with **statement 7**. The authors speculate that the vast *number* of agencies and stakeholders that are involved in the NRA in Sweden may be a reason for this sentiment. Of all the countries that are included in this survey, the authors felt that Sweden has the most 'spread-out process', due to the number of authorities that are involved. This may make it more difficult to incorporate stakeholder feedback compared to other countries. One can expect, however, that as the offshore sector evolves in Sweden, so too will the stakeholder consultation process.

The respondents were also asked if there is a need to improve the communication between the maritime and offshore wind industry stakeholders, via **statement 8**. This particular limitation of NRA processes cannot be *explicitly* identified in any literature – but given the technical and *specialized* nature of the NRA, and wind turbine/farm design processes, the authors wanted to identify whether approval authorities would like to see more cooperation between the two industries. The researchers expected the respondents to be polarized on this issue: it can be argued that the maritime and offshore wind energy stakeholders *only* need to the know information that is relevant to them – and not necessarily understand the intimate technical *details* underlying each-other's work; on the other hand, one can also make the case that a better mutual understanding of navigational risks and wind turbine/farm design may lead to better cooperation amongst stakeholders, as well as more effective use of sea space.

As expected, there was no unanimous agreement between the respondents on **statement 8**. The respondents from the UK and NL disagreed with this statement, and stated that they felt that the communication between these two groups of stakeholders is adequate in their countries. Respondents from SE and the US, meanwhile, agreed with statement 8 – whilst respondents from the other three countries neither agreed nor disagreed.

There was a very interesting discussion with the respondent from BE on **statement 8**. Stakeholders from the energy industry often assume that ships *only* sail along well-planned routes and follow routeing measures as shown on spatial plans or nautical charts, as shown in **Fig. 2** for the Belgian EEZ. In reality, ships have absolute freedom of navigation under UNCLOS[18] - and vessels, particularly fishing-boats and pleasure crafts, often also sail *outside* corridors that are reserved for shipping, as shown in **Fig. 3** for the Belgian EEZ. In fact, some vessels may regularly sail *in* areas that are specifically *designated* for OREIs on a spatial plan (where an OREI has yet to be approved) – but developers may not realize this until they submit their plans for approval because they are not familiar with maritime operations.

If an OREI is *planned* solely on the basis of nautical charts and spatial plans, without due consideration of actual shipping traffic, it can lead to unwarranted issues during the *approval* stages: in such scenarios, NRA studies may recommend more *stringent* risk control options than usual to mitigate the higher-than-anticipated navigational risk. Such stringent safety measures can, in turn, potentially reduce the *efficiency* of maritime operations, by – for instance – forcing ships to take longer routes around OREIs; subsequently these measures may be seen as unwelcome cost-burdens by maritime stakeholders. In some cases, the OREI developers may *also* be required to pay more than they anticipated for the implementation of risk control options such as collision-fenders, or markings and lightings on turbines. In extreme cases, OREIs may have to be redesigned in the interest of navigational safety. In fact, the respondent from BE highlighted a case where a row of turbines had to be eliminated before the OREI was approved. This is clearly not an ideal situation for OREI developers, nor for other maritime stakeholders.

[18] The exception to this is areas that are specifically designated as being mandatorily off-limits for ships by a coastal state and/or IMO; such areas are generally only enforceable *after* an OWF has been granted approval or in some cases, after the turbines have been installed.

From the above discussion, it is apparent that while communication between maritime and offshore wind energy stakeholders may be adequate during the *approval* stages, this may not necessarily be the case during the *planning* stages. If – as recommended by the respondent from BE in relation to **statement 8** – there is improved communication between the two sectors during the *planning* stage as well, unexpected and costly 'surprises' might be reduced during the subsequent *approval process*.

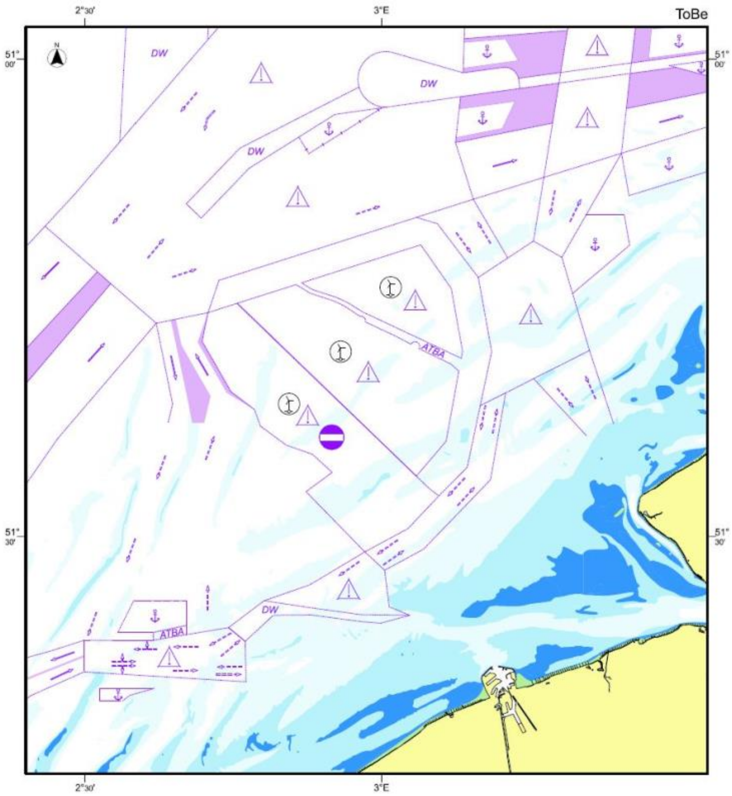

Fig. 2. Spatial plan of the Belgian EEZ. Source: Authors

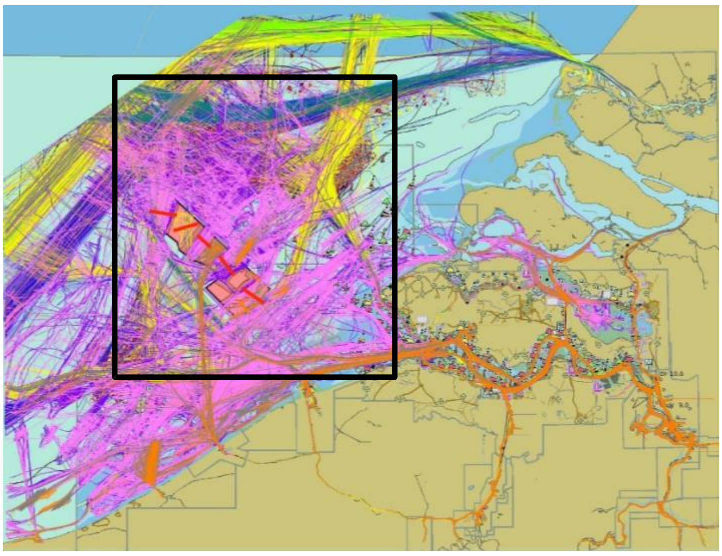

Fig. 3. Actual ship movements in the Belgian EEZ, mapped using AIS data. Source: EMSA (European Maritime Safety Agency). The black-box indicates the area shown in Fig. 2.

Statement 9 asked respondents if there is a *need to improve the communication of NRA results to operational end-users who operate near OREIs – particularly seafarers*. Respondents from the UK, DK, and NL disagree with this statement. They believe that the NRA process – while open to feedback from seafarers – is not *intended* to provide any information to seafarers, but is merely a tool for decision-makers to approve or deny the application for an OREI. The respondents for UK, DK, and NL further point to the measures such as notice to mariners, which, they say, provide the relevant information to operational end-users including seafarers.

By contrast, the respondents from the US and BE agree and strongly agree with statement 9. The respondent from BE particularly felt that the direct results of the NRA process should be more open and accessible to seafarers – and that they should not only be used as feedback providers. Belgium has quite a small, crowded EEZ, which poses severe spatial challenges – so much so that authorities often struggle to find adequate space *between* OREIs and shipping lanes. The respondent from BE believes that seafarers being more aware of the direct results of NRAs is therefore quite important.

It was mentioned earlier that a survey found seafarers who *are* aware of NRA studies tend to be more concerned about navigational risks than seafarers who are not (Mehdi et al. 2017a). One reason for this was suggested to be that seafarers are *asked* for feedback, but not necessarily communicated the *results* of the NRA process. In particular, some of the seafarers who were *critical* of the NRA process stated:

- 'I did not get results feedback' [*on an unidentified North Sea OREI*]
- 'Only aware of the study as it [sic…result] was not promulgated' [*on the London Array*]
- 'I was deeply disappointed as I expressed my concerns and have not even been contacted to explain reasons why my concerns where not addressed' [*on an OREI near Liverpool – possibly Burbo Bank*]

The above statements from seafarers are perhaps a sign that the communication of NRA results to seafarers *does* need be improved further.

This leads to **statement 10**, which asked the respondents if *seafarers should be provided with decision support tools* when operating near OREIs. The respondent from BE, unsurprisingly agreed with this statement – as did the respondent from UK. Respondents from DK and NL disagreed, while those from the other three countries neither agree nor disagree with this statement.

The respondents that *disagree* with statement 10 cite their concerns that seafarers may be *overloaded* with information; these respondents believe that prudent seafarers already make adequate decisions by performing thorough situational awareness, and that existing information provisions and tools are enough. Those that agree with statement 10, meanwhile, say the seafarers *need* such information to operate near OREIs safely – and that regardless of risk control options, the ultimate barrier to avoiding accidents are seafarers themselves. This latter group of respondents who advocate the provision of decision-support tools and information – say that seafarers can use these tools if needed, or ignore it if they find them to be irrelevant. In other words, it is better to 'have' and 'not-need', than to 'need' and 'not-have'.

It is clear that the level of agreement towards statements 7, 8, 9 and 10 is also significantly dependent on the *personal* perceptions of the various respondents – and highlights the need for stakeholders from different countries to come together, share their experiences and discuss these issues which are not sufficiently addressed in existing works.

4. Recommendations for Improving Existing NRA Processes

The strength of a NRA is that it is a risk based process, and thus quite flexible in terms of models, methods and tools which can be used. In their current form, NRA tools are used by OREI developers to demonstrate to approval authorities that their developments will not pose unacceptable risks to maritime operations. Simplifying the tools, methods and models used in NRA can be useful to improve the safety and efficiency at the operational end – and allow seafarers to address spatial conflict reactively during ongoing operations. Integrating NRA tools, methods and models with other, more complex tools such as energy generation calculations, ship emission calculators, etc. can make it an immensely useful tool for planning purposes – and an integral part of MSP – almost an 'equivalent' to the ecosystems based approach (EBA); while EBAs consider the conflict between marine users in an ecological/environmental context, whereas NRAs consider the same conflicts in terms of impact on navigational safety and efficiency. NRAs can be used on specific OREI sites, as well as on wider sea-areas. It is thus paramount to improve the process further – especially when considering the forecasted evolution of the OREI and maritime sectors.

Based on the findings of the study, the authors thus present the following recommendations and final thoughts. The NRA processes of different countries should be harmonized. In particular, the calculation-methods, factors, and data sources used for probability and consequence calculations should be similar, especially across countries in close proximity to each other. This will help to avoid problems in approving transnational OREIs – and if done right, encourage further growth of the offshore sector by reducing the bureaucratic burden on OREI developers. It would also reduce the chances of transnational OREIs being approved in one country, and being denied approval in another.

The NRA process is already quite similar in most countries, in terms of the factors that are considered and the stakeholders that are consulted. This means that harmonization is not as far-fetched as cynics might think.

Methods and models used for probability and consequences calculations are also pretty similar (but not the same) in most countries; the exception is the consequence calculation process in Germany, where authorities seek quantitative proof of ‘collision-friendly’ design of turbines. If the processes are to be harmonized, the authors recommend combining the consequence-assessment approach of Germany with probabilistic tools used by Belgium and the Netherlands. Thus far, most risk-control options have been focussed on reducing the probability of accidents, but as the offshore wind sector continues to evolve, accidents may become inevitable; it is thus prudent to understand the consequences of navigational accidents in more detail, and promote measures such as ‘collision-friendly’ design on at least the outermost turbines.

Harmonization does not mean that all countries or all OWFs should have the same acceptability criteria. Each country should still approve OWFs individually, based on what their approval authorities and local society perceive to be acceptable levels of probability and consequences. Harmonization also does not mean that the risk-control options implemented around OWFs to maintain navigational safety need to be the same: e.g. countries should still be able to have different safe-passing distances between shipping lanes and OWFs. Harmonization simply means having the same steps when doing things such as calculating probabilities or consequences of navigational accidents.

The IMO – based, for instance, on the experience of the North Sea countries – should produce guidelines for probability and consequence calculation-methods, stakeholder consultation, etc. as they have done for accident investigation or FSA. Ultimately, however, the *implementation* of the harmonization process should be led by the countries themselves on a regional level; this would help to ensure that countries around specific sea-basins (e.g. Baltic, Mediterranean, or North Sea) have common interpretations of the harmonized NRA process guidelines during the implementation and application phase. A regional implementation approach for harmonized NRA process should also promote further communication and collaboration during the NRA process, and allow countries to share experiences from mutual topics and issues. With the IALA guidelines on risk assessment in MSP (IALA 2017) and the works of authors such as Mehdi & Schröder-Hinrichs (2016), the first-steps towards harmonization have already been taken.

Due to lack of consensus amongst the respondents, the authors cannot conclusively state whether there is a need for more transparency, or if the models or input data need to be improved further. Instead, the authors recommend that various countries share the experiences in these matters through forums such as IMO working groups, or regional platforms such as the Political Declaration on energy cooperation between the North Seas Countries. In particular, countries that are satisfied with their processes should share guidelines and ‘lessons-learnt’ with countries that feel the need to improve their own NRA processes.

Promoting harmonization can also indirectly lead to greater transparency of models and input-data: decision makers could scrutinize the calculation-methods and parameters much more closely before deciding on which model or tool to advocate in any joint-standard.

Academia and industry stakeholders should work together to ensure that the best possible methods, models and tools are used for NRA. Most national guidelines are flexible and allow developers to use the tools of their choice as long as they cover all the required factors. However, developers and consultative bodies should move out of their comfort zone, and academics should promote their work better – as improved models could lead to significantly help to reduce over- and under-design for safety.

There is also no consensus amongst the respondents on whether stakeholder communication needs to be improved. The authors suggest a sharing-of-experiences, and discussions between countries. Another possible option is the use of simulators, as a means of eliciting better stakeholder responses and of understanding different viewpoints better.

The authors also advocate improving the communication of the NRA results to seafarers, and also feel that decision-support systems (DSSs) should be developed further. Having such DSSs could even help to alleviate some of the burden on planning and approval authorities, and allow more effective use of sea-space. Instead of having fixed and expensive risk control options DSSs can provide more bespoke solutions for seafarers operating near OREIs, whilst accounting for 'live' dynamic and static environmental conditions. In this sense, spatial conflicts could be addressed by effective vessel traffic management. Such solutions could then mitigate the need for excessively large SDs, for example.

The above recommendations have the potential to reduce the administrative load on OREI developers, and improve both the planning and licensing of OREIs.

It is clear that NRA processes have been extremely beneficial for approval authorities in various coastal states during licensing phases. Learning from their example, MSP authorities and planners can also adopt a risk-based approach and increase their reliance on NRA processes during planning phases. This adoption would help to significantly close the gap between planning and approval authorities. Indeed, opting for a risk-based approach using may ensure that marine-areas-as-planned are indeed marine-areas-as-approved in terms of SDs, shipping lane widths and configurations, etc. This, in turn, can lead to more effective use of sea-space and allow stakeholders to find the right balance between navigational safety, efficiency and exploitation of space for energy generation – leading to better coexistence of maritime activities and OREIs.

Disclaimer

A modified version of Part II of this report has also been submitted to the WMU Journal of Maritime Affairs for publication as a journal article.

The responses from the various participants may not reflect the views of their organization or their colleagues.

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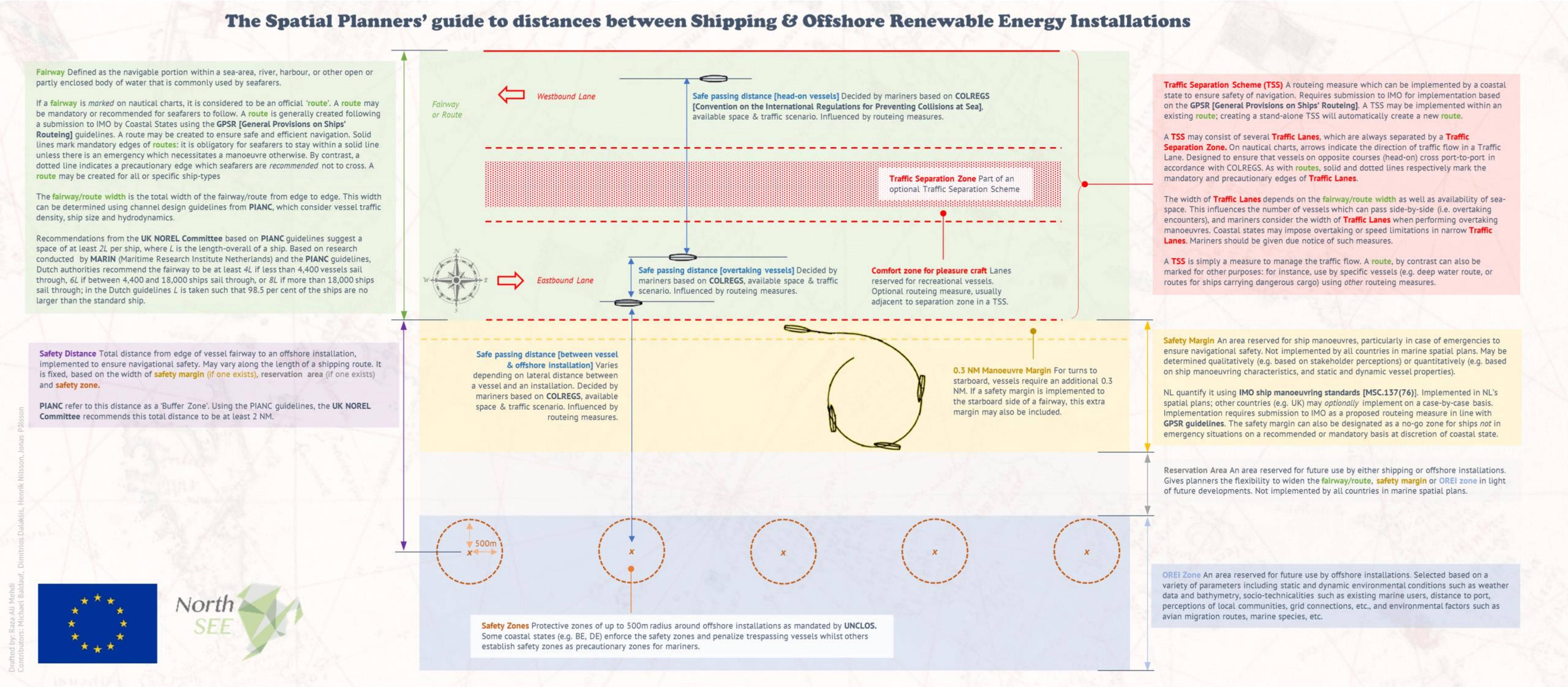
Annex


The Spatial Planners' guide to distances between Shipping & Offshore Renewable Energy Installations
Fairway Defined as the navigable portion within a sea-area, river, harbour, or other open or partly enclosed body of water that is commonly used by seafarers.
If a fairway is *marked* on nautical charts, it is considered to be an official 'route'. A route may be mandatory or recommended for seafarers to follow. A route is generally created following a submission to IMO by Coastal States using the GPSR [General Provisions on Ships' Routeing] guidelines. A route may be created to ensure safe and efficient navigation. Solid lines mark mandatory edges of routes: it is obligatory for seafarers to stay within a solid line unless there is an emergency which necessitates a manoeuvre otherwise. By contrast, a dotted line indicates a precautionary edge which seafarers are *recommended* not to cross. A route may be created for all or specific ship-types
The fairway/route width is the total width of the fairway/route from edge to edge. This width can be determined using channel design guidelines from PIANC, which consider vessel traffic density, ship size and hydrodynamics.
Recommendations from the UK NOREL Committee based on PIANC guidelines suggest a space of at least *2L* per ship, where *L* is the length-overall of a ship. Based on research conducted by MARIN (Maritime Research Institute Netherlands) and the PIANC guidelines, Dutch authorities recommend the fairway to be at least *4L* if less than 4,400 vessels sail through, *6L* if between 4,400 and 18,000 ships sail through, or *8L* if more than 18,000 ships sail through; in the Dutch guidelines *L* is taken such that 98.5 per cent of the ships are no larger than the standard ship.
Safety Distance Total distance from edge of vessel fairway to an offshore installation, implemented to ensure navigational safety. May vary along the length of a shipping route. It is fixed, based on the width of safety margin (if one exists), reservation area (if one exists) and safety zone.
PIANC refer to this distance as a 'Buffer Zone'. Using the PIANC guidelines, the UK NOREL Committee recommends this total distance to be at least 2 NM.
Fairway or Route
Westbound Lane
Eastbound Lane
Safe passing distance [head-on vessels] Decided by mariners based on COLREGS [Convention on the International Regulations for Preventing Collisions at Sea], available space & traffic scenario. Influenced by routeing measures.
Traffic Separation Zone Part of an optional Traffic Separation Scheme
Safe passing distance [overtaking vessels] Decided by mariners based on COLREGS, available space & traffic scenario. Influenced by routeing measures.
Comfort zone for pleasure craft Lanes reserved for recreational vessels. Optional routeing measure, usually adjacent to separation zone in a TSS.
Safe passing distance [between vessel & offshore installation] Varies depending on lateral distance between a vessel and an installation. Decided by mariners based on COLREGS, available space & traffic scenario. Influenced by routeing measures.
0.3 NM Manoeuvre Margin For turns to starboard, vessels require an additional 0.3 NM. If a safety margin is implemented to the starboard side of a fairway, this extra margin may also be included.
500m
Safety Zones Protective zones of up to 500m radius around offshore installations as mandated by UNCLOS. Some coastal states (e.g. BE, DE) enforce the safety zones and penalize trespassing vessels whilst others establish safety zones as precautionary zones for mariners.
Traffic Separation Scheme (TSS) A routeing measure which can be implemented by a coastal state to ensure safety of navigation. Requires submission to IMO for implementation based on the GPSR [General Provisions on Ships' Routeing]. A TSS may be implemented within an existing route; creating a stand-alone TSS will automatically create a new route.
A TSS may consist of several Traffic Lanes, which are always separated by a Traffic Separation Zone. On nautical charts, arrows indicate the direction of traffic flow in a Traffic Lane. Designed to ensure that vessels on opposite courses (head-on) cross port-to-port in accordance with COLREGS. As with routes, solid and dotted lines respectively mark the mandatory and precautionary edges of Traffic Lanes.
The width of Traffic Lanes depends on the fairway/route width as well as availability of sea-space. This influences the number of vessels which can pass side-by-side (i.e. overtaking encounters), and mariners consider the width of Traffic Lanes when performing overtaking manoeuvres. Coastal states may impose overtaking or speed limitations in narrow Traffic Lanes. Mariners should be given due notice of such measures.
A TSS is simply a measure to manage the traffic flow. A route, by contrast can also be marked for other purposes: for instance, use by specific vessels (e.g. deep water route, or routes for ships carrying dangerous cargo) using *other* routeing measures.
Safety Margin An area reserved for ship manoeuvres, particularly in case of emergencies to ensure navigational safety. Not implemented by all countries in marine spatial plans. May be determined qualitatively (e.g. based on stakeholder perceptions) or quantitatively (e.g. based on ship manoeuvring characteristics, and static and dynamic vessel properties).
NL quantify it using IMO ship manoeuvring standards [MSC.137(76)]. Implemented in NL's spatial plans; other countries (e.g. UK) may *optionally* implement on a case-by-case basis. Implementation requires submission to IMO as a proposed routeing measure in line with GPSR guidelines. The safety margin can also be designated as a no-go zone for ships *not* in emergency situations on a recommended or mandatory basis at discretion of coastal state.
Reservation Area An area reserved for future use by either shipping or offshore installations. Gives planners the flexibility to widen the fairway/route, safety margin or OREI zone in light of future developments. Not implemented by all countries in marine spatial plans.
OREI Zone An area reserved for future use by offshore installations. Selected based on a variety of parameters including static and dynamic environmental conditions such as weather data and bathymetry, socio-technicalities such as existing marine users, distance to port, perceptions of local communities, grid connections, etc., and environmental factors such as avian migration routes, marine species, etc.
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