Can multi-use of the sea be safe? A Framework for Risk Assessment of Multi-use at sea

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Abstract

By 2050 the world population is expected to reach 10 billion people. This population needs food, water and energy. Increasingly, opportunities are sought out at sea to accommodate these needs. As there is already competition for space, especially in the near-shore, opportunities for multi-use, including the combination of, for example, food and energy production in a single location, are sought. One issue that needs to be addressed to allow for multi-use at sea is safety. Existing frameworks for (marine) risk assessment tend to be rather sector specific and, although existing models and frameworks for risk analysis provide useful elements for an integrated analysis, none of the approaches fully caters for the need of having a framework based on a cyclical process of stakeholder input in all steps of the process of risk identification, risk management and risk evaluation and communication, identifying actions to be taken and providing tools useful in each of the steps, while integrating the three perspectives of maritime safety, food (and feed) safety, and environmental impact assessment and the different perspectives of the actors involved. This study developed a common framework for the risk assessment of multi-use at sea, consisting of six steps (Exploring, Understanding, Appraising, Deciding, Implementing and Evaluating & Communication). The framework encompasses and integrates an analysis of food and feed safety aspects, the safety of people and equipment, and environmental safety aspects. For each step, actions are defined, tools that can be of help to stakeholders are presented, and stakeholder participation measures are described. The framework is iterative and dynamic in its nature; with constant communication and evaluation of progress, decisions can be taken to either take a step forward or back. The framework is developed to assist operators and producers, policymakers, and other stakeholders in assessing and managing risks of multi-use at sea.

Key Words: Multi-use at sea, Risk assessment, Risk governance, Wind farms, Seaweed production

1 Introduction

The world human population is growing; an expected 9.7 billion by 2050 according to United Nations estimates (Béné et al., 2016; SAPEA, 2017). Not only will there be many more people, but today's nutritional challenges (hunger, undernutrition and micronutrient deficiencies), will intensify the global demand for food and biomass. We need to look at how the 71% of the planet that is ocean (Hannah et al., 2019) can deliver human necessities such as food and energy (Commission of the European Communities, 2012). Seas and oceans are already used – among others - for shipping, oil and gas extraction, aquaculture, tourism, new islands and fishing. Developing new activities will increase competition over space, especially in the near-shore zone as resources are either locally available or vicinity to shore influences time and costs when transporting resources to land (van Hoof et al., 2014a).

One solution to the competition over ocean space is to abandon the current practice of single activity use and start sharing sea/ocean space between multiple activities (Lagerveld et al., 2014; Röckmann et al., 2015; Zanuttigh et al., 2016). Schupp et al. (2019; p4) define such multi-use as: " ...the joint use of resources in close geographic proximity by either a single user or multiple users. It is an umbrella term that covers a multitude of use combinations in the marine realm and represents a radical change from the concept of exclusive resource rights to the inclusive sharing of resources and space by one or more users." (Lukic et al., 2018; Schultz-Zehden et al., 2018b; Schupp et al., 2019). Schupp et al. distinguish

4 types of multi-use: multi-purpose/multifunctional, symbiotic use, co-existence/co-location and subsequent use/repurposing (Schupp et al., 2019). In the case of multi-purpose/multifunctional use the uses share the same space, occur at the same time and the main functions are intrinsically connected. In the case of symbiotic use uses operate in the same zone (i.e., a connection exists in the spatial dimension) but they do not share the same core infrastructure, but have for example shared crew transports, harbours, or monitoring data. Co-existence/co-location is characterized by a moderate to low degree of connectivity between the involved uses. And subsequent use/repurposing takes place when two uses are connected in the spatial dimension but not in time, such as when the permanent installation of a maritime use (e.g., oil and gas, offshore wind) remains in place after end of its lifetime and is repurposed for another maritime use. (Schupp et al., 2019).

Multi-use can be established when two or more activities are developed at the same time, or when an activity is added to an already existing activity. In addition a distinction can be made between the multiple uses being implemented by a single user or by several different users.

Examples of such marine multi-use can be found in co-locating offshore wind farms and open-water mussel cultivation in the Baltic sea (Di Tullio et al., 2018), offshore wind farms and fisheries sharing the same space in Denmark and the UK (Schultz-Zehden et al., 2018a), finfish aquaculture and wave energy generation in Mingary Bay (Scotland)(Lukic et al., 2018),and the combination of fisheries, tourism and environmental protection along the French Atlantic coast (Calado et al., 2019) and in several countries in the Mediterranean (Depellegrin et al., 2019).

Combining several activities can serve to divide and reduce the costs of offshore operations and the demand on the space needed for different activities (European Commission, 2018). For example, aquaculture near an offshore wind farm, can achieve synergetic effects through savings on operation and maintenance costs (Buck et al., 2010; Lagerveld et al., 2014; Röckmann et al., 2017). Based on an analysis of operational boundaries of various activities, van den Burg et al. (2019) conclude that areas within 16 NM from the shore and with depth ranges of less than 100 m have the highest potential for the multi-use of sea space (van den Burg et al., 2019).

However, because of technical, as well as socio-economic and ecological challenges (Stuiver et al., 2016) multi-use at sea is not yet well developed. Individual operators do not always favour co-location (Röckmann C. et al., 2015; Klijnstra et al., 2017), and are hesitant to combine operations of, for example, aquaculture and wind farms. A main issue that prohibits multi-use at sea is safety of co-location of activities. Insurance companies may not favour multi-use at sea (van Hoof et al., 2014b; Schultz-Zehden et al., 2018b) and regulatory frameworks may prohibit multi-use; for example, until recently no major activities were allowed inside offshore wind farms at sea in the Netherlands (Tweede Kamer der Staten-Generaal, 2014).

By tackling safety related to the multi-use of sea/ocean space, a major obstacle to creating additional sources of energy and food at sea is then addressed (Stuiver et al., 2016). This involves several groups of stakeholders with their differing stakes, perceptions, requirements concerning expertise, as well as different use of language/terminology (International Risk Governance Council, 2012; Aven and Krohn, 2014; Haapasaari et al., 2015). The stakeholders involved in processes of multi-use range from the actual operators of the multi-use activities and actors involved in the production and market chain (hence ancillary industry, processing, transport and trade parties and consumers). In addition there are government parties involved related to licensing, marine spatial planning and marine management. Financiers, risk assessors and insurers play an important role (van Hoof et al., 2014b). And of course other users of the marine environment, NGOs and the wider public are to be considered stakeholder in this process. Due to this heterogeneity of stakeholders, it is necessary to develop an approach that integrates different views and perceptions into a single approach to risk assessment. Next to considering general maritime safety aspects, wider food (and feed) safety aspects and ecological aspects need to be considered. These need to be integrated in the risk assessment as well, which requires integration of the approaches of maritime safety, food (and feed) safety, and environmental impact assessment.

Existing frameworks for (marine) risk assessment tend to be rather sector specific (Almklov et al., 2014; Haapasaari et al., 2015). They built upon a history of sector specific experiences and have safe and unsafe operating practices codified into protocols and standards (IMO, 2002; Haapasaari et al., 2015; IMO, 2015). Joint development of offshore wind and (seaweed) aquaculture activities is at its infancy and hence does not come with a history of experiences yet, but does have the responsibility to take safety issues on board from the very beginning (safety by design) (Lloyd's Register Group Limited, 2016; Lukic et al., 2018; Schultz-Zehden et al., 2018a). Although existing models and frameworks for risk analysis provide useful elements for an integrated analysis, none of the approaches fully caters for the need of having a framework based on a cyclical process of stakeholder input in all steps of the process of risk identification, risk management and risk evaluation and communication, identifying actions to be taken and tools useful in each of the steps, while integrating the three perspectives of maritime safety, food (and feed) safety, and environmental impact assessment and the different perspectives of the actors involved.

As risks may differ between the different stages of multi-use (planning, installation, operation, maintenance, decommissioning) the framework should be applicable to the risk assessment of each of the stages. As such the framework should allow to take the process of Marine Spatial Planning (MSP), aimed at managing conflicts between maritime uses and foster more efficient and sustainable use of maritime spaces and resources by allocating marine space to different uses (Foley et al., 2010), a step further to allow individual operators to jointly develop multi-use in a given location.

The framework is meant to assist operators to develop safe operational practices which includes operating within the current setting of allocating marine space to activities (MSP) and operating under a multitude of legislative and licensing practices (which in case of multi-use may imply that not only the legal framework of the two individual activities needs to be taken into account but that the combination of activities may invoke additional legislation). The framework is also meant to be helpful to authorities to decide whether additional regulation and legislation is needed.

The objective of this study is to develop a common risk assessment framework for multi-use at sea given the scenario of seaweed cultivation at a wind-mill park. The proposed framework is based on a review of the scientific literature for existing models for risk assessment, which focuses on ongoing discussions related to risk assessment and a review of discussions of definitions of risks and hazards (section 3). The combination of the production of food and feed (seaweed) along with energy (wind farm) calls for an analysis of risk from three angles: food and feed safety, safety of people and equipment, and environmental safety. In these three domains, established approaches for risk assessment are in place. These are reviewed in section 4. A common framework for risk assessment, risk management and communication of multi-use at sea is presented in section 5; it addresses issues and shortcomings of current risk assessment practices identified in sections 3 and 4. Finally, in section 6 the way forward is considered.

2 Approach

In order to develop a framework for the risk assessment for multi-use at sea, a series of steps were taken that are described here. The focus is on the additional risks that are generated when multiple activities are being combined in a single location: multi-use at sea. This implies that next to the risks associated with the individual activities, additional risks may occur.

A literature study was conducted to identify key elements and approaches to be considered in drafting the framework (see below and section 3). In addition, when combining activities, especially combining the production of, for example, food within a wind farm, risks must be considered from different perspectives. A threefold perspective for safety considering food and feed, people and equipment, and environmental impact was developed. From the perspective of safety of seaweed for food and feed, the focus is on acquiring knowledge on the possible hazards, their likelihood of occurrence, and ways to control them. The perspective of safety of people and equipment in multi-use of maritime locations focuses on hazardous incidents and seeks to assess the probability of occurrence and severity of the associated consequences. As for the perspective of environmental impact, the focus is on identifying possible risks and opportunities arising in the marine environment from the combination of (novel) activities, especially relating to aspects of multi-use in a single location, competition between alternative uses and the cumulative[1] pollution aspects of all activities combined.

In order to develop the framework the three approaches (models) of the three perspectives described above where taken (see section 4). During a workshop with some 30 experts, the risks of multi-use were discussed. Experts included scientists from universities and institutes involved in seaweed cultivation, practitioners involved in the construction of windfarms and seaweed parks at sea, NGOs and national governmental authorities. In order to focus the discussion, the case of seaweed production within a wind farm was used (section 2.2). Using a World-Café method for each of the three perspectives, rounds of discussions in smaller groups were held facilitated by the authors. The different views were brought back together in a plenary session during which conclusions as to the identified risks were drawn. Based on these conclusions the participants again in break out groups sketched an outline of elements they felt that needed incorporation into the framework. The risks identified, and the process through which these risks were identified, were used during the workshop to draft a first version of the risk assessment framework.

This draft was discussed during two subsequent workshops and several meetings with producers, policy makers, scientists, risk assessors and other stakeholders. During these sessions the draft framework was presented and the participants were invited to, in break out groups, discuss the elements of the framework and comment on the framework. In addition seven in-depth interviews, using a semi-structured questionnaire were held with stakeholders involved in seaweed cultivation and safety analysis concerning environmental risks, regulations dealing with these risks, and how these risks are dealt with in practice. Finally a fieldtrip was made with some 35 participants during which the North Sea Innovation Lab was visited and the practices of seaweed cultivation were discussed in situ. During the fieldstrip Augmented Reality was used to visualise for the participants how the combination of seaweed farming and a wind farm would look like and how a collision with a wind pylon would result in the spilling of oil. The entire process was supervised by an Advisory Board which consisted of an expert on marine multi-use, an expert on seaweed cultivation, two experts on marine risk assessment (classification), and an expert on marine activity development.

Based on this input, the framework steps, tools, and approaches were further fine-tuned, resulting in the common safety framework for multi-use at sea (section 5).

2.1 Literature review

A review of current scientific literature on maritime risk assessment frameworks and definitions of risks and hazards was implemented. First, Scopus and Google Scholar were screened with search terms such as "maritime safety", "maritime safety framework", "maritime risks", "maritime hazards," and "integrated maritime safety assessment framework". In addition, a more general search on "integrated safety assessment framework" was implemented. Depending on the search terms used the number of hits varied between 110.000 for "integrated maritime safety assessment framework", up to over 2 million hits for the general term "integrated safety assessment framework".

The search was then further narrowed down to reflect the most recent developments in this field, by restricting search results in first instance to 2015-2017. Based on the title and abstract, a further selection was made of potentially relevant literature, with the main focus on marine and maritime aspects. The long-list of over 100 publications was then further screened on relevance to the topic. In reading some of the manuscripts, additional relevant (older) references were found.

Finally, a selection of the most relevant documents was made, of which we present an overview below (section 3). Most relevant were considered those manuscripts that were not too case specific, meaning

[1] Cumulative as both the cumulation of pollutants and effects over time and space as the cumulation of impact as a result of the combination of activities. Hence cumulative effects as in "linkages between multiple activities with multiple effects on multiple ecosystem components"(Judd et al. 2015).

they are also relevant for other activities and sectors, and where they provided an overview of the discourse and/or sought to integrate safety aspects.

In Annex 1, a glossary of terms, definitions, concepts and methods used in the risk assessment of multi-use at sea is presented. This is not meant to portray a comprehensive list of terms used in the analysis of risks of multi-use but rather defines concepts needed for the assessment of multi-use in which notions may obtain a different interpretation than the regular common definitions used in risk assessment for each of the three fields.

2.2 Constructed case-study

As mentioned above, the intention was to specifically develop a case of multi-use in which the production of food and feed was combined with another activity: the production of renewable energy. As there were no concrete cases of such multi-use, other options for looking into a combination of these activities were sought. Hence the development of a 'virtual' case: what if we use the characteristics of an active seaweed farm and project these into an active wind farm. The case-study was to provide a real life case environment to analyse risk assessment under multi-use and provide elements that could be used to develop the risk assessment framework.

The case study location chosen was based on an existing wind farm, Egmond offshore wind farm, in the North Sea. The combination with seaweed production was selected given the current developments in the North Sea with seaweed use, specifically from the North Sea Innovation lab.

The Egmond offshore wind farm is the first large-scale offshore wind farm built off the Dutch North Sea coast. It is located between 15 and 18 km off the coast of Egmond aan Zee, the Netherlands. It has 36 wind turbines with each a capacity of 3 MW, together supplying 100.000 households with sustainable energy. The turbines have a total height of 115 m, a hub height of 70 m and a rotor diameter of 90 m founded on a grounded monopole with a 4.6 m diameter (4Coffshore, 2018). The seaweed farm 'North Sea Innovation Lab,' located 15 km off the coast of Scheveningen, the Netherlands, is growing *Saccharina latissima* (sugar kelp) from autumn to spring (Noorzee Boerderij, 2018).

During the workshop with stakeholders, some of the multi-use issues that were identified were for example the collision of a vessel with one of the wind pylons resulting in the spilling of oil in the water which potentially contaminates the seaweed; as a result of the combination of hard substrate in the water (pylons) and seaweed production, fish aggregate in the location and there is an increased growth of crustacean on the hard substrate of the pylons, this may well attract more birds, which can lead to an increased occurrence of collisions of birds with the rotors of the wind farm; the risk of ship-ship conflicts within the area between the two operators.

3 Review of literature on hazards and risks

Below we will present a review of literature on hazards and risks in order to understand what risks are, how risks can be assessed and how risks can be governed. Section 3.1 examines the definition of risks and the role knowledge and understanding play in defining risks. Section 3.2 describes the aspects of assessing risks. Assessing risks depends on the perception of the risks involved, which is location and situation specific, and depends on the actual perception different groups of stakeholders may have. This is also reflected in section 3.2.2 in which ways of looking at risks in complex (distributed) systems, such as in a case of multi-use, are presented. Section 3.2.3 deals with the social dimension of risks and the fact that analysing risks in cases of multi-use requires the risk assessment to be able to deal with different perceptions, a large degree of uncertainty and, over time, accommodate an increase in knowledge and understanding of the risks involved. In section 3.3 the risk governance aspects of this complex web of actors, rules, conventions, processes and mechanisms concerned is presented.

3.1 Defining risks

Risk analysis and risk management approaches are used in a variety of management regimes covering such areas as engineering, business, and human health and safety (Cormier et al., 2013; P4). Risks are a probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal vulnerabilities, and that may be avoided through pre-emptive action, in combination with the consequences of the occurrence on animal or/and human health (IMO, 2002; European Commission, 2017; FAO, 2017). Next to risks there are hazards; a phenomenon, physical or immaterial, that has the potential to cause adverse effects or outcomes (IMO, 2002; IMO, 2015).

Risk assessment refers to the systemic effort to think about what might cause harm to people, to infrastructures, and to the environment (Anderson and Patrick, 2019; Cormier and Kannen, 2019). Risks have been treated in terms of probability and effects, dose and response, and agent and consequences. This dominant framing of risk is underlying what has been referred to as the technocratic, decisionistic, and economic models of risk assessment and management (Renn et al., 2011).

In the last decades, it has become clear that such models are only practical for specific types of 'simple risks' where the cause is well known, the potential negative consequences are obvious, the uncertainty is low, and there is hardly any ambiguity about the interpretation of the risk. Risks are being more frequently analysed from a dynamic rather than a static perspective (Zischg, 2018) and various stakeholders (e.g., operators, regulators, and government) in their respective working contexts are very often involved in a sequence of events leading to an accident; this is the most critical issue in developing an effective risk or accident analysis (Trucco et al., 2008).

In defining hazards and risks, and the resilience of an activity, construction or system, according to Montewka et al (2014), there are basically three fundamental questions that need to be answered: what can go wrong in the system?; how likely is it that it will go wrong?; and what are the consequences if the assumed scenario occurs? A formal, and well-established definition of risk in decision analysis is "a condition under which it is possible both to define a comprehensive set of all possible outcomes and to resolve a discrete set of probabilities across this array of outcomes" (Montewka et al., 2014a). To define a set of outcomes, knowledge and proper understanding of the system or phenomena being analysed is a prerequisite. This in turn enables scenarios leading to the outcome of interest and their probabilities to be defined.

At the core of the risk analysis lies a classification of risks. Many authors discuss risk definition and classification (Aven, 2012; Aven and Krohn, 2014; Bandaa et al., 2014; Montewka et al., 2014a; Montewka et al., 2014b; Goerlandt and Montewka, 2015b; Goerlandt and Montewka, 2015a; Aven, 2016; Knapp and Heij, 2017). For example, Aven (2012) distinguishes nine risk categories.

- Risk =Expected value (loss) (R=EV)
- Risk =Probability of an (undesirable) event (R=P)
- Risk =Objective Uncertainty (R=OU)
- Risk =Uncertainty (R=U)
- Risk =Potential/possibility of a loss (R=PO)
- Risk =Probability and scenarios/Consequences/severity of consequences (R=P&C)
- Risk =Event or consequence (R=C)
- Risk =Consequences/damage/severity of these + Uncertainty (R=C&U)
- Risk is the effect of uncertainty on objectives (R=ISO) (Aven, 2012).

According to Mazaheri et al. (2016), the risk of a system can be defined as a function of the scenario for a mishap to occur, the likelihood of that specific scenario to occur, and the consequence of that specific scenario if it occurs. However, since our knowledge of the system is never complete, the system can never be characterized exactly. Therefore, what we will describe as the risk for a given system, at the end will be formulated merely based on our best knowledge about the system. This incompleteness, which is rooted in our lack of background knowledge on the given system, should always be recognized and communicated. The background knowledge is understood here as a mixture of knowledge, understanding, beliefs and acceptance about the analysed phenomenon. Therefore, the amount of available background knowledge about the system should additionally be considered in the definition of risk (Mazaheri et al., 2016). Montewka and co-authors (2014) take this a step further by adding that not only should background knowledge be taken into consideration, but also that for risk in socio-technical systems, background knowledge is defined as a mixture of knowledge and understanding. Lam and Lassa (2017) add to this the exposure to multi-hazards, in which the total risk of a system consists of the sum of the exposure of the system to different types of (natural) hazards.

3.2 Assessing risks

3.2.1 Risk perceptions

According to Aven (2016) there are three major strategies commonly used to cope with risks: *risk-informed*, *cautionary/precautionary* and *discursive* strategies. The *risk-informed* strategy refers to the treatment of risk, using risk assessments in an absolute or relative way. The *cautionary/precautionary* strategy highlights features like containment, the development of substitutes, safety factors, redundancy in designing safety devices, as well as strengthening of the immune system, diversification of the means for approaching identical or similar ends, design of systems with flexible response options and the improvement of conditions for emergency management and system adaptation. The *discursive* strategy uses measures to build confidence and trustworthiness, through reduction of uncertainties and ambiguities, clarifications of facts, involvement of affected people, deliberation and accountability (Aven, 2016).

According to Goerland and Montewka (2015), much of the controversy about risk analysis as a tool for informing decisions is rooted in fundamentally opposing views on the foundations of risk analysis, distinguishing *realist*, *constructivist* and *proceduralist* approaches. *Risk realists* typically consider risk as a physically given attribute of a technology or system, which can be characterized by objective facts, with risk essentially characterized by quantitative (often probabilistic) information regarding events or consequences. *Risk constructivists* typically hold that risk is a social construct, attributed to (rather than part of) a technology or system. The risk analysis is presented as a reflection of a mind construct of a (group of) expert(s) and/or lay people. In the *proceduralist* approach different stakeholders such as scientists, experts, risk-affected lay persons and policy makers, take part in a process in which risk is characterized through a shared understanding, balancing facts and values (Goerlandt and Montewka, 2015b).

In summary, for the development of the common framework for risk assessment of multi-use it is good to note that stakeholders can hold different perceptions as to the risks involved in multi-use. To assess the risks, building confidence and trustworthiness, through the reduction of uncertainties and ambiguities, clarifications of facts, involvement of affected people, deliberation, and accountability, is advised. Where possible, risks can be characterized by objective facts, as well as be explained, predicted, and controlled by science. In other instances, a more *proceduralist* approach is preferred, with stakeholders characterizing risks through a shared understanding of balancing facts and values.

3.2.2 Risk modelling

According to Grabowski and co-authors (2000), modelling risk in distributed, large-scale systems (such as for example in the case of multi-use at sea) presents its own challenges. First, because the systems are distributed, risk in the system can migrate (one problem in the system introduces other, unintended consequences in another part of the system), making risk identification and mitigation difficult. Modelling risk in distributed large-scale systems is also difficult because incidents and accidents in the system can have long incubation periods due to poor information flow between distributed sub-systems, making risk analysis and identification of leading error chains difficult. Finally, modelling risk in distributed, large-scale systems is difficult because such systems often have organizational structures with limited physical oversight, which makes the process of identifying and addressing human and organizational error complicated (Grabowski et al., 2000).

The requirements of distributed, large-scale systems, hence, suggest the need for specific types of risk models:

- *dynamic risk models* to capture the dynamic nature of risk in complex systems, and to capture risk migration in the system,
- *historical analyses of system performance over appropriately long periods of time* in order to develop benchmarks of system performance,
- *assessments of the role of human and organizational error,* and its impact on levels of risk in the system, and
- *domain-appropriate models and analyses* to address any special risk in distributed, large scale systems (Grabowski et al., 2000).

In addition, in dealing with contaminants in a biological environment, such as the growing of seaweed, Hyland and co-authors argue the need for a framework for integrated contaminant assessment as chemical contamination does not always correspond with biological effects, indicating that both analyses are required (Hylland et al., 2017). The key to this assessment is the development of method- and species-specific criteria, which allow for the setting of thresholds of assumed equal significance for contaminants, exposure indicators and effect indicators, eventually allowing the different data types to be combined in a common indicator (Hylland et al., 2017). In addition, Knapp and Hoorn argue that another shortcoming of current methods is that the underlying location specific environmental criteria, such as the effect of wind, wave and currents are omitted due to the complexities involved in quantifying their effect on risk exposure (Knapp and Hoorn, 2017).

According to Knapp and Hoorn (2017), one problem with current approaches in maritime risk assessment is that the decision maker is led to believe that the results are definitive and exclude uncertainty. However, two types of uncertainty are discussed in the literature: aleatory uncertainty (the randomness of the system itself) and epistemic uncertainty (the lack of knowledge about the system) (Merrick and Van Dorp, 2006). Uncertainties arise from input data, parameter estimates, as well as simplifications and assumptions used in the modelling approach (Knapp and Hoorn, 2017). In the data collection case, epistemic uncertainty can be reduced by further study and data collection, whereas aleatory uncertainty is irreducible, as it is a property of the system itself (Merrick and Van Dorp, 2006). If qualitative methods are used based on subjective judgement, additional challenges arise, which are mostly relevant for estimating the effects of risk control options. In order to handle uncertainty, uncertainty arising from each source would first need to be considered separately (Knapp and Hoorn, 2017).

3.2.3 The social dimension of risks

Lee and colleagues (2017) argue that accidents do not occur as the act of an isolated individual or a front-line operator, but due to highly interactive and collective processes as well as the influence of involved decision-makers in all relevant levels of society. Analysis should not only consider the activities of players in each level, but more importantly, the interactions between them, which take the form of decisions propagating downward and information propagating upward (Lee et al., 2017).

In addition there is a need in multi-use to consider integration of policies and institutions. Policy integration is the management of cross-cutting issues in policy making that transcend the boundaries of the established policy fields and do not correspond to the institutional responsibilities of individual organisations. The term institutional integration indicates institutions that are built and managed to benefit communication, cooperation, and coordination between or among parties (Ran and Nedovic-Budic, 2016).

According to Wang (2000), risk criteria may be different for different individuals. They would also vary between societies and alter with time, accident experience and changing expectation of life. Risk criteria can therefore only assist judgements and be used as guidelines for decision making (Wang, 2000). Following Haapasaari and co-authors, risk assessment criteria and an acceptable and tolerable level of risks must be agreed. Criteria, and their mutual weighting, are also needed for ranking alternative riskcontrolling measures in relation to one another. In addition, criteria are required for defining the cost-effectiveness of risk management, or acceptable costs in relation to expected benefits (Haapasaari et al., 2015).

The analytical framework developed by the International Risk Governance Council (IRGC) deals with public systemic risks, that is, risks that cross boundaries between the environment, society and human health, and between nations and sectors, and that have both factual and socio-cultural dimensions. The framework stresses that judgments of risk depend on perspective and context, and therefore different types of knowledge and values must be addressed when assessing and evaluating risks. For combining scientific evidence with socio-cultural and economic considerations, the framework engages all relevant stakeholders in the governing of risks (Haapasaari et al., 2015).

When developing the common framework, multi-use is defined as a distributed, large-scale system. Hence, the need to integrate the analysis of contributing factors from different parts of a socio-technical system with interactions between them. Also, as multi-use is a newer phenomenon, little is known about the risks of the combination of activities. Hence, the risk assessment needs to be able to deal with a large degree of uncertainty and, over time, accommodate an increase in knowledge and understanding of the risks involved.

In order to select between alternative risk-control measures selection criteria and their mutual weighting need to be developed. Risk acceptance criteria are normative statements of what is deemed acceptable and what is not in a society (Vanem, 2012). Accordingly, acceptance is unlikely to be based solely on a numerical risk assessment. Risk criteria may be different for different individuals. They would also vary between societies and alter with time, accident experience and changing expectation of life. Risk criteria can therefore only assist judgements and be used as guidelines for decision making (Wang, 2000). The criteria developed can both be used to choose between risk management options and, after implementation, be used for evaluation of the risk management measures.

3.3 Governing risks

Sources of risk to marine systems include such events as equipment failure, external events, human error, and institutional error (Ayyub et al., 2002). Marine ecosystems, and especially near-shore coastal areas such as estuaries, are typically subjected to a variety of stressors, both natural and anthropogenic, which can impair the health and fitness of resident biota. Multiple stressors including pollutants, nutrients, hypoxia, turbidity, suspended sediments, and altered habitat and hydrologic regimes can impact resources through single, cumulative, or synergistic processes (Adams, 2005).

Under these circumstances the simple risk model, in which the cause for the risk is well known, the potential negative consequences are obvious, the uncertainty is low and there is hardly any ambiguity with regard to the interpretation of the risk (Renn et al., 2011), does not remain valid. Operating in the marine socio-ecological system, many risks are not simple and cannot be calculated as a function of probability and effects and regulatory models which build on that assumption are not just inadequate, but constitute an obstacle to responsibly dealing with risk (Zwietering, 2009; Renn et al., 2011). Risks become ‘‘systemic’’ as risks are embedded in the larger contexts of societal processes and require a more holistic approach. Systemic risks are characterized by a high degree of complexity, uncertainty, and ambiguity in addition of spreading out to other risk areas and risk arenas (OECD, 2003).

The nature of such systemic risks requires cooperation, coordination, and trust between a range of stakeholders who have diverging interests and different perceptions of the (potential) risks involved. Managing risks will inevitably be directed by relevance claims (e.g. what matters to society and what are important phenomena that should receive our attention?), evidence claims (e.g. what are the causes and what are the effects?) and normative claims (e.g. what is good, acceptable and tolerable?), identifying what is relevant and worth further investigation is clearly a task that demands both sufficient knowledge about impacts and a broad understanding of the basic values and concerns that underlie all procedures of selection and priority setting (Renn, 2008).

Risk governance looks at this complex web of actors, rules, conventions, processes and mechanisms concerned with how relevant risk information is collected, analysed and communicated, and how management decisions are taken (Renn, 2008). It includes the totality of actors, rules, conventions, processes and mechanisms and is concerned with how relevant risk information is collected, analysed and communicated, and how management decisions are taken (International Risk Governance Council, 2012). Noting the characteristics of multi-use at sea, with multiple actors operating in the complex marine ecosystem, this is, following Renn (2008), van Asselt & Renn (2011) and the International Risk Governance Council (2012), a clear example requiring consideration of the legal, institutional, social and economic contexts in which risk is evaluated, and involvement of the actors and stakeholders who represent them.

In the next section we will start by looking at three sectoral approaches to risk assessment after which, in section five, we will construct a common risk assessment framework for multi-use at sea; common in the sense that it will allow for the inclusion of risk assessment from different perspectives and perceptions.

4 Current practices: sectoral approaches for risk analysis

There are various approaches used in risk assessment. Below we will look at three standard approaches, one for each of the scientific domains used in the analysis of safety of multi-use at sea: food (and feed) safety, maritime safety, and environmental impact. These analyses are in itself not geared towards multi-use. In section 5 these approaches will be joined to be applicable to cases of multi-use, especially addressing the aspect of having to integrate different perspectives to arrive at a common framework of risk assessment.

4.1 Food and feed

The Codex Alimentarius Commission (CAC) is a joint FAO/WHO inter-governmental body that works to protect consumer health, ensure fair food trade practices, and promote coordination of food standards by governmental and non-governmental organizations (Banach et al., 2018). The CAC has adopted the Codex Alimentarius (Food Code), which is a collection of standards, guidelines, and codes of practice related to food. This food code is a global reference for several stakeholders, including national control agencies, food producers, food processors, and consumers. In this food code, principles for food safety risk analysis, including risk communication, risk assessment, and risk management are outlined (FAO, 2017). The risk analysis approach of the CAC helps set a foundation for food safety regulation and is important to address when implementing food (and feed) safety into multidisciplinary frameworks (Banach et al., 2018).

A 5-stage roadmap highlights the steps for food and feed safety, including their potential effects on human health and how hazards can be monitored and controlled (Table 1). Herein, the parts of the risk analysis framework of the CAC are extrapolated, namely, risk assessment coincides with stage 2 (analyze), risk management with stages 3-5 (design, implement and evaluate), while risk communication coincides with all 5 stages (Banach et al., 2018). The evaluation of the 5-stage roadmap as can be used for the multi-use at sea case scenario is described in Table 1.

Table 1:Description of the food and feed safety approach given single-use and multi-use in the context of seaweed cultivation at an offshore windmill park, reproduced from Banach et al., 2018.

Steps of food & feed safety roadmap	**Description**
1. Establish the	• Describe the multi-use scenario, including the location, type of seaweed

situation, including relevant activities, actors, and hazards	cultivated, etc. • Identify the actors in the food and feed chain, including the potential advantages and disadvantages, in terms of safety, that may result from their interactions with one another and with other stakeholders. • Evaluate the multi-use situation and identify any ambiguities that may affect potential food and feed safety hazards (i.e. chemical, biological, and physical hazards) in addition to those of single-use and which objectives (public health, economic, etc.) are desired. • Describe current legislative issues for pre-identified hazards (e.g., contaminants) and identify data and governance gaps given the multi-use scenario (e.g., with multi-use of seaweed cultivation at an offshore windmill park: the presence of marine toxins, dioxins, micro- and nano-plastics).
2. Analyze the risk in relation to the hazards	• Perform a "risk assessment," which consists of the following steps: 1. Hazard identification, 2. Hazard characterization, 3. Exposure assessment, and 4. Risk characterization. • If a full risk assessment is not possible (given resources available), consider other methodologies such as risk ratio methods, risk matrix, multi-criteria decision analysis, expert judgment, etc. (see van der Fels-Klerx et al. (2015) for an overview of methods). • Evaluate how the results of the assessment affect your desired objectives and future recommendations. Also, consider how the probabilities of actor interactions may affect your results.
3. Design a prevention and control plan	• Review the analysis and recommendations of point 2 on the risk to human health, also considering societal, economic, and political factors. • Prioritize the recommended options based on effect and resources needed: decide which recommendations to take; indicate why each option was chosen (or not); and elaborate on this choice. • Develop a work plan for implementing the selected options (interventions), making clear which objectives are sought after, a practical timeline for implementation, and a description of collaborating persons. • Allocate resources for the commissioning plan, including a budget cost estimate of expenses such as personnel, investments, materials, etc.
4. Implement the plan	• Implement a project organization according to the commissioning plan. • Execute the plan by commissioning an offshore multi-use location producing seaweed, according to the safety rules agreed upon. • Evaluate frequently during safety meetings the applicability of the set of safety rules.
5. Evaluate the process	• Strategically review the process for identification and control of food and feed safety hazards – during implementation - using analysis mechanisms such as SWOT (strengths, weaknesses, opportunities, and threats). • Use control findings to improve the process to obtain the desired objectives. Make a note of any deviances or ambiguities that may arise, including how external forces may affect your overall objective. • Continue collecting and analyzing data on evaluated measures to be able to support risk-based monitoring, control, and application of relevant public standards and protocols. • Communicate outcomes and future proposed recommendations to stakeholders.

4.2 People and equipment

The International Maritime Organisation IMO developed guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process (IMO, 2002; IMO, 2015). FSA can be used as a tool to help evaluate new regulations for maritime safety and protection of the marine environment or in making a comparison between existing and possibly improved regulations, with a view to achieve a balance between the various technical and operational issues, including the human element, and between maritime safety or protection of the marine environment and costs (IMO, 2015). It is not intended that FSA should be applied in all circumstances, but its application would be particularly relevant to proposals which may have far-reaching implications in terms of either costs (to society or the maritime industry), or the legislative and administrative burden which may result. FSA may also be useful in those situations where there is a need for the risk reduction but the required decisions regarding what to do are unclear, regardless of the scope of the project. In these circumstances, FSA will enable the benefits of proposed changes to be properly established, to give Member Governments a clearer perception of the scope of the proposals and an improved basis on which they take decisions (IMO, 2015).

FSA mainly focusses on maritime shipping, in which the generic model should not be viewed as an individual ship in isolation, but rather as a collection of systems, including organizational, management, operational, human, electronic and hardware aspects which fulfil the defined functions. The functions and systems should be broken down to an appropriate level of detail. Aspects of the interaction of functions and systems and the extent of their variability should be addressed (IMO, 2015). In Table 2, below, the steps of risk assessment and management are presented.

Table 2: Steps in maritime safety assessment, reproduced from NEN, 2009

Steps in maritime safety assessment	**Description**
1. Establishing the context (The objectives, strategies, scope and parameters of the activities of the organization(s), or those parts of the organization(s) where the risk management process is being applied)	• Establishing the external context: to ensure that the objectives and concerns of external stakeholders are considered when developing risk criteria. It is based on the organization-wide context, but with specific details of legal and regulatory requirements, stakeholder perceptions and other aspects of risks specific to the scope of the risk management process. • Establishing the internal context: anything within the organization that can influence the way in which an organization will manage risk • Establishing the context of the risk management process: the objectives, strategies, scope and parameters of the activities of the organization, or those parts of the organization where the risk management process is being applied • Defining risk criteria: criteria to be used to evaluate the significance of risk
2. Risk assessment	• Risk Identification • Risk Analysis • Risk Evaluation
3. Risk treatment (select one or more options for modifying risks, and implement those options. Once implemented, treatments provide or modify the controls)	• Selection of risk treatment options • Note: Risk treatment involves a cyclical process of: o assessing a risk treatment; o deciding whether residual risk levels are tolerable; o if not tolerable, generating a new risk treatment; and o assessing the effectiveness of that treatment. • Preparing and implementing risk treatment plans
4. Monitoring and review	• Monitor and review all aspects of the risk management process • Provide a performance measure for progress • Record and report results externally and internally as appropriate

4.3 Environmental impact assessment

The assessment of environmental impacts is documented in an Environmental Impact Assessment (EIA). The EIA of projects is a key instrument of the European Union environmental policy. The EIA Directive (European Commission, 2017) requires that public and private projects that are likely to have significant effects on the environment be made subject to an assessment prior to Development Consent being given. Development Consent means the decision by the Competent Authority or authorities that entitles the Developer to proceed with the Project. Table 3 below sets out an overview of the stages and steps usually taken when completing an EIA (European Commission, 2017).

Table 3: Steps in Environmental Impact Assessment, reproduced from European Commission, 2017

EIA step/ phase	Description
1. Screening	• Screen whether an EIA is required
2. Scoping	• Identifies the content and the extent of the assessment and specifies the information to be included in the EIA
3. IEA report	• Information regarding the project, the Baseline scenario, the likely significant effect of the project, the proposed Alternatives, the features and Measures to mitigate adverse significant effects as well as a Non-Technical Summary and any additional information specified in Annex IV of the EIA Directive
4. Information and consultation	• Public to review EIA report: opportunity to comment on the project and its environmental effects
5. Decision Making and Development Consent (article 8)	• Competent Authority examines the EIA report including the consultation comments; issues a Reasoned Conclusion on whether the project entails significant effects on the environment. This must be incorporated into the final Development Consent decision
6. Information on	• Public is informed about the Development Consent decision

Development Consent	
7. Monitoring (as appropriate)	• During construction and operation phase of the project the Developer must monitor the significant adverse effects on the environment identified as well as measures taken to mitigate them

These three models form the starting point for the integral analysis of safety assessment of multi-use at sea that is introduced in section 5.

5 A common framework for risk assessment

Based on experiences with seaweed farming and wind farms in the Dutch part of the North Sea, an array of interviews with operators and stakeholders and a series of workshops with these groups, and based on the literature review presented above, several elements were explicated that needed to be part of the integrated framework for risk assessment of multi-use at sea, described below.

Constructing the framework builds on other frameworks, such as the three sectoral approaches described above. In addition elements from other frameworks were used, such as the basic structure of the IMO developed guidelines for Formal Safety Assessment (FSA) (IMO, 2002; IMO, 2015), the cyclical IRGC risk governance model (International Risk Governance Council, 2012) and the International Council for the Exploration of the Seas (ICES) developed Ecosystem-based risk management framework (Cormier et al., 2015). Also Aven's model of risk informed decision making (Aven, 2016), Goerlandt and Montewka's framework for risk analysis (Goerlandt and Montewka, 2015a) Haapasaari et al. model for participatory risk assessment (Haapasaari et al., 2015) and Mazaheri et al. model of complex socio-technical systems (Mazaheri et al., 2016) were used in the development of the framework.

5.1 Principles for a framework for multi-use

Multi-use will be time, location, and activity specific. This requires a specific step in which the characteristics of the activity, aspects of co-location and multi-use, and identification of relevant actors and stakeholders should be assessed. Then the framework should allow for the integration of safety aspects from different angles and scientific fields. Hence, it should allow for a multi-disciplinary and interdisciplinary safety analysis. The three perspectives of food (and feed) safety, safety of people and equipment, and environmental impact need to be integrated from different perspectives, on different time and spatial scales.

The framework should facilitate a process of developing safe multi-use operations, including prevention, mitigation, and corrective actions. The framework should be applicable to all stages of multi-use, hence in design and planning, construction, operation, maintenance and decommissioning. Be applicable to all types of multi-use ranging from sharing infrastructure or sharing services to sharing space consecutively over time. And cater for the inclusion of multiple perceptions, such as differences of perception by actors directly involved, and the wider range of relevant stakeholders, but also of activities operating under different legal and policy frameworks. Hence, the framework should be participatory, allowing for the inclusion and integration of perceptions.

Given multi-use, each of the activities in itself along with the concept of multi-use, e.g., from the three perspectives, brings political, social, economic, sectoral, and governance factors that need to be considered singly and comprehensively.

As the situation will differ between different cases of multi-use and time, location, and activity specific, the framework will need to be able to integrate information that is generated along the way. Hence, the framework should be reflexive with an extensive role for stepwise evaluation and being dynamic and adaptive. As over time we learn, more data and more information will become available. Also, the level of knowledge and understanding will change over time.

As the process of developing multi-use is highly innovative and dynamic, there is a need to pay ample attention to governance aspects such as transparency, legitimacy, and participation. Not only is a possible outcome of the process at a given time the establishment of formal rules and legislation but also the development of practical modes of safe operation on a case specific basis can be a result. Over time, these outcomes need to be evaluated as practices may change over time.

Parallel to the IRGC risk governance model (International Risk Governance Council, 2012), allowing to capture changes over time and especially capturing development of knowledge and understanding, it is suggested to have different steps in the framework, such as a phase of "identification", a phase of "understanding" and a phase of "deciding". Central in the framework is risk communication and evaluation. As these elements are central to an integrated participatory safety assessment, they are of importance in every step.

Risk is a truly interdisciplinary, if not a transdisciplinary, phenomenon (Renn, 2008). It is widely acknowledged that such an interdisciplinary approach is rather time consuming (Jones, 2010), as a common ground for analysis needs to be developed. This requires, next to developing a common credible framework, developing a common language and understanding of terms (Holt et al., 2017).

In Table 4 and Figure 1, the steps of the proposed framework, the role of participation in each of the steps and the tools that can be used to facilitate a step in the framework are presented.

Table 4: Framework for risk assessment of multi-use at sea, including elements of participation and overview of tools

Step	What is it about?	Participation	Tools
Exploring	Identify the multi-use activities planned or taking place Identify relevant actors Describe the multi-use system	Arrive at a description of the system and its governance, policy, market, sectoral and societal context. Stakeholders can provide data, information and evidence on crucial steps in the multi-use system	Policy Analysis Stakeholder Mapping Stakeholder Analysis
Understanding	Identify opportunities and threats (hazards) to the multi-use system Identify ambiguities and uncertainties in the multi-use system Implement a Formal and Participatory Risk Assessment Identify control options, mitigation measures and coping strategies	Stakeholders assist in developing a shared identification of hazards and risks	Event and fault trees Probability estimations Bayesian networks
Appraising	Assess hazards, risks, consequences under different scenarios and events, given the current level of knowledge and understanding Appraise risk management options	Stakeholders provide norms and values to be included in the appraisal of scenarios, likelihoods and consequences and in the development of acceptance criteria for mitigating measures.	Identification critical hazards Cost-Benefit Analysis Multi-criteria Analysis Societal Cost-Benefit analysis
Deciding	Decide on actions to be taken	Stakeholders are involved in the process via co-decision	Bayesian networks Decision Support Systems
Implementing	Implement actions on safety recommendation	Actors implement the mitigating measures	
Evaluation and Communication	Review the safety concerns and action that were taken Determine if additional measures need to be included Communicate on findings and progress and seek input	Stakeholders are involved in the analysis of the results	Participatory Evaluation Techniques Efficiency & effectiveness Evaluation

The phase of **Exploring** consists of identifying the multi-use system and the relevant actors and stakeholders. Among others, it will contain a description of the exact activities and the location of these activities including its physical characteristics, and the policy, societal, economic/market, sectoral and governance context in which the individual and multi-use activities are taking place. It also features a main task in bringing together the relevant actors and stakeholders necessary to embark on a process of safety assessment.

The system description will include a description of the interplay and synergies between the different individual activities and the multi-use aspects as well as a description of the underlying business case. Including the stakeholder analysis which will also consider, for as far as relevant, up- and downstream links in the market chain such as parties in the ancillary industry and processing and marketing activities.

The phase of **Understanding** aims at identifying the opportunities and threats (hazards) surrounding the multi-use system. It will, given possible scenarios, likelihoods and consequences, and given the current level of knowledge and understanding, implement a Formal and Participatory Risk Assessment and identify options for risk control, prevention and/or mitigation. This will include a thorough analysis of the interplay of the different activities in the system and the uncertainties and ambiguities surrounding the system.

It will focus on an identification of the nature of the identified risks (simple, complex, uncertain and/or ambiguous) and the resilience or vulnerability of the system. Based on the identified hazards and consequences risk control, prevention and/or mitigation measures can be defined.

In the phase of **Appraising** the different management options based on the hazards, risks, consequences under different scenarios and events, given the current level of knowledge and understanding will be valued. This entails among others providing data and information that will allow support to the decision-making process. It also encompasses an assessment of the perceived costs and benefits of the different events and possible mitigating measures.

During the phases of Exploring, Understanding and Appraising acceptance criteria for risk control, prevention and/or mitigation measures will be developed.

The phase of **Deciding** focusses on deciding on recommendations regarding safe operations in a specific multi-use setting. This is the phase during which information from the prior steps is combined with the acceptance criteria developed and the "values" as defined by the relevant actors to arrive at a set of recommended practices. This against a backdrop of the different scenario's and strategies as identified by the stakeholders during the understanding and appraisal phases.

During the phase of **Implementation** the multi-use activities and the risk control, prevention and/or mitigation measures are being implemented by the relevant actors This will also include relevant actions by the pertinent authorities in terms of monitoring and control and by application of relevant public standards and protocols.

Central in the safety assessment for multi-use are **Evaluation** and **Communication**. During and after each step, informing relevant actors and stakeholders is of importance. Also, after each step, it is important to evaluate findings and progress and decide the next steps to take. As multi-use at sea in its current form is a relatively newer phenomenon, background knowledge is not widely available. With time and growing experience, knowledge and understanding may increase. This then may call for a renewed safety assessment, against the backdrop of new information.

With experience gained and new information generated after some time the evaluation and re-assessment of the safety aspects can be effectuated, including both an evaluation of the relevance, efficiency, and effectiveness of the risk control, prevention and/or mitigation measures as well as an evaluation of the appropriateness of the measures. In this, the evaluation can consist of two steps. A first step being an evaluation of actual practices against the developed mitigating measures and a second step against new insights, knowledge and understanding against the relevance of the current set of mitigating measures.

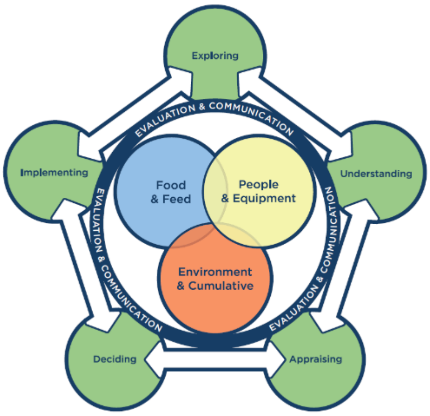

Figure 1: Framework for risk assessment of multi-use at sea

5.2 Relating the proposed framework to sectoral approaches

In Table 5, we relate the framework to the three sectoral approaches presented earlier. The common framework caters for most of the steps in the three sectoral approaches. As we followed a rather linear approach in this table, it appears that steps 5-7 of the EIA approach are not catered for in the integrated framework. However, if we ignore the stepwise order of the EIA approach these steps are catered for in steps 4-6 of the common framework.

Table 5: Comparison of the framework of risk assessment of multi-use at sea with three sectoral approaches.

Framework for Risk Assessment of Multi-use at sea	Stage of Food & Feed safety roadmap[2]	Safety of People and Property[3]	Environmental Impact Assessment[4]
1. Exploring	1. Establish the situation, including relevant activities, actors, and hazards	1. Establishing the context (The objectives, strategies, scope and parameters of the activities of the organization(s), or those parts of the organization(s) where the risk management process is being applied)	1. Screening 2. Scoping
2. Understanding			
3. Appraising	2. Analyse the risk in relation to the hazards	2. Risk assessment	3 IEA report
	3. Design a prevention and control plan	3. Risk treatment (selecting one or more options for modifying risks, and implementing those options. Once implemented, treatments provide or modify the controls)	
4. Deciding			
5. Implementing	4. Implement the plan		

[2] Food and Agriculture Organization of the United Nations, 2017

[3] NEN. 2009. Risk management - Principles and guidelines. NEN31000.

[4] European Commission, 2017

6. Evaluating	5. Evaluate the process	4. Monitoring and review	4. Information and consultation
			5. Decision Making and Development Consent (article 8)
			6. Information on Development Consent
			7. Monitoring (as appropriate)

The table illustrates that the proposed framework for risk assessment of multi-use at sea relates to all the steps of the sectoral approaches. It illustrates that similar steps are taken in each of the approaches, yet named differently and, in instances, timed differently. What the proposed framework adds is the integration of each of these sectoral approaches. It clearly adds the role of stakeholders in each step of the process of risk assessment, and it suggests different tools that can be of help when implementing each of the steps. Moreover, it emphasises the cyclic nature of risk assessment and risk management and the need to, in each step, clearly communicate with all stakeholders involved.

6 Concluding remarks and moving forward

With marine space becoming increasingly scarce, the call for multi-use of marine space is increasing (Calado et al., 2019; Depellegrin et al., 2019; Schupp et al., 2019). In some countries already the national Marine Spatial Plan reflects this development by stimulating multi-use (Lukic et al., 2018; Schultz-Zehden et al., 2018). An important issue in developing multi-use is dealing with risks.

An approach to risk assessment of multi-use at sea was developed, based on the case of seaweed production at windfarms in the North Sea, a series of workshops and interviews with relevant stakeholders and a literature review of maritime risk frameworks and risk and hazard concepts.

Producing food (and/or feed) in multi-use brings risk assessment issues to the fore that do not exist in single-use. In the case of multi-use, traditional maritime safety issues and marine environmental management objectives need to be integrated with risk assessment of food (and feed) safety.

The case study used was based on an existing wind farm, Egmond offshore wind farm, in which the experiences of seaweed production in the North Sea by the North Sea Innovation lab were projected. From the analysis of the case study it became clear that each of the two activities operate under their own context of risks and legislation. In combining the two uses additional, multi-use issues emerge, such as ship-ship conflicts between the two operators. Also it became clear that stakeholders involved do have different perceptions of the risks involved.

The literature analysis produced a vast body of work related to (maritime and marine) safety. Yet in order to accommodate the need to come to an integrated analysis a further development of a framework was required. The framework is to be applicable to all sorts of cases of multi-use, ranging from multi-purpose/multifunctional and symbiotic use to mere co-location and subsequent use. In addition the framework is to assist in all steps of the multi-use process from design and construction to operation and maintenance to decommissioning, and both in the case of multi-use being developed already in design, to cases in which an additional activity is added on to an existing use. The risk inventory and assessment should lead to concrete measures of prevention, mitigation and corrective measures.

Multi-use operates in a complex socio-technical-ecological system. As there is not a lot of experience and knowledge about the risks involved in multi-use, and the complexity of multiple hazards involved, there will be a limit to the risks that can be characterized by objective facts, as well as be explained, predicted, and controlled by science. A more proceduralist approach is preferred, with stakeholders characterizing risks through a shared understanding of balancing facts and values. Multi-use is time, location, and activity specific. This requires a description of the characteristics of the activity, aspects of co-location and multi-use, and identification of relevant actors and stakeholders. In order to select between alternative risk-control measures selection criteria and their mutual weighting need to be developed based on normative statements of what is deemed acceptable.

The stakeholders involved in this process of risk assessment of multi-use range from the actual operators of the multi-use activities and actors involved in the production and market chain (hence ancillary industry, processing, transport and trade parties and consumers). In addition there are government parties involved related to licensing, marine spatial planning and marine management. Financiers, risk assessors and insurers play an important role. And of course other users of the marine environment, NGOs and the wider public are to be considered stakeholder in this process.

The framework stresses the importance of stakeholder involvement when dealing with unknowns and dealing with uncertainty. The framework encompasses and integrates an analysis of food and feed safety aspects, safety of people and equipment, and environmental safety aspects. The framework is iterative and dynamic. With constant communication and evaluation of progress, decisions can be taken to either take a step forward or back in the process.

The framework can be helpful for practitioners, legislators, risk assessors, and all other stakeholders that seek to address the risks of multi-use at sea. The framework helps relevant actors to assess hazards and evaluate control measures to ensure safe multi-use at sea and provides methods and tools to assist in analysing safety aspects and appraise multi-use. So on the one hand it can assist the individual operators to together develop safe multi-use activities. On the other hand it can assist government authorities to, in case needed, develop adequate legislation to guide safe multi-use operations. As such the analysis can be helpful in processes of allocating space to activities for example such as in Marine Spatial Planning.

With the development of a framework for the risk assessment of multi-use at sea, we hope to contribute to a better understanding of safety aspects of multi-use and the development of safe practices of multi-use, by catering to a proactive approach to the multiple risks of multi-use rather than a reactive approach. The next step is to validate the framework in actual multi-use cases. Then, based on those experiences, the framework can be further developed. The proposed framework is developed to contribute to discussing and governing safety aspects of multi-use and avoid negative human and/or environmental impacts.

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9 Annex 1: Glossary

Actors: *Individuals or collectives that are a direct player in the implementation of multi-use at sea.*

Bayesian networks: *Bayesian networks are an example of multi state models. A Bayesian network, Bayes network, belief network, Bayes(ian) model or probabilistic directed acyclic graphical model is a probabilistic graphical model (a type of statistical model) that represents a set of random variables and their conditional dependencies via a directed acyclic graph* (Faber, 2007; Morales Nápoles, 2010).

Cost and Benefits: *The positive or adverse effects of an event consisting of both the private and social costs (including externalities) as well as the private and social advantages or profits gained from the event.*

Cost-Benefit Analysis: *The systematic and analytical process of comparing benefits and costs in evaluating the desirability of a project or programme* (Quah and Haldane, 2007).

Critical hazards: *As part of the Failure Modes Effect and Criticality Analysis the consequences of the failure events corresponding to the different failure modes are assessed. Both the probability of failure and the consequences of failure are assessed subjectively for the identified failure events and the considered failure modes (Minor, Significant, Critical, Catastrophic) for all identified sub-systems and components* (ISO, 2000; Faber, 2007).

Decision Support Systems: *A DSS is an interactive system, usually based on a computer system, that processes unstructured input data into structured output data* (Sprague Jr and Carlson, 1982)*. Output data becomes information when it is relevant and utilised by decision makers* (Alter, 1998)*. Not all DSSs utilise computer-systems. A DSS may also consider approaches of dealing with expert opinions, involve graphic presentation methods, and use of paper work* (Bolman et al., 2018).

Efficiency & Effectiveness Evaluation: *Assessing whether the action/project is doing the right things and is doing the things right* (Swoboda et al., 2010).

Event Tree: *An event tree is a representation of the logical order of events leading to some (usually, but not per sé, adverse) condition of interest for a considered system* (ISO, 2000; Faber, 2007).

Event: *Something that occurs/happens. The occurrence in this context triggers either positive or negative impacts on the multi-use system.*

Fault Tree: *A fault tree is based on a deductive logic starting by considering an event of (sub)system failure and then aims to deduct which causal sequences of component failures could lead to the system failure* (ISO, 2000; Faber, 2007).

Governance: *All of the processes of governing, whether undertaken by a government, market or network, whether over a family, tribe, formal or informal organization or territory and whether through the laws, norms, power or language of an organized society, involved in the process of decision making* (International Council for the Exploration of the Sea, 2009; van Asselt and Renn, 2011).

Hazard: *A phenomenon, physical or immaterial, that has the potential to cause adverse effects or outcomes. Hazards in the context of multi-use, where events can both have positive as well as negative consequences in terms of costs and benefits, is related closely to the concepts of threats and opportunities.*

Impact: *A marked effect or influence.*

Mitigating actions: *The process of developing options and actions to enhance opportunities and reduce threats to project objectives. Risk mitigation implementation is the process of executing risk mitigation actions.*

Multi-criteria Analysis: *Is a decision-making tool developed for complex multi-criteria problems that include qualitative and/or quantitative aspects of the problem in the decision-making process* (Macoun and Prabhu, 1999; Dodgson et al., 2009).

Multi-use at sea: *Different activities taking place in a defined and specific location/area at sea simultaneously.*

Opportunity: *A phenomenon, physical or immaterial, causing an appropriate or favourable occasion*

Outcome: *Something that follows as a result or consequence.*

Output: *The production, or yield; product. Can also be the result produced by a system or process from a specific input.*

Participatory Evaluation Techniques: *Participatory evaluation implies that, when doing an evaluation, researchers, facilitators, or professional evaluators collaborate in some way with individuals, groups, or communities who have a decided stake in the program, development project, or other entity being evaluated* (Cousins and Whitmore, 1998)*.*

Policy Analysis: *Public policy analysis is a rational, systematic process that generates information on the consequences that would follow the adoption of various policies. It uses a variety of tools to develop this information and to present it to the parties involved in the policymaking process in a manner that helps them come to a decision.* (Walker, 2000; Walker, 2009)

Private and Public regulations: *Although terminology regarding public and private standards appears straightforward, the boundaries between public and private standards along with mandatory and voluntary standards can become ambiguous.*

Private regulations: *Are here defined as the ability of private actors to establish rules and standards of behaviour that are being recognised and implemented by agents who never formally delegated their sovereign rights to the bodies in charge of their definition and implementation.*

Probability estimations: *In for example a fault tree, calculate probabilities of '(sub-) system' failures, following a sequence of parallel and serial events* (ISO, 2000; Faber, 2007).

Public Regulations *are defined as government regulating activities by a principle, rule, or law designed to control or govern conduct.*

Risk: *a probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal vulnerabilities, and that may be avoided through pre-emptive action, in combination with the consequences of the occurrence on animal or/and human health.*

Safety: *the condition of being protected from or unlikely to cause danger, risk, or injury.*

Societal Cost-Benefit analysis: *Cost-benefit analysis is a widely used technique of applied welfare economics, which is used to throw light on the societal desirability of undertaking an economic project. It has been widely accepted that economic evaluations should include all potential effects, positive as well as negative (side effects)*(Jönsson, 2009). *The analysis includes the analysis of market failure, as it offers the calculation of direct effects, indirect effects, external effects, and distribution effect and addresses uncertainty* (de Joode et al., 2004).

Stakeholder Analysis: *Analysis of the roles, relationships and positions of internal and external stakeholders inside and outside of the activity's or system's governance structure* (Derakhshan et al., 2019).

Stakeholder Mapping: *Identification of stakeholders and, following Almutairi et al. (2019) clustering the stakeholders based on their levels of power over and interest in specific events* (Almutairi et al., 2019).

Stakeholders: *Everyone that claims to have an interest or concern in the multi-use at sea.*

System: *Both a set of activities implemented as parts of an interconnecting network as a set of principles or procedures according to which something is done.*

Threat: *A phenomenon, physical or immaterial, likely to cause damage or danger.*

Uncertainty: *A situation involving imperfect and/or unknown data, information and knowledge in which outcomes and impacts cannot be precisely and accurately predicted.*