Review of environmental risk and uncertainty for supporting policy development and decision making for the marine renewable energy sector

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Environment Risk Futures

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EXECUTIVE SUMMARY

The NERC Marine Renewable Energy Knowledge Exchange Programme (MREKEP) identified 'Uncertainty and risk' in relation to environmental policy, regulation and consenting as a priority area for Knowledge Exchange (KE) activity. This report presents the outputs of a short term project to provide a contemporary review of environmental risk and uncertainty in the rapidly developing Marine Renewable Energy (MRE) Sector.

The report first highlights the concept of risk assessment and the important elements that need to be taken into account; an overview of the general framework recommended for conducting risk assessments is then presented; followed by an assessment of current risk methods used within the marine sector; including consideration of the limitations on knowledge when assessing risk of MRE and hence how uncertainty is dealt with; this then leads to an analysis of how the sector perceives risk and a proposed integrated environmental risk assessment framework for the Marine Renewable Energy industry. Finally, the report develops and recommends the first stage for a comprehensive, robust, qualitative and visually engaging framework that should allow the end user to understand the types of appropriate analysis and methods available for mapping of risks and uncertainties applicable to policy and regulation in the UK MRE sector.

Fundamental to an assessment of risk is the application of an analytical, holistic approach. This approach is often guided by risk management 'frameworks' which act as the route maps for decision-makers to complete these assessments. In the first section of the report it is shown that frameworks are a guide rather than a rigid set of instructions and therefore offer flexibility for incorporating new or emerging issues. Consideration of the component parts and the way a risk framework should be constructed is essential for appropriate risk assessment and application to risk management. Furthermore, each hazard should be properly characterised (including the spatial and temporal characteristics) and the probability of exposure via plausible pathways should be determined before the risk is evaluated and importantly an assessment of uncertainty is undertaken.

When considering the risk to the marine environment from Marine Renewable Energy Development (MRED) it is important to properly identify the stressors on the system and just as importantly the receptors of those stresses. There is an important distinction between how an environmental receptor is affected by anthropogenic actions (i.e. stressors) and the impact on the receptor. There may be some change to a natural process (e.g. sedimentation regime) or a response by a set of organisms (e.g. birds avoiding wind turbines) or a human response to the visual landscape. Whatever the receptor, what is crucial is to determine if these effects have some actual impact on the receptor(s). For decision and policy makers the only real interest is in significant effects (i.e. impacts that a policy or decision can address). Hence individual impacts and also multiple/cumulative impacts are where the knowledge base has to be targeted at. This knowledge base is fed by research and understanding.

A convenient approach to identify and characterise risk is through the source-pathway-receptor model. Such a structured approach then allows the consideration of the probability of an event occurring, the likelihood of exposure to the hazard and the probability of a receptor being affected by the hazard to then determine the consequences of a risk.

Uncertainty is arguably the greatest issue for all risk assessments. Uncertainty may manifest as a lack of knowledge, an inability to control an outcome or a lack of

understanding of the effectiveness of particular management strategies. Estimates of risk are fundamentally determined by the origin, quality and provenance of the evidence that supports them and understanding how best to assess the value of the evidence becomes important.

In order to develop a true representation of the risks present within a system, information from the available literature, evidence and expert opinion, is used to define the system components and the pathways linking stressor and receptor. However if information is poor or biased then it is very challenging to define accurately the system and the linkages with such a top-down approach. This then leads to poor assessment of the system. A systemic and integrated modelling approach aims to consider all factors influencing the risks regardless of the preconceived contribution to the environmental impact. Hence a bottom up approach can ensure that the system behaviour emerges from pathways of exposure to hazards assessed. This leads to the suggestion for using systemic models to develop analyses of the MRED environmental system which are minimally influenced by prior beliefs and motivational biases.

Following a review of current practice within the MRE sector to determine what methods are currently used and to assess the current status of risk assessment practice with the sector the overriding picture was that risk assessments were sparse and generally supplemented or substituted with the outputs of the Environmental Impact Assessment (EIA) process. EIAs and Risk Assessments are not the same; they are separated by the fact that Risk Assessments identify a hazard. On reviewing the current practice using EIA it was found that MRED EIA guidance provides a structured approach for identifying, investigating and assessing impacts. In this sense they are not unlike risk frameworks which provide similar clarity and rigour to investigating an issue. However, risk frameworks provide a logical sequence of steps that enable users to fully comprehend the extent of risk posed by an activity. This is done in a repeatable, transparent manner and enables decision makers to address those issues that pose the greatest unmanaged risk. Therein lies the key point, which is to identify the issues that pose the greatest risk or threat, rather than manage all issues regardless of the likelihood of their occurrence. Hence, currently the UK MRE industry does not possess a clear, well-articulated framework for assessing risk. Furthermore, within the MRE sector huge data gaps exist which makes the assessment of risk extremely difficult.

When considering the data gaps there are advantages and disadvantages to the current stressor-receptor knowledge base for MRE. Some of the stressor-receptor relationships appear to be well researched whilst others have very little research evidence. The greater the knowledge on stressors then the more confident is the determination of the type of effects on vulnerable receptors that may be found. However, determining this is highly dependent on our knowledge of which organisms or processes are vulnerable to change.

The biggest problem is that the huge gaps in the knowledge base may be viewed by some as too much of a hurdle to overcome. Expert judgement is then relied on to deal with stressor-receptor combinations where there is little knowledge base. Expert judgement needs to have some scientific basis for policy and decision makers hence there is either the ‘precautionary approach’ or the ‘ignore because there is no knowledge approach’. Neither is suitable in terms of meeting national or international legislative requirements or minimising or mitigating environmental impacts. The result is that the research focus moves to those organisms and processes that have greater information (and by association greater certainty). The imbalance in the research evidence-knowledge base needs to be addressed if knowledge is going to advance across all stressors and receptors and therefore reduce uncertainty. This has to be the direction of environmental research relating to the interactions between MRE and the marine environment receptors in order to improve the assessment of risk and therefore provide the evidence base required by policy and decision makers.

Significantly, for the management of environmental risks and uncertainties, an evidence-based approach to both marine licensing and enforcement processes is advocated, and highlights: a) The use of a risk-based approach, allowing for uncertainty and recognising the need to use sound science; b) The need to be sensitive to any potential impacts on sites of particular significance; and c) The mitigation of negative impacts throughout the development's lifecycle. This includes the potential use of licensing conditions or alternative sites or designs to mitigate effects. There is also an emphasis on the importance of engagement and discussions between stakeholders and licence applicants to resolve any issues.

Marine licensing processes contain mechanisms that potentially allow for flexibility and adaptive management-based approaches in the light of uncertain environmental risks associated with marine renewable energy developments. In addition to marine licensing provisions, marine spatial planning processes also have the potential to enable flexible management of uncertain environmental risks.

A variety of methods are available to communicate confidence and many explicitly highlight the information gaps that exist. The main objective is to identify optimal strategies in the face of uncertainty, make strategies resilient and adaptive and identify low regret but large benefit measures. The precautionary principle is also highlighted as a way to address uncertainty; however, it is key to acknowledge the limitation of adopting the precautionary approach is that it can prevent adaptation or change.

It is important to recognise that political timescales do not follow ecological timescales hence there needs to be a clearer acknowledgement of this limitation and a better cross-consideration between the disciplines to ensure appropriate risk assessment and management occurs.

To supplement the review of the existing information relating to MRE risk and uncertainty a literature search and review of other marine sectors environmental risk assessment was undertaken. During the review a problem of variability in what was termed risk became apparent. Either the risk was not properly understood or environmental impact was considered as a proxy for risk; a mistake that has been repeated in the marine renewable energy sector. There were however some sections of other marine industries that were more specific and were useful in defining risk and promoting some methodology by which the risk could be assessed.

The Institute of Environmental and Ecological Management (IEEM) advocates that it is important to consider the likelihood that a change or activity will occur as predicted and also the degree of confidence in the assessment of the impact on ecological structure and function. IEEM documents provide a meaningful scale for assessing likelihood and confidence. For issues related to offshore development where evidence is scarce expert judgment may be relied upon to provide objective assessment of likelihood and confidence.

In the Offshore Sector health and safety applies the ALARP principle (As Low As Reasonably Possible) to manage risk. This principle relies upon a robust assessment of realistic risk, not simply worst case scenarios, and then determines how this risk can be managed.

Within the UK, offshore safety regulations apply an integrated risk based approach that begins with feasibility studies and extends through the life cycle of the installations. In a risk based approach, early considerations are given to those hazards which are not foreseeable to design out by progressively providing adequate measures for prevention, detection, control and mitigation and further integration of emergency response.

The risks associated with climate change represent a significant uncertainty for decision-makers and has resonance with the MRE sector. However, whereas the consideration of risks and uncertainties by the marine renewable energy sector is in its relative infancy, awareness of climate change risks and uncertainties and their management is more mature. A range of climate change scenarios and projections are available for use by decision-makers to assess climate change risks and uncertainties. Until relatively recently deterministic scenarios were used to address uncertainties. However, user demands for further information regarding uncertainty have resulted in the development of the probabilistic projections. Whilst the shift to probabilistic projections has a number of advantages, including allowing users to make more robust decisions and making uncertainty more transparent, it has raised significant challenges. In particular, the projections are more complicated and overwhelming for users. The explicit consideration, characterisation and communication of uncertainty are approaches that are commonly used by those addressing uncertain climate change risks. In particular, the Intergovernmental Panel on Climate Change (IPCC) highlights two key attributes, which are important when making judgements on climate change that may be of value to those wishing to address uncertainties in the marine environment: 1) The amount of evidence available to support the judgement being made; and 2) The degree of scientific consensus within the scientific community about that judgement.

In the UK the UK Climate Impacts Programme (UKCIP), Department for Environment Food and Rural Affairs (Defra) and the Environment Agency (EA) have developed a climate change risk-uncertainty-decision-making framework to support climate change risk decision-making. The framework offers a flexible, iterative approach for decision-making and has three key attributes: it is circular, iterative and tiered. Each stage of the framework is accompanied by a series of questions helping decision-makers to understand the issues involved and to aid decision-making. The framework emphasises the need for a formal process or audit trail, enabling the recording and review of decisions. The framework also highlights the importance of communicating the uncertainties and their potential influence on decisions.

Through this project it became apparent that risk assessment and uncertainty estimation methods for supporting decision-making for marine renewable energy projects are currently lacking. Whilst this is a significant finding, it only represents one element of the risk management challenge facing the marine renewables industry, with another key issue being how industry and individual organisations perceive the handling of environmental risks and uncertainties. This is an area that has received very little attention to-date. To address this research gap, a preliminary assessment of how organisations and the wider marine renewables sector perceive the handling of environmental risks and uncertainties (termed here as ‘organisational risk appetites’) was conducted through a questionnaire survey. From this initial scoping study it was evident that the MRE sector views commercial risks arising from the current and future consenting process as the greatest risk. Environmental risks appear to be viewed as being low, except for those relating to consenting. The apparently low level of concern regarding the potential environmental impacts associated with marine energy devices and developments, and the risk that the environment poses to them, is of concern. Indeed, this is both a surprising and potentially significant finding arising from this research. In particular, it suggests that there may be a lack of awareness of the risks that environmental processes may pose to devices and developments, despite the experiences from the development of offshore wind, which have highlighted the vulnerability of offshore infrastructure to such risks.

Furthermore, the findings have a number of potentially important implications that the NERC MREKE programme should consider: There is a clear and potentially urgent need to raise awareness of environmental risks across the sector. EIA and risk management tools, training and guidance are required to support and up-skill both the industry and regulators. Knowledge gaps and uncertainty need to be addressed however engaging the sector is challenging. Information sharing and the development of a community of practice are required.

As is evident from the preceding sections there are a number of issues relating to risk and uncertainty in the MRE sector and these translate to problematic decision making and policy formulation. To draw together the findings from this review and highlight where future developments and research should be directed a simple gap analysis was conducted. Through the gap analysis consideration of a) the current situation regarding risk and uncertainty, b) where the topic should be in the future, and c) what needs to be done to get there was undertaken.

It is clear that in order to ensure that the MRE sector take into account risk and uncertainty some form of integrated assessment is necessary. The current document provides the evidence that this is not currently happening; there is a real and significant imbalance to the way in which the MRE sector is set up to deal with risk and uncertainty in whatever form. What is required is an integrated framework, which is a logical structure that enables organisations to assess a variety of different risks and issues from a common perspective. The ability to assess risk in this way is important for providing consistent and relevant risk information to decision makers. The aim of the framework is to provide a means for comparing different risks in a fair and transparent manner.

An outline framework is presented that links sector specific risk assessments with larger, systems oriented analysis which then feeds into a risk comparison and strategy development. Importantly, the framework requires that no risk assessment be completed in isolation. Rather, the risks posed by an MRE activity should be considered in the broader operational context of the organisation, no matter their magnitude, to ensure that risk management strategies developed are both appropriate and cost effective. The framework is not purely linear and includes a series of feedback loops that enable stakeholders and decision makers the opportunity to reassess decisions in the event that further information is made available (i.e. an adaptive framework). In this respect the framework can become a living document that requires continual update and evaluation.

An integrated risk framework developed for the MRE sector can be employed uniformly across government, industry and academia. Such a framework would ensure the consistent use of terminology, method, and assessment criteria. The integrated framework will provide the structure for which evidence may be incorporated to address and mitigate environmental risk and uncertainty. The framework will also guide research needs, likely highlighting requirements for research conducted with an industry relevant context. From the industrial perspective, an integrated framework will indicate the focal points they have to manage in terms of their own assessment of environmental risk.

In addition to the integrated framework, there is a distinct need to develop robust, yet simple and understandable ways to communicate uncertainty. It is also crucial to build capacity and confidence in uncertainty methods. Furthermore, the current gaps in knowledge must be addressed by conducting research in a balanced way, across all stressors and receptors. It is recommended that an online "MRE evidence base" service is created which aims to regularly review new published evidence in the field, and translate this knowledge into short, useable "evidence snippets" which are uploaded to an online system. Such a tool would be useful to regulator, industry, and academic users, and could include a regular newsletter service alerting users to new evidence and research. In order to raise awareness a programme of intense knowledge exchange is required. Evidence of environmental impacts should be communicated in an open forum. It is envisaged that the development of mature risk management practice across the community could be achieved through the provision of training and workshops with a critical need for transparent and risk based processes to accompany them.

In addition, because the knowledge base is so patchy and unbalanced it is important that the decision makers draw on a wide set of expertise. Whilst innovative risk communication tools need to be developed for communicating and comparing the uncertain environmental risks associated with marine renewable energy developments.

Overall an integrated approach to understanding the full suite of risks posed by MRE activity is necessary. This will ensure the same information is available for developers, local authorities and regulators thus enabling risk informed and transparent decision processes across the sector.

Contents

1 INTRODUCTION

1.1 Background

The NERC Marine Renewable Energy Knowledge Exchange Programme (MREKEP) identified 'Uncertainty and risk' in relation to environmental policy, regulation and consenting as a priority area for Knowledge Exchange (KE) activity. This report presents the outputs of a short term project to review the topics of risk and uncertainty to meet the following two objectives:

(1) To facilitate a step change improvement in the quality of risk assessment methods currently in use, taking a whole life cycle approach to the deployment and operation of marine renewable energy technologies,

(2) To promote wider understanding of the application of risk analysis tools and methods available to support decision making at different scales, and within domains of policy development, regulation and consenting.

In order to address these objectives we undertook:

(i) A review and synthesis of information on existing risk assessment and uncertainty assessment methods already in use to support environmental decision making for marine renewable energy projects. This involved an initial scoping activity to address how risk is currently defined and managed at different scales, in relation to different environmental receptors, from different perspectives (policy and regulation) and include critical evaluation of the status of these methods.

(ii) A review and synthesis of a selection of risk and uncertainty methods routinely used in other sectors (eg. O&G, aggregates, climate change) to deal with environmental risk; including an assessment of risk definition to add to (i). The output was then evaluated to highlight the potential for application to the Marine Renewable Energy (MRE) sector;

(iii) A preliminary assessment of how organisations/industry perceive the handling of the risks with the associated uncertainties. We termed this 'organisational risk appetites' and viewed it as another important aspect for the project because the tools and methods (from i and ii above) were only part of the challenge.

(iv) Dissemination of the results of the reviews at an event where there were opportunities to discuss the outputs and how best to exchange the knowledge obtained with relevant stakeholders.

A key aspect of this project was the development and presentation of a comprehensive, robust, qualitative and visually engaging framework that would allow the end user to understand the types of appropriate analysis and methods available for mapping of risks and uncertainties applicable to policy and regulation in the UK MRE sector. Based on the outputs of the review, the general framework enabled us to develop a baseline of understanding relating to current risks and uncertainties associated with MRE before embarking on a determination of methods that could potentially address them. The framework was augmented and refined through reference to the selection of methods from the other sectors and also helped to identify ambiguities between MRE and other sector methodologies. It was important that the review and framework reflected the complexities and dynamics of UK MRE and was adaptive for future application and development.

1.2 Purpose and scope

The purpose of this report is to provide a contemporary review of environmental risk and uncertainty in the rapidly developing Marine Renewable Energy Sector. The report first highlights the concept of risk assessment and the important elements that need to be taken into account; an overview of the general framework recommended for conducting risk assessments is then presented; followed by an analysis of current risk methods used within the marine sector; including consideration of the limitations on knowledge when assessing risk of MRE and hence how uncertainty is dealt with; this then leads to an analysis of how the sector perceives risk and a proposed integrated environmental risk assessment framework for the Marine Renewable Energy industry.

1.3 Key definitions

Several key definitions pertaining to environmental risk assessment and management are important to state for a clear understanding of the topic:

- *Decision-making*: The process of identifying the likely consequences of decisions, establishing the importance of individual factors and selecting the best course of action to take to manage an environmental risk.
- *Environmental security*: An environment protected from harm or adverse effects from natural or human processes so that resources are sustained for future generations.
- *Exploiting risk*: Adopting a strategy to increase the likelihood of exploiting unexpected positive effects (Hillson, 2001). Rather than hoping for an identified potentially positive effect to result from a chosen strategy, exploiting the risk can involve making an identified opportunity happen.
- *Governance:* On a national scale, governance refers to the structure and processes for decision making that involve non-governmental and governmental actors (Nye and Donahue, 2000). On a global scale, governance represents an organised structure of regulation encompassing state and non-state actors that bring combined decision making without the presence of one superior authority (IRGC, 2005).
- *Hazard:* An event or biological, chemical or physical agent that may lead to harm or cause adverse effects.
- *Risk:* The potential consequence(s) of a hazard combined with their likelihoods/probabilities.
- *Risk assessment:* The formal process of evaluating the consequence(s) of a hazard and their likelihoods/probabilities.
- *Risk management:* The process of appraising options for responding to risk and deciding which to implement.
- *Stakeholders:* Individuals who are interested in, or affected by, an issue or situation.
- *Uncertainty:* Limitations in knowledge about environmental impacts and the factors that influence them. Uncertainty originates from randomness (aleatory uncertainty) and incomplete knowledge (epistemic uncertainty).

1.4 Introduction to Risk and Assessment

Decision processes are often guided by an assessment of risk, which is the measure of potential for damage and harm as the result of a realised hazard. The measure of risk is dependent upon what the decision maker is trying to protect and the value they place on it. Risk assessment allows decision makers to prioritise management activities based on the levels of risk.

Completing a risk assessment provides a structured approach for assessing a hazard and enables relative comparison of risk amongst a range of different hazards, even if the attributes of those hazards are disproportionate.

Risk is most commonly communicated in the form of a risk matrix (Figure 1). The consequence and likelihood (probability) of a given hazard occurring are represented along two axes with risk increasing from the origin to the outer edges of the matrix. The attributes of risk are qualitatively measured by assigning a high-medium-low category with associated colours to communicate a decision maker's appetite for risk (Figure 1 shows a 'traffic-light based' colour matrix). Risks in the low-consequence / low-probability area (green) are typically perceived as acceptable and therefore only require some form of monitoring. In contrast, high-consequence / high-probability risks (red) are perceived as unacceptable and a strategy is required to manage the risk. Other risks (amber) may require structured risk assessment to better understand the features that contribute most to the risk. These features may be candidates for management (HM Treasury, 2004)

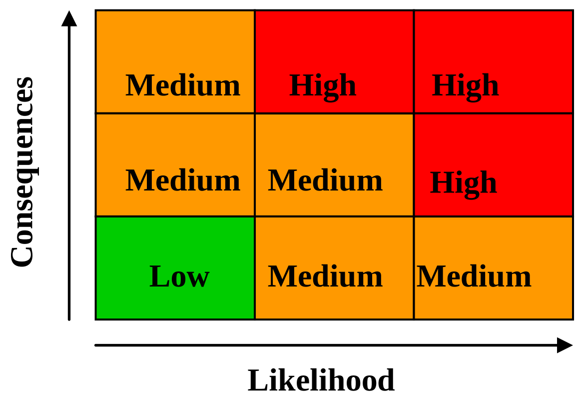


Figure 1. Assessment of risk based on the consequences and likelihood of a hazard being realised.

A challenge for risk assessment and associated risk frameworks is that the language of risk is often not precise, creating ambiguity as to what it is being assessed. These shortcomings can be thought of in terms of:

- activities that can be a source of risk, such as marine renewable energy exploitation;
- specific hazards that pose a threat, such as turbine blades;
- exposure to hazards, such as collision with rotating turbine;
- the harm that might result from exposure, such as injury or mortality following collision;
- a loss of value placed on these consequences by society, such as temporal bird or cetacean population declines from exposure.

Language also becomes an issue for emerging risks (highly relevant to the Marine Renewable Energy Sector), which routinely generate disproportionate public concern because they are usually assumed to be uncontrollable, not well understood or not competently managed. Therefore, it is important for those involved in policy and decision making in the marine environment to reduce the uncertainty surrounding a given risk and to consider social factors that may have influence during the stages of risk assessment and management so that the process provides, as far as possible, no unexpected outcomes and helps to secure beneficial outcomes. These aspects form a basic foundation for the report.

1.4.1 A structured approach to risk assessment

Fundamental to all assessment of risk is the application of an analytical, holistic approach. This approach is often guided by risk management 'frameworks' which act as the route maps for decision-makers to complete these assessments. The purpose of any framework is to offer structure to what would otherwise be a complex array of considerations for the decision-maker. Frameworks are a guide rather than a rigid set of instructions and therefore offer flexibility for incorporating new or emerging issues.

Risk management frameworks are useful in explaining to stakeholders the process of risk assessment and how this leads to the management of the risk(s). They can be a valuable aide-mémoire to multidisciplinary teams progressing with a risk assessment.

Figure 2 illustrates the structured cyclical approach to risk assessment and management underpinning the fact the exercise is not a single, one-off exercise, but a dynamic, iterative process. This framework identifies four main components:

(1) formulating the problem;

(2) carrying out an assessment of the risk;

(3) identifying and appraising the management options available; and

(4) addressing the risk with the chosen risk management strategy.

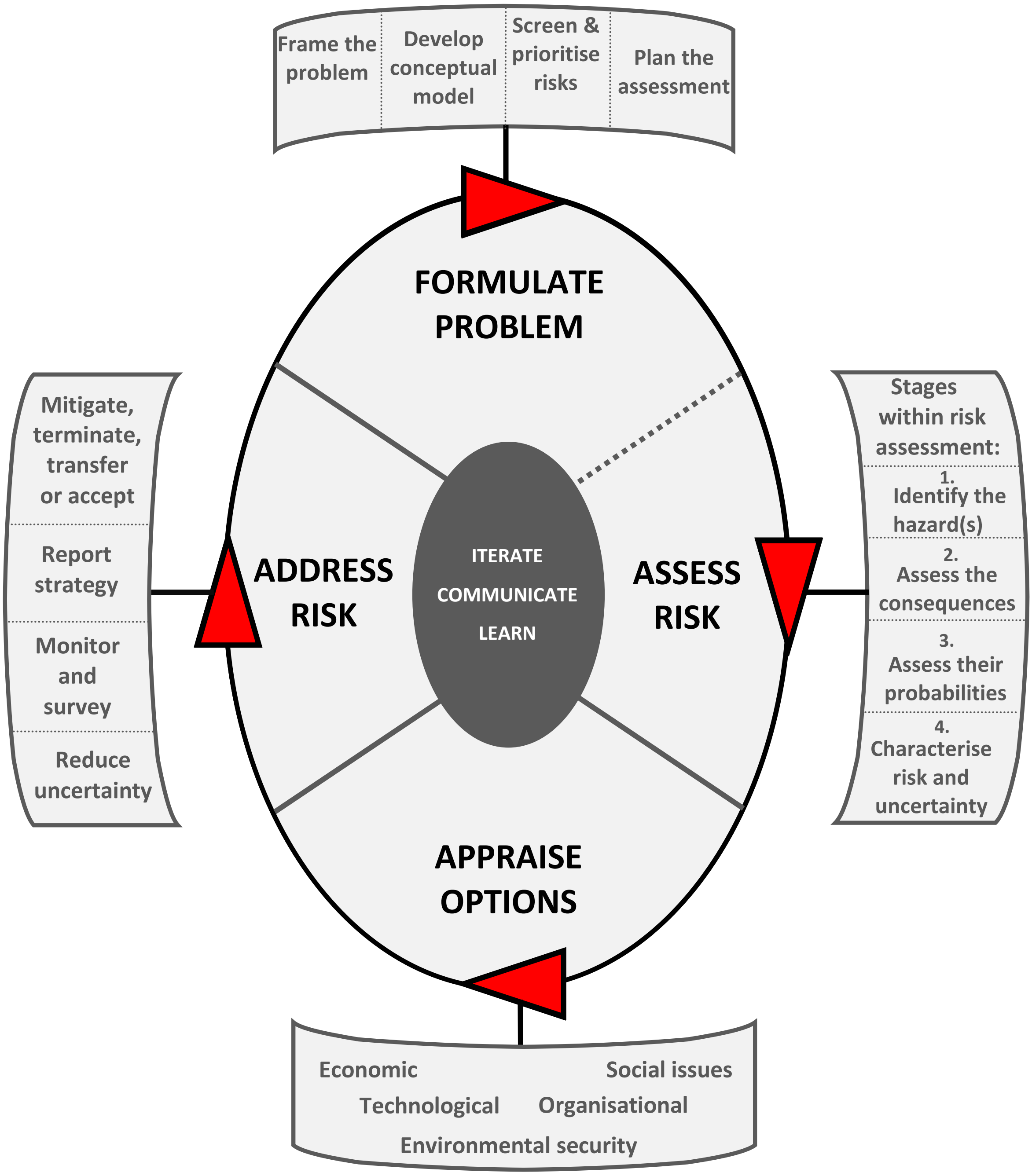


Figure 2. A framework for environmental risk assessment and management. The dashed line between the 'formulate problem' and 'assess risk' stages on the figure indicates the strong interdependencies between these two stages. (Cranfield University & Defra, 2011)

Each of the four components are illustrated with additional considerations in Figure 2 shown as banners adjacent to each component. Some cross-cutting features are also shown at the centre of Figure 2. Decision-makers should expect to use an adaptive approach which will enable them to reconsider their analyses and decisions as new information comes to light (iteration), to communicate early and often, and to make arrangements for implementing the learning that comes from assessing risks, so as to move towards a preventative approach to risk management.

It is important to note that not all risks require comprehensive and detailed assessment. Clear and effective problem formulation should allow decision-makers to evaluate the extent of subsequent analysis required. The level of effort put into assessing each risk should aim to be proportionate to its significance and priority in relation to other risks. Furthermore, the assessment of the risk should consider its complexity, the likely impacts, which are heavily dependent on the level of knowledge and certainty of the risk. Consideration should also be given to stakeholders' perceptions of the nature of the risk.

1.5 Features of the risk assessment

Risk assessment is the formal process of evaluating the combined likelihood and consequences of some event in which a hazard (the stressor) causes harm to some environmental component which we want to protect (the receptor).

Most important is the fact that hazards may impact a receptor in a multitude of ways and improper assignment of probability will lead to ambiguity and the potential for misunderstanding of the actual risk posed. Addressing this issue requires a well-articulated description to frame the problem and give an explicit statement of system boundaries.

When conducting a risk assessment typically four main tasks are undertaken:

(1) characterisation of each hazard (i.e. assessment of the potency of the hazard or the sensitivity of relevant receptors to the hazard);

(2) assessment of the probability of receptor exposure to the hazard (how important is the source of the hazard, is there a plausible pathway linking the source to the receptor, how likely is this pathway to be active and are there effective barriers in place to mitigate exposure?);

(3) characterisation of the risk (i.e. evaluating some combined measure of consequence and likelihood) and

(4) assessment of the uncertainty (which might be associated with any of the above tasks).

For any hazard there may be a range of potential impacts and these may vary across spatial and temporal scales. For example, if a marine renewable energy site location is considered there are a variety of characteristics and scales involved in the environmental risk, spanning local habitat change; fisheries exclusion; visual disturbance to local communities and effects on the economic and social value of the development. Given this range of possible scenarios it is vital to frame the hazard and set the boundaries of assessment beforehand thus lending the assessment a measure of tractability.

To address these tasks a stepped approach is taken, as shown in Figure 3.

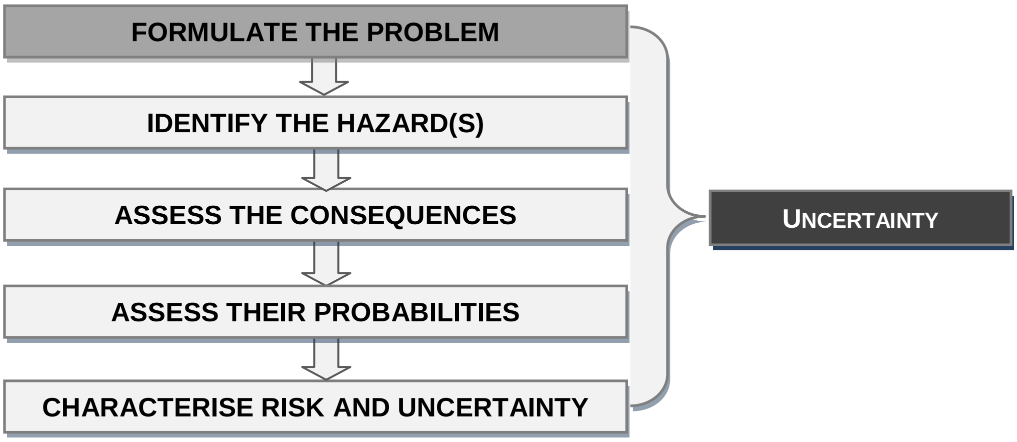


Figure 3. The primary steps of environmental risk assessment that sit within the overarching framework for risk assessment and management shown in Figure 2. Key questions to ask during these steps include (a) what can go wrong; (b) what the consequences are; and (c) how likely the consequences are. Uncertainty should be considered at every step of the process.

Within each step there are additional considerations intended to provide the user with the necessary guidance to capture all information. As most decisions are made in the absence of perfect knowledge it is common (and advisable) for decision makers to periodically reconsider their analysis as new data and knowledge becomes available. This iterative approach allows risk managers to update their risk management strategies as necessary.

Not all risks require comprehensive and detailed assessment. Some risks may be evaluated qualitatively at the problem formulation stage or during "screening" assessments, which allow low risk components to be separated from those which require additional subsequent analysis. This is very similar to the 'screening and scoping' stages within the Environmental Impact Assessment process, where the characteristics of a development are qualitatively assessed for their need for an EIA (usually in line with environmental guidance and legislation) and the most significant environmental impacts are highlighted. This similarity between risk assessment problem formulation and EIA screening and scoping is important in the context of the marine sector as they appear to have been used interchangeably.

1.5.1 Problem Formulation

Formulation involves clearly setting out the problem, its boundaries and the context within which it impacts a decision process. Unfortunately, often this step of the process is omitted, particularly where there is pressure to complete a risk assessment quickly. Failure to clearly formulate the problem could reduce the efficacy of a risk management strategy due to poorly targeted or disproportionate actions. Proper formulation is also necessary for selecting the appropriate level and type of assessment (i.e. quantitative v qualitative) and provides an audit trail detailing the rationale behind a decision.

Problem formulation is not merely the domain of the risk assessor; it requires input from stakeholders and experts. Early input from these actors will tend to make risk management decisions more effective and durable. For example, assessing risk in the marine sector may require reference to legislation (e.g. Marine Act) and therefore should include early discussions with regulators.

Risk is composed of hazards with different spatial and temporal characteristics. Defining these boundaries help to inform the scale and scope of an assessment, bringing clarity and tractability to the process.

Horizon scanning techniques can also be used to complement risk assessment of potentially wider consequences by helping to identify low probability, high impact events, which are often termed 'unknown unknowns' or 'wild cards' (Petersen, 2008), or rare, extreme impact events with retrospective predictability, which are often termed 'black swans' (Taleb, 2007).

During the problem formulation step it is of critical importance that the level of basic information known about a risk is established. This includes knowing the 'what' , 'to whom' (or which part of the environment), 'where' (location) and 'when' (in time) of a risk. For example, framing a risk assessment for an offshore wind farm development will require early agreement about the location of the site, the ecological status of the area, the affected receptors, and the time period of the activity and development of the final outcome measures.

Examples of well formulated risk questions include:

- What is the risk of an environmental release from an engineered, contained process (e.g. fuel spill from a damaged marine construction vessel)? What areas does this affect? For how long may there be a risk?
- What is the likelihood of environmental effects from the use of anti-fouling paints used to protect renewable devices? What is the time frame for potential effects being realised?
- How likely is the collision of migratory species with marine renewable energy devices in UK waters? What are the potential consequences, and to what extent does this cause impact?
- What is the likelihood of the construction of an off-shore renewable energy development impacting the reproductive activities of local marine species?

Social questions such as the significance (or acceptability) of the risk are usually addressed separately to the estimation of the magnitude of the risk (similar to the EIA process). However, in some cases, it may be inappropriate to separate magnitude from significance, especially where the outcomes have a significant social component (e.g. equity issues). This issue should be recognised during the problem formulation stage (most likely in planning the assessment).

1.6 Environmental stressors and receptors

As with any assessment of risk to the environment, when considering the risk to the marine environment from Marine Renewable Energy it is important to properly identify the stressors on the system and just as importantly the receptors of those stresses.

Stressors are those anthropogenic activities, or consequences of anthropogenic action, that are deemed to have some form of impact (often seen as negative, and often without full justification) on a receiving set of organisms (e.g. birds) or on natural processes that occur in the marine environment (e.g. sediment dynamics; Boehlert & Gill, 2010). Figure 4 summarises the existing stressors that have been associated with MRE Developments (MRED).

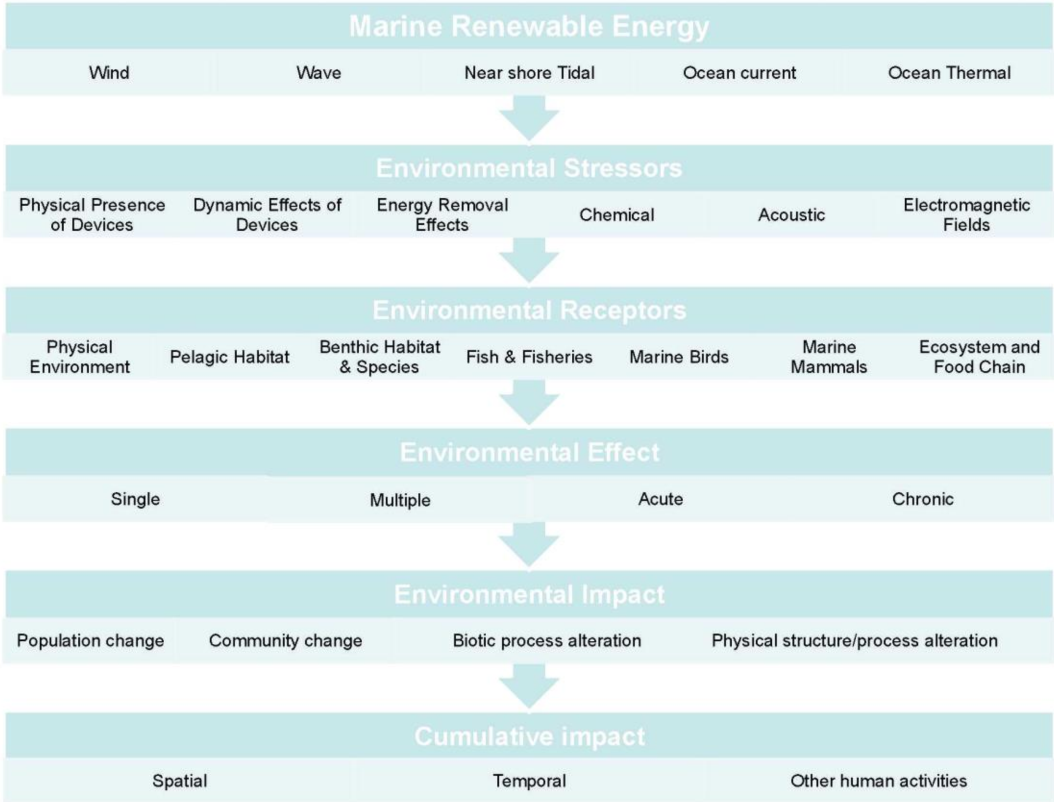


Figure 4. The stressor and receptor links between marine renewable energy and the ecological components of the marine environment.(Source**:** Boehlert & Gill, 2010).

An ecological receptor is usually defined as a taxonomic grouping (e.g. cetacean) or a community of organisms (e.g. benthic fauna; see Figure 4). The level of receptor definition is a reflection of the knowledge base for any given grouping of organisms. Hence for birds and cetacea the knowledge available is far greater than for benthic epifauna. Furthermore, there is a focus on species of conservation designation. To a lesser extent commercially important fisheries species are identified as a receptor (e.g. Atlantic salmon, Gill *et al.*, 2012). The advantage to this approach is that the level of confidence in determining any impact for a given stressor is higher than for lesser known receptors by virtue of more research that has been undertaken on them. The greater the confidence the lower will be the uncertainty.

1.7 Environmental Effect v Impact and Receptors

There is also an important distinction that should be acknowledged between how an environmental receptor is affected by anthropogenic actions in the marine environment and the impact on the receptor. There may be some change to a natural process (e.g. sedimentation regime) or a response by a set of organisms (e.g. birds avoiding wind turbines) or a human response to the visual landscape; whatever the receptor, what is crucial is to determine if these effects have some actual impact on the receptor, or on other receptors (perhaps through indirect mechanisms). In terms of Figure 4 the level that most research is at the Environmental Effects level. However for those making decisions and drawing up policy the only real interest is in significant effects (i.e. impacts) that would be deemed as a negative (or perhaps a positive: i.e. enhancing fish stocks through no fishing designation) that a policy or decision can address. Hence individual impacts and also multiple/cumulative impacts are where the knowledge base has to be targeted at. This knowledge base is fed by research and understanding at the higher levels. Currently the majority of research looks at effects rather than impacts. The impacts are often assumed but not demonstrated. Hence there is a critical requirement to identify research streams that follow the right knowledge path.

1.7.1 Risk Identification and Characterisation - source-pathway-receptor

Conceptual models present the hypothesised relationships between the source (S) of a hazard, the pathways (P) by which exposure might occur, and the receptors (R), which are features in a system that is valued. Using the S-P-R approach enables potential links between the components of risk to be visualised and then set out in a tabular form thus summarising the relationships (Pollard, 2008). For example, Table 1 provides an example of identifying and representing the S-P-R linkages for the acute impacts of noise due to underwater construction activities, the combination of a conceptual model and S-P-R method clarifies the system boundaries and articulates the risk, in essence they scope out a problem that has been formulated.

Table 1. An example of identifying and representing the S-P-R linkages regarding the generation of underwater noise during construction of renewable energy devices.

Hazard	Source	Pathway	Receptor
Pile Driving Noise	Construction of renewable energy device	Underwater acoustic transmission (pressure and particle motion)	Sedentary marine species Mobile marine species

Another common model that is used to conceptualise risk is the Drivers-Pressures-State-Impacts-Responses (D-P-S-I-R) model. Using sediment disturbance as an example, a driver is the force (e.g. marine construction) that creates a pressure on the marine environment (e.g. sediment disturbance). The state is the condition of the marine environment (e.g. habitat smothering) while the impacts are the consequences of the activity (e.g. loss of marine biodiversity). Responses are those made by society in response to the impact of a certain activity. Generally more favoured by policy makers the D-P-S-I-R method is similar to that of S-P-R in that they categorise an environmental risk and structure the understanding in an easily accessible and understandable format.

1.7.2 Consequences

Defining thresholds for the level of impact and its probability involves judgments about what levels of risk are acceptable. These judgments require weighing the risk against other factors that are relevant for decision-making (e.g. legal, economic, social) and, in some contexts, may involve consultation with stakeholders. It would therefore be useful if standard thresholds can be established, e.g. the Action Levels for Dredged Material Assessments (Cefas Guidelines). Often, the standard threshold for routine assessment is set at a precautionary level and, when this is exceeded (i.e. anything >Action Level 1 for Dredged Material Assessments), a refined assessment is conducted to characterise the risk more precisely. This is an efficient procedure for targeting assessment resources on cases with potentially unacceptable risk. Sometimes a second, higher threshold is also set, above which action to reduce risk is indicated without the need for further assessment (e.g. Action Level 2 for Dredged Material Assessments).

Hazards which lack standard thresholds require consideration on a case by case basis. Given the complex judgments that may be involved in setting a threshold for acceptable risk, it may be practical to set the initial threshold at a precautionary level. This might, for example, be a short recovery time at the site of the activity and no detectable effect outside the site, but still requires careful consideration and maybe consultation with decision-makers, experts and local stakeholder. If initial assessment shows that this precautionary threshold is exceeded, then a refined assessment will be required to assess the risk and its acceptability more precisely. It should be highlighted that in some cases it may not be possible or even desirable, to set a threshold owing to lack of data and understanding as it may prove to be too precautionary and therefore hamper activities. This is certainly a common opinion that is expressed by the MRE industry. In these cases the risk assessment will have very high uncertainty and the response should be to improve data available on which to make the assessment of environmental risk.

1.7.3 Probability

What sets risk assessment apart from Environmental Impact Assessments is the concept of likelihood of occurrence, or the probability that a hazard may be realised. In general, if a hazard will not be realised then there is no risk, regardless the scale of potential impacts. The important point here is properly identifying the hazard and the receptor and defining the source and pathway of the hazard impacting on the receptor.

If possible it is important to assess probability with some degree of confidence, however for many complex or emerging issues there are a lack of data to support such an assessment. Without sufficient credibility a risk assessment may be undermined, even if the probability presented appears to be wholly subjective or, conversely, indefensibly precise.

Using data to define probabilities for discrete and rare events is more difficult than for those that can be readily observed. Generally, risk assessors consider three aspects of the likelihood of consequences being realised.

a) The probability of an event occurring.

b) The probability of exposure to the hazard.

c) The probability of the receptors being affected by the hazard.

The probability of the occurrence of an event may be expressed numerically, for example 0 to 1 (representing the range impossible to certain), as a distribution or for uncertain events qualitatively using ‘what if’ (Regan *et al.*, 2003).

For hazards where there is no possibility of exposure to the hazard then there can be no risk. Therefore, probability becomes the likelihood of exposure to a hazard rather than simply the realisation of a hazard. It then becomes valuable to define the source-pathway–receptor links for these hazards. For example, consider the leaching of TriButyl Tin (TBT) from anti-fouling paint on an offshore structure, or the discharge of waste water in a long-shore outfall. In these cases, the temporal and spatial distribution of hazardous agents from the point of release to relevant receptors must be characterised (in other words assess the relevance of the "pathway"). It may be that degradation and dispersion processes along the pathway reduce the concentration of the hazardous agent such that it is unlikely to damage or significantly impact on the receptor. A wide variety of modelling methods to determine environmental dispersion exist to characterise contaminant transport, which are sometimes used to estimate the likely 'dose' at the receptor.

Should exposure to a hazard occur, the risk analyst is then interested in the likelihood of harm that may result from that exposure. The likelihood of harm depends on a combination of the sensitivity of the receptor to the hazard and on the amount or extent of exposure. For chemicals and pathogens, this is often simplified in terms of a dose–response relationship, which relates exposure to the expected magnitude of harm for certain receptor types. When considering some of the stressor-receptor pairings related to MRE devices (MRED) then dose-response may not be so easily defined owing to lack of knowledge, hence uncertainty is high.

1.8 Factors affecting risk

A number of factors can affect the risk. One way to formalise these factors is by developing a conceptual model. The level of detail required in the conceptual model will differ depending on the complexity of the risk assessment. A conceptual model can be highly specific and concentrate on just one facet of a large project, or it may attempt to capture all risks in one model. For example, when considering a single renewable energy device affecting a single receptor, the conceptual model will most likely be simple; in the case of an array of renewable energy devices affecting multiple receptors (e.g. wind farm or tidal array affecting migratory paths of organisms) the model may be more complex. Conceptual models work particularly well for physical features present in environmental settings.

It is desirable, wherever possible, that clarity is sought at this stage about the purpose of the assessment, any legislative and regulatory requirements, boundaries of ownership and any international issues.

It is also important to be aware of wider issues that could affect the risks. For example, factors such as energy policy, technology development and social acceptance can control the scale, location and type of renewable energy build. If influencing factors are not considered at an early stage, difficulties may arise in conducting meaningful risk assessment and selecting practical options for management.

1.8.1 Risk at different scales

Risks will vary in their character of harm. These variations may be temporal or spatial however it is the scale of the harm that dictates to the greatest extent how risk management might approach the issue.

Once the problem has been framed (protection goals agreed, hazards associated with an activity identified, along with the possible receptors, including where they are and when they might be affected) and a conceptual model of system behaviour developed, a number of choices need to be made about how to assess the risks. Assessments can be both qualitative and quantitative. Both approaches have advantages and disadvantages. Ultimately, the approach taken may depend on the amount, type and quality of data available.

The assessment plan outlines the approach selected for risk assessment and any data requirements. It should also consider which assessment endpoints are most relevant, such as a quantitative measurement of the abundance of a sensitive marine species in relation to an environmental stress. Levels of change might be expressed quantitatively (e.g. as an estimated % change) or on an ordinal scale (e.g. low, medium, high). More generally, measures with multiple dimensions are required to characterise the consequences. For example, the spatial extent and duration of the change in abundance of organisms. Again, each dimension may be expressed quantitatively or on an ordinal scale. Any specific consequence can then be characterised on each dimension (e.g. high change with medium spatial extent and short duration). In some cases it may be relevant to characterise change in the abundance of multiple species, each with a different spatial extent and duration. In practice, however, it is more common to choose one or a small number of measures of impact (end points) with one combination of spatial and temporal scale (e.g. local, short term change in abundance of one key indicator species).

1.9 General issues in risk assessment

Uncertainty is arguably the greatest issue for all risk assessments. Uncertainty may manifest as a lack of knowledge, an inability to control an outcome or a lack of understanding of the effectiveness of particular management strategies.

The uncertainties that exist are either epistemic, which is brought about by a lack of knowledge; or aleatory, which occurs because of the inherent variability present in any natural system.

Identifying and acknowledging the source of the uncertainties is an important first step towards quantifying them. Whilst only epistemic uncertainties can be reduced, clear recognition of all uncertainties will improve the quality of the risk assessment.

Uncertainty can arise from incomplete data (e.g. data may be lacking on the temporal variability of underwater noise, or the cumulative effects of many pile-driving events), poorly specified or erroneous data (e.g. measurement errors or mistakes in recorded units), sampling error (e.g. arising from a small sample size), sampling bias (e.g. in the times when data were collected), or poorly extrapolated (e.g. data from other noise making activities that may be significantly different to the noise made through pile-driving).

There are multiple ways to dealing with uncertainty within environmental risk assessments. These include the collection of more specific data to enhance the knowledge and understanding, thereby contributing to reduced uncertainty. There may be situations where further research data can address sparse or imprecise data sets which will reduce uncertainty (Aven & Steen, 2010). Additional benefits arising from further research is greater certainty when using modelling and subsequently decision making.

Uncertainty factors (also called safety factors) can also be used to take account of uncertainty (OECD, 1995). They attach a factor-based correction to the data being used which is designed to reflect the level of uncertainty present. Some uncertainty factors are used to take account of extrapolation uncertainties, for example, the standard uncertainty factors used to take account of species differences in toxicology and ecotoxicology.

Sensitivity analysis, as used in mathematical modelling, determines the sensitivity of a model output to the parameters within the model. These parameters are usually based on known variables that define the subject being studied. If small changes in a parameter result in large changes in the output, the model is said to be sensitive to that parameter. Conversely, if the model output remains similar when an input is changed, the model is said to be insensitive. Sensitivity analysis can be used in risk assessment for understanding the sensitivity of predicted risk to potentially influential factors. If the risk is insensitive to a given factor then uncertainty about the value of this factor is not important. On the other hand if the model is sensitive to this parameter, it is worth investing significant effort to reduce epistemic uncertainty (e.g. about the value of a parameter). Sensitivity analysis can, therefore, highlight the aspects of the system that contribute most to the risk (Saltelli *et al.*, 2008) and help to identify the areas that require further research. Depending on the degree of control one has over the system, these features may then become priorities for management. A useful overview and qualitative comparisons of available sensitivity analysis methods, including mathematical, statistical and graphical methods, is provided in Fray & Patil (2002).

1.9.1 Direction, strength and weight of evidence

Rarely does sufficient evidence exist to fully support all hazards described in a conceptual model. Conclusions therefore rely on different sources of data and it becomes the responsibility of the risk assessor to consider the direction (does the evidence offer support for or against the plausibility of the relationship between cause and effect?), strength (how confident is the assessor that individual lines of evidence support the plausibility of the causal relationship?) and weight (given other possible competing theories, what is the overall balance of evidence?) of the evidence. The conditions needed to establish a causal relationship between two items can be based on (Bradford-Hill, 1965):

- *analogy* – if a similar agent exerts similar effects, it is more likely for the association to be causal;
- *consistency* – the more studies finding similar results, the more likely it is to be causal;
- *coherence* – a coherence between empirical and laboratory evidence suggests more causality, however the absence of coherence cannot nullify the findings;
- *experimental evidence* – an association from experiments may be enough to show causation;
- *strength* – the stronger the association, the stronger the likelihood of causation;

- *specificity* – the more specific the association between a cause and effect is, the larger the probability of a causal relationship;
- *plausibility* – a plausible mechanism between cause and effect is helpful, but may be limited by current knowledge;
- *temporality* – the cause must precede the effect; and
- *biological gradient* – greater exposure should generally lead to greater incidence, frequency or magnitude of the effect, i.e. dose-response.

The use of different lines of evidence raises the issue of how best to assess their degree of independence and the quality of the underlying content. Estimates of risk are fundamentally determined by the origin, quality and provenance of the evidence that supports them (Suter & Cormier, 2011) and understanding how best to assess the value of the evidence becomes important.

An example of measures used to assess the quality of scientific evidence include the pedigree analysis approach, which is part of the NUSAP (numbers unit spread assessment pedigree) system for uncertainty assessment (van der Sluijs *et al*., 2005).
In addition, there is an argument for explicitly addressing the question of data availability and quality (EFSA, 2009). Table 2 suggests a generic means of scoring the data available, which in turn can provide a measure of epistemic uncertainty, i.e. when uncertainty is brought about by a lack of knowledge.

Table 2. Scoring system for addressing the question of data availability regarding epistemic uncertainty (taken from EFSA, 2009).

Score	Description
Low (1)	• Solid and complete data available; strong evidence in multiple references with most authors coming to the same conclusions; or • considerable and consistent experience from field observations.
Medium (2)	• Some or only incomplete data available; evidence provided in small number of references; authors' or experts' conclusions vary; or • limited evidence from field observations; or • solid and complete data available from other species which can be extrapolated to the species being considered.
High (3)	• Scarce or no data available; evidence provided in unpublished reports; or • few observations and personal communications; and/or • authors' or experts' conclusions vary considerably.

Assessing the quality, reliability and relevance of experimental or empirical evidence, and the underpinning conceptual model, is an important part of risk assessment. It is necessary both when considering a single line of evidence and when multiple sources are used.

1.9.2 Expert elicitation

Expert judgement is an important component for all risk assessments. It can provide value in ensuring the accuracy of the conceptual model, for choosing representative data from multiple sources, or for evaluating the plausibility of specific risk scenarios. For instance, where data are lacking, expert judgment becomes invaluable for estimating risk. Judgement can be used informally (e.g. a single expert estimating model parameters) or it may be more formal (e.g. multiple experts using a formal structured procedure such as an expert opinion workshop, questionnaire or DELPHI method).

Examples of formalised expert elicitation exist in the hydroelectric dam risk assessment and radiological waste literature (e.g. Rashad & Hammad, 2000). These are highly contentious issues where the consequence of a poor decision is substantial and therefore these industries have developed highly structured approaches for the selection and use of evidence. These formal elicitations gather experts perceived level of risk relevant to particular risk scenarios. For a comprehensive review of the many different approaches used for expert elicitation see O'Hagan *et al*. (2006).

Expert judgement methods may be used to elicit: a) distributions; b) preferences, rankings or pair comparisons; c) qualitative information (links, interrelationships); d) point values (most likely, minimum, maximum, quantiles); or e) probabilities. The following steps describe how probabilities (of defined events) can be elicited (after Vanrolleghem, 2010):

1) identify and select experts;
2) explain the nature of the problem and the elicitation procedure to the experts;
3) chose a scale and unit familiar to the experts for defining the quantity;
4) discuss and document the sources of current knowledge and evidence, its relevance to the problem, its strengths and weaknesses;
5) elicit and assess extremes of the distribution;
6) elicit and specify the distribution;
7) confirm that the distribution represents the experts' beliefs; and decide if the distributions elicited from different experts should be aggregated and, if so, how (Bedford & Cooke, 2001)

Risk assessments based on expert knowledge are however dependent on the capacity of the expert to provide appropriate judgement. This relates to how the data are collected to determine the magnitude of the expert opinion and ensuring the experts understand the events being assessed. Vague guidance on how the risk assessment is to be developed and expert time availability are important to how the experts will provide their input (Neale, 1998).

1.10 Risk Assessment Methods

Risk assessment approaches can be broadly categorised as qualitative, quantitative, and semi-quantitative. A vast array of tools and techniques exist. Qualitative methods include S-P-R analysis, ranking methods and qualitative event trees. These methods can be simple and cost-effective to execute, but are inevitably more subjective than quantitative methods. Qualitative methods may also be subject to ambiguity as there is no way to know how similar one person's interpretation of a risk is to another's. This makes qualitative measures less useful for characterising the absolute magnitude of a risk but valuable for assessing relative risk and for establishing a sound logic for analysing issues that suffer from lack of data.

Semi-quantitative methods include ranking, scoring, indexing, causal criteria and logic-based systems. These methods often offer a consistent and systematic approach when risk prioritisation is required. However, these methods are ultimately also subjective.

Quantitative methods include quantitative exposure assessments, quantitative fault-tree analysis, simple deterministic risk estimation and Monte Carlo simulation techniques. These can be based on inputs derived by data or by expert judgement.

As with all tools and techniques, the assumptions used and a justification of the data applied, and its reliability, needs to be communicated with the assessment. Often the design and operation of the approach influences the outcome of the analysis and so there is a continued need to ensure judgements about risk have a scientific evidence base.

1.11 Modelling the Risks of a System

In order to develop a true representation of the risks present within a system (here the interaction between MRED and the marine environment) requires information, usually from the available literature and expert opinion which then defines the system components and the pathways linking stressor and receptor – known as the system behaviour. However if information is poor or biased then it is very challenging to define accurately the systems and the linkages. This then leads to poor assessment of the system.

Expert based models and scenario based models are the current way of dealing with risk assessment. They follow a top-down approach and as such are open to prejudices as end point consequences are postulated and then the mechanisms by which these consequences may be reached are then laid out (Freeze *et al.,* 2005).

Expert based models usually scan the entire system but can suffer from not always specifying or considering pathways of hazard exposure to a great degree of detail. They are useful for short term overviews where some action is required to assess a given situation (usually owing to lack of data) but are limited in the way they provide answers to the requirement for risk assessment (Defra, 2011); this could be played out with MRED.

Scenario models go into much greater depth as data are specifically collected and applied to particular stressor-receptor relationships (e.g. bird or cetacean species collision modelling). The models are detailed, but are resource and time consuming and their wider applicability is not apparent. Hence the number of risk pathways is restricted owing to the heavy data requirement and time that needs to be allocated, so they fail to produce analyses of the whole system. The result is that the focus will be on particular species which will be driven by the risk assessors and/or experts. This can then lead to biases of the risks identified by expert based assessments and the selection of pathways to risk exposure suggested by scenario based assessments. Hence, conventional models of risk often fail to identify events driving exposure to hazards that are outside the concerns of those analysing the risk and experts supporting the assessments.

A systemic and integrated modelling approach aims to consider all factors influencing the risks regardless of the preconceived contribution to the environmental impact. Hence a bottom up approach can ensure that the system behaviour emerges from pathways of exposure to hazards assessed. This leads to the suggestion for using systemic models to develop analyses of the MRED environmental system which are minimally influenced by prior beliefs and motivational biases (Dangerfield & Morris, 1992; Grundke, 2010). A systemic approach can detect drivers of hazard exposure that have a significant effect on the system but which were previously overlooked. Also, this provides the potential to identify how and where to intervene in a system. A further advantage of systemic models is they minimise the influence of prior knowledge and biases in the outputs produced, allowing them to detect risks and hazards previously overlooked.

1.12 Futures

The utility of “futures” research methods – most especially scenario building – as a complement to the development of a conceptual risk assessment model is now beginning to be recognised. Scenarios are plausible descriptions of how the future may develop. They enable envisioning of alternative evolutions of whole systems rather than individual entities. Scenarios are based on a coherent and internally consistent set of assumptions about key relationships and driving forces concerning the issue(s) being researched. Scenario construction can be used to explore future risks, opportunities, strengths and weaknesses of current strategy and policy approaches, and to provide a long-term vision independent of political timetables. Done well, scenario building exercises can help to identify critical decision points and strategic options, but also develop a clear context for future strategies and polices (Finger *et al.*, 2007).

1.13 Risk Assessment Summary

After problem framing and conceptual model development (including hazard identification), risk assessment involves four main stages: (1) assessing the potential consequences (hazard characterisation); (2) assessing exposure level i.e. the probability that a hazard will be realised (including relevance of pathways); (3) characterising the risk (i.e. combining hazard and exposure) and (4) evaluating uncertainty. The output of this structured process informs a judgement about the risks posed by an activity and their significance. The evidence required to provide judgements and subsequently to characterise a risk in this way can be qualitative, quantitative, or semi-quantitative. In all cases, for each problem, appropriate tools must be employed. Where data are missing or inaccessible, formal elicitation can help to provide expert judgement. Uncertainty is always present at each stage of an environmental risk assessment. Various techniques exist to analyse, understand and employ these uncertainties.

2 THE CURRENT RISK BASELINE FOR UK MARINE RENEWABLE ENERGY

2.1 Review and synthesis of information on existing risk methods and uncertainty assessment

The first section of this report has outlined the topic of risk assessment, presented relevant terminology and set out a generic framework with associated activities that are required to be undertaken to meet the requirements of a risk assessment according to best available practice. With this general understanding in mind we reviewed current practice within the MRE sector to determine what methods were currently used and to assess the current status of risk assessment practice with the sector.

2.2 Methods used and Subject Scope

Literature searches were conducted to identify research on offshore wind, wave and tidal energy (or derivative terms) cross referenced with the following key words:

- Risk/risk framework/risk management
- Uncertainty/certainty/confidence
- Environmental assessment/impacts;
    - Collision/avoidance
    - EMF
    - Noise
- Strategic environmental assessment/impacts
- Socio-economic assessment/impacts
- Legislation/Policy/planning
    - Marine Strategy Framework Directive
    - Marine Act
- Marine Ecology:
    - Birds
    - Mammals
    - Fish and benthic
    - General
- Physical impacts:
    - Scour
    - Coastal processes
    - Hydrodynamics
    - Sediment transport

Information Resources

Searches were carried out in the following areas:

- Web of Science databases - Science Citation Index (SCI-EXPANDED), Social Science Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI) and Conference Proceedings Citation Index – Science (CPCI-S).
- SciVerse SCOPUS/ScienceDirect - Physical Sciences, Social Sciences and Life Sciences subject areas.
- Online information sources including the web sites of UK, EU and US government agencies, environmental consultancies, and other relevant bodies *e.g. COWRIE, RenewableUK,*
- NERC Marine Renewable Energy knowledge exchange programme's website.

The review focussed on UK based material unless there was an obvious gap, in these cases the search was widened to the international community. The material reviewed was deemed the most appropriate, but does not represent all available information on the topic. The outputs of the literature searching and reviewing are summarised in Table 3 with the detail for each category found in the appendices indicated.

Table 3. Summary of the sources of information for each main topic area reviewed accessed through the literature searches.

Subject Specific Category	Country	Regulator	Statutory Guidance	Non-Statutory Guidance	Industry	Journals & Proceedings	Appendix
Risk and Marine Renewable Energy (MRE)	UK, USA	9	5	6	5	32	A
Environmental and Marine Ecological Impacts and MRE	UK, EU USA	17	16	22	9	101	B
Physical impacts and MRE	UK	7	-	3	-	26	C
Environmental Impact Assessment guidance and MRE	UK, EU, USA	9	-	-	-	5	D
Socio-economic impacts and MRE	UK	3	-	1	-	32	E
Strategic Environmental Assessment and MRE	UK	4	3	-	-	2	F
Policy, planning and MRE, and relevant legislation	UK, USA	14	8	-	-	16	G – including reference for legislation
Uncertainty and MRE	EU	-	-	1	-	5	H

2.3 Review results

In terms of risk assessments used for marine renewable energy the overriding picture was that risk assessments were sparse and generally supplemented or substituted with the outputs of the environmental impact assessment (EIA) process. As highlighted in Section 1 EIAs and Risk Assessments are not the same, they are separated by the fact that Risk Assessments identify a hazard. However, as the impacts of MRED on the marine environment appear to have largely been assessed using EIA we have reviewed the outputs here to form a basis for determining potential risk of MRED to marine receptors.

The Environmental Impact Assessment Directive 85/337/EEC states that an EIA is to be carried out for certain offshore projects (e.g. “installations for the harnessing of wind power for energy production (wind farms)” (OSPAR, 2008). The main objective of the EIA is to provide an approval authority the evidence base for determining the impacts a project may have on the environment. The outputs of an EIA are reported in an Environmental Statement (ES), which also doubles to assist the developer in determining the preferred construction method and for informing the public.

An EIA considers the effects an activity may have on the environment, the spatial and temporal variability of those effects, the cumulative nature of the effects and the sensitivity of the environment to the threat. An EIA is “...a means of drawing together, in a systematic way, an assessment of a project’s likely significant environmental effects.” (Cefas, 2004). Procedural in nature, the EIA is a systematic assessment of all environmental effects derived from a specific activity.

Numerous guidance documents for conducting EIAs for marine renewable energy development exist (e.g. Cefas, 2004; MMO, 2011; SNH, 2012). These documents are prescriptive and systematic intended to provide developers and decision makers a comprehensive understanding of potential impacts. However, of the guidance reviewed, few suggest an assessment of risk when considering strategies for mitigating impacts. The EIA does not provide an understanding of the risks derived from a particular activity. Risk is defined as the likelihood of an adverse effect or harm to materialise and this requires an explicit statement of likelihood. EIAs do not consider this dimension of risk and therefore provide only a comprehensive list of potential impacts. Without explicit assessment of likelihood all effects appear important and equally likely to happen and therefore merit similar management strategies. For projects constrained by tight budgets this approach to environmental management may quickly become cost prohibitive. Furthermore, reality may reveal that only a few impacts are likely to be realised and those that do may not be intuitively obvious.

Of the EIA guidance that does provide an assessment of likelihood it is often insufficient to inform a complete assessment of risk. Defra Offshore Wind Farm Guidance note for EIA provides the rational for a comprehensive EIA but does not provide the suggestion of how to expand an EIA to consider risk. The Nature Conservation Guidance on Offshore Wind farm Development uses likelihood to provide an initial coarse screening of the impacts. For example, for a particular offshore activity if the likelihood that migratory birds will use the area of concern for feeding, breeding or as a nursery area an investigation of impact will be carried out. If birds will not use the area the process of investigation is terminated and the operator is asked to follow best practice and monitor. This crude screening stage helps guide resource towards assessing issues that pose actual threat but is not sufficient in differentiating the level of risk posed by each hazard.

Another challenge is in defining or characterising the hazard in question. Some guidance suggests that the EIA should consider the likely worst case variations within a project. These may then be assessed according to significance and then prioritised (Advice Note 9 – Using the Rochdale Envelope). A similar approach has been suggested elsewhere (EMEC, 2005). However, assessing and prioritising worst case scenarios with no concept of their likelihood to occur may lead to disproportionate mitigation. For projects reliant on cost-benefit ratios, disproportionate mitigation measures may tilt the economic balance towards unfeasibility.

Most EIA guidance provides a structured approach for identifying, investigating and assessing impacts. In this sense they are not unlike risk frameworks which provide similar clarity and rigour to investigating an issue. In general, risk frameworks provide a logical sequence of steps that enable users to fully comprehend the extent of risk posed by an activity. This is done in a repeatable, transparent manner and enables decision makers to address those issues that pose the greatest unmanaged risk. Therein lies the key point, which is to identify the issues that pose the greatest risk or threat, rather than manage all issues regardless the likelihood of their occurrence.

2.4 Risk and the Decision Maker

Site specific or sector specific EIAs help progress the discussion of risk but may not provide suitable information for the decision maker. For decision makers it is important to understand the broad context of risk, how activities impact the environment, society and the economy and how likely it is to occur. This raises the important issue of audience, who is asking for the assessment and how are they using the outputs.

From the marine renewable energy operators perspective EIAs are mandatory and fill the role of ensuring all impacts are made explicit. Provided the operators address the guidance for completing the EIA it is unlikely they will expand the assessment, principally on the grounds of limited resources. They also will not seek to make a risk assessment for unknown risks or those with such high uncertainty that there is no formal guidance. From the regulator or decision makers perspective there is a desire to understand the broad view of an activity. This requires a consideration of the risks an activity poses to not only the environment but to society and the economy as well. This additional information enables prioritisation of risk and an assessment of options for mitigating risks in as cost effective a manner as possible. Such a holistic approach ensures a shared availability of information (between industry and government)

In terms of MRED risk assessment, EIAs are limited in the following ways:

- Provide only a partial assessment of impact (i.e. environmental impact), ignoring consideration of impacts to human health and well-being or the economy
- Do not provide an explicit statement of likelihood of occurrence, which limits the capacity of the EIA to inform risk comparison
- Do not provide a common basis (i.e. risk) for conducting prioritisation or options appraisal
- Do not adequately address the needs of the decision maker who require investigation of the ‘so what’ issue; an activity may have an impact but how likely is that impact to be realised?

An integrated approach to understanding the full suite of risks posed by an offshore activity is necessary. This will ensure the same information is available for developers, local authorities and regulators thus enabling risk informed and transparent decision processes across the sector. An integrated framework would be a first step towards improving decisions about risk and benefit.

Through current regulations, organisations are required to provide EIAs, and they are keen to deliver, however the question remains as to whether or not this information is actually useful to decision makers. Hence it is important to consider who the final audience are, how they intend to use the information and what the purpose of the assessment is.

2.5 Defining risk and uncertainty for UK MRE

Based on the review, it appears that currently the UK MRE industry does not possess a clear, well-articulated framework for assessing risk. Current regulation requires that operators complete an EIA, whose outputs are placed in an Environmental Statement (ES). The lack of risk guidance in the sector should not come as a surprise given the regulatory lag many sectors have experienced (e.g. nuclear energy).

Conceptually risk assessment sounds straightforward but generally it is not (see Section 1). The main reasons are data gaps which lead to significant uncertainties about the risk being considered, the likelihood of occurrence of an event or the sensitivity of the receptor (i.e. the potency of the hazard). Within the MRE sector huge data gaps exist which makes the assessment of risk even more difficult.

Table 4 shows an example of a set of quality indicators for scientific evidence, which could be used to frame the current evidence base for MRE sector. Additional measures are offered using the pedigree analysis approach, which is part of the NUSAP (numbers unit spread assessment pedigree) system for uncertainty assessment (van der Sluijs et al., 2005).

Table 4. Example of quality indicators for scientific evidence (after Bowden, 2004 and presented in Defra, 2011).

Indicators of evidence quality

Quality rank	***Theoretical basis***	***Scientific method***	***Auditability***	***Calibration***	***Validation***	***Objectivity***
Very high	*Well established theory*	*Best available practice: large sample; direct measure*	*Well documented trace to data*	*An exact fit to data*	*Independent measurement of sample variable*	*No discernable bias*
High	*Accepted theory; high degree of consensus*	*Accepted reliable method; small sample; direct measure*	*Poor documented but traceable to data*	*Good fit to data*	*Independent measurement of high correlation variable*	*Weak bias*
Moderate	*Accepted theory; low consensus*	*Accepted method; derived or surrogate data; analogue; limited reliability*	*Traceable to data with difficulty*	*Moderately well correlated with data*	*Validation measure not truly independent*	*Moderate bias*
Low	*Preliminary theory*	*Preliminary method of unknown reliability*	*Weak and obscure link to data*	*Weak correlation to data*	*Weak indirect validation*	*Strong bias*
Very low	*Crude speculation*	*No discernable rigour*	*No link back to data*	*No apparent correlation*	*No validation presented*	*Obvious bias*

In addition, there is an argument for explicitly addressing the question of data availability and quality (EFSA, 2009). Table 5 suggests a generic means of scoring the data available, which in turn can provide a measure of epistemic uncertainty, i.e. when uncertainty is brought about by a lack of knowledge.

Table 5. Scoring system for addressing the question of data availability regarding epistemic uncertainty (taken from Defra, 2011 and originally from EFSA, 2009).

Score	***Description***
Low (1)	*• Solid and complete data available; strong evidence in multiple references with most authors coming to the same conclusions; or • considerable and consistent experience from field observations.*
Medium (2)	*• Some or only incomplete data available; evidence provided in small number of references; authors' or experts' conclusions vary; or • limited evidence from field observations; or • solid and complete data available from other species which can be extrapolated to the species being considered.*
High (3)	*• Scarce or no data available; evidence provided in unpublished reports; or • few observations and personal communications; and/or • authors' or experts' conclusions vary considerably.*

Assessing the quality, reliability and relevance of experimental or empirical evidence, and the underpinning conceptual model, is an important part of risk assessment and related management decision making. It is as necessary when considering a single line of evidence as it is when multiple sources are used. Likewise, the appropriateness of the techniques/methods used in the risk assessment should be reviewed by internal or external risk assessors, or other experts who can comment on the data used within the risk assessment and the validity of the results. A helpful review of the use of multiple conceptual models, assessment of their pedigree and reflection on their how reasonable they are is provided in Refsgaard *et al.*, (2006).

2.6 Marine Renewable Energy Environmental Stressors and Receptors

There are advantages and disadvantages to the current stressor-receptor knowledge base for MRE. Some of the stressor-receptor relationships appear to be well researched (e.g. offshore wind device effects on birds in relation to collision) whilst others have very little research evidence (e.g. effects of cables on benthic and demersal species). The greater the knowledge we have on stressors then the more confident we can be about the type of effects we might expect to find (e.g. sound intensity levels relating to piling causing injury or disturbance to organisms). We can then look for receptors that are considered vulnerable or likely to respond to the stressor. However, determining this is highly dependent on our knowledge of which organisms or processes are vulnerable to change. Hence for lesser known stressors (e.g. EMF or noise) we know little about them and even less about what organisms may/may not respond. The result is that uncertainty levels are very high.

The biggest problem is that the knowledge base may be viewed by some as too much of a hurdle to overcome owing to the lack of knowledge. Expert judgement is relied on to deal with stressor-receptor combinations where there is little knowledge base. The expert knowledge is not always consistent and is associated with high uncertainty.

Expert judgement needs to have some scientific basis for policy and decision makers hence there is either the ‘precautionary approach’ or the ‘ignore because there is no knowledge approach’. Neither is suitable in terms of meeting national or international legislative requirements or minimising or mitigating environmental impacts. The result is that the research focus moves to those organisms and processes that have greater information (and by association greater certainty).

The research evidence-knowledge spiral needs to be addressed if knowledge is going to advance in a balanced way across all stressors and receptors and therefore reduce uncertainty. This has to be the direction of environmental research relating to the interactions between MRE and the marine environment receptors in order to improve the assessment of risk and therefore provide the evidence base required by policy and decision makers.

2.7 Different perspectives - policy and regulation

In relation to policy and decision making, a key element of the project has involved reviewing current marine licensing, planning and policy processes to determine how they account for environmental risks and uncertainties, and to enable the identification of areas where further research may prove beneficial. One immediately apparent issue arising from the review is that devolution has resulted in a wide array of organisations holding responsibility for the management of the marine environment and the licensing of marine renewable energy developments in the UK (Table 6). Despite this, commonalities in approaches and challenges exist, with much of the underlying legislation, such as the Marine and Coastal Access Act (MCAA) and the Marine Scotland Act, being similar. Hence, this brief review attempts to identify common generic issues relating to the management of uncertain environmental risks in the UK, and provides examples for illustrative purposes.

Table 6. Responsibilities for marine licensing in relation to marine renewable energy developments Modified from Scottish Government (2011).

Organisation(s)	**Licensing area/responsibilities**
Marine Management Organisation	English inshore and offshore waters Welsh and Irish offshore waters Non-fisheries harbours orders in Welsh inshore waters
Marine Scotland	Scottish inshore and offshore waters
Welsh Assembly Government	Welsh inshore waters Issue of marine licences for renewables projects over 100MW
Department of Environment Northern Ireland and Northern Ireland Environment Agency	Northern Irish inshore waters

Planning Inspectorate	Consenting for renewables projects over 100MW in England and Wales and issue of development consent order

Marine Activities, Environmental Risks and Uncertainties
Marine activities have the potential to cause detrimental impacts on the marine environment, and as such, many activities require a marine licence before they can be undertaken (MMO, 2011a). When determining licensing applications, licensing authorities must not only consider the need to protect the environment and human health, but the potential for the proposed activity to interfere with legitimate uses of the sea and any other matters that may be relevant (MMO, 2011b). In addition to marine licensing, activities may also require a formal Environmental Impact Assessment (EIA), whilst those projects that are either within or adjacent to a Natura site, designated under the Habitats and Birds Directives may also require a Habitats Regulation Appraisal (HRA) (MMO, 2011b).

The review has identified that whilst current marine licensing, planning and policy processes consider uncertainties, the current development of the marine renewable energy industry poses a number of potential challenges. These are outlined below.

Marine Licensing
As introduced above, the marine licensing system evaluates the potential and adverse impacts of any proposed activity, with licensing authority Case Officers considering the project's characteristics, the nature and purpose of the regulated activities and the environmental features likely to be affected by the project (MMO, 2011a). Significantly, for the management of environmental risks and uncertainties, an evidence-based approach to both marine licensing and enforcement processes is advocated, and highlights:

- The use of a risk-based approach, allowing for uncertainty and recognising the need to use sound science responsibly as set out in the high level objectives for the marine area (including the precautionary principle).
- The need to be sensitive to any potential impacts on sites of particular significance (for example designated sites).
- The mitigation of negative impacts throughout the development's lifecycle. This includes the potential use of licensing conditions or alternative sites or designs to mitigate effects (Defra, 2011c).

The rapid expansion of the marine renewable energy industry, involving the deployment of new types of technology and marine activities with uncertain environmental impacts, potentially poses challenges for both licensing authorities and licence applicants alike. However, the MMO notes that the licensing process considers *'The extent to which the applicant may reasonably be required to compile the information, having regard to current knowledge and methods of assessment* (MMO, 2011a). In addition, applicants are able to seek a scoping opinion, and licensing authorities, such as the MMO and Marine Scotland both provide and promote the use of their pre-application services. Indeed, there is an expectation that organisations proposing complex projects will use such processes to resolve issues prior to the submission of a formal licensing application (MMO, 2011a). As such, the MMO highlight that *'the process of resolving issues raised by consultees and the public is often an iterative process*' (MMO, 2012).

Whilst pre-application engagement is valuable, situations may exist where uncertainties continue to pose difficulties. In such situations a number of possible options are available to licensing authorities. These include the use of enquiries, enabling evidence relating to a licence application to be heard from all parties, internal reviews, where applicants disagree with a decision or licensing conditions, or even appeals (MMO, 2012). Of particular note for the development of the marine renewable energy industry are the Marine and Coastal Access Act (2009) and Marine (Scotland) Act (2010), which allows inquiries to be held:
'In the case of large, complex or potentially controversial projects Scottish Ministers may cause an inquiry to be held in connection with a Marine Licence Application. Factors influencing their decision include projects using novel technologies'.
(Marine Scotland, 2012a, p.16).

However, licensing authorities, such as Marine Scotland emphasise the importance of engagement and discussions between them, stakeholders and licence applicants to resolve issues. Furthermore, it also notes that the *'the existence of marine planning documents, including marine plans, should also reduce the likelihood of appeals'* (Marine Scotland, 2012a).

Licensing Conditions and Monitoring
The ability to use licensing conditions to mitigate uncertain environmental risks is available to licensing authorities and they have been applied in the licensing of marine renewable energy developments. For example, when licensing a marine current turbine in Strangford Lough, the Department of Environment Northern Ireland included licensing conditions for the recording and interpretation of sound information to support improved understanding of the possible effect of turbine noise on marine mammals (DOENI, 2011). In addition to licensing consents, post consent validation and monitoring returns (e.g. marine mammal reports) can also be used by licensing authorities to monitor the potential impacts of marine renewable energy developments where uncertainties exist (MMO, 2011a).

Survey, deploy and monitor policy (Scotland)
In Scotland, a draft survey, deploy and monitor policy has recently been published by Marine Scotland (Marine Scotland, 2012b). The draft policy outlines a *'risk-based approach'* for assessing wave and tidal energy licensing applications that considers three areas - the environmental sensitivity, scale, and device/technology risk associated with the proposed development (Marine Scotland, 2012b). Marine Scotland envisages that the draft policy, which considers the uncertainties associated with new wave and tidal technologies, will result in more proportional and appropriate licensing based on the characteristics of the proposed development and the adoption of a precautionary approach (Marine Scotland, 2012b).

Whilst it is recognised that the policy is currently only in draft form there are a number of limitations with the approach outlined by Marine Scotland. Such limitations are worth highlighting because they potentially retain the risk of subjectivity affecting licensing processes. They include:

- The draft policy document lacks a clear definition of risk.
- The assessment approach is impact rather than risk-based because it fails to consider the potential consequences of hazards combined with their likelihood.
- The assessment procedure aggregates scores into a single overall mean score.
- Clearly defined classifications are lacking making it difficult to determine what high, medium or low environmental sensitivity or risk, for example, refers to.
- The methodology used to produce the environmental sensitivity maps is unclear.

- A one-size-fits all approach may be difficult to utilise in practice due to the complexity of the types of projects and technologies being assessed (e.g. novel technologies and site specific risks).
- The resulting risk management options are vague.

Enforcement

Whilst active engagement between marine licence applicants and licensing authorities, and the use of licensing conditions are clearly sensible approaches to adopt, licensing authorities also have the powers to use statutory notices *'where a person is in breach of their licence, and/or where there is a risk that their activity or development is causing harm to the environment or human health, or interferes with legitimate uses of the sea (e.g. navigational interference)'* (Defra, 2011a). Indeed, as presented in Table 7, a number of enforcement notices are available that could be applied in relation to the management of environmental risks and uncertainties. Significantly, for marine renewable energy development, which is associated with uncertainties, Defra highlights that the MMO may vary, suspend or revoke a marine licence granted by it only in certain circumstances including *'because of a change in circumstances or increased scientific knowledge relating to the environment or human health'* (Defra, 2011b).

Table 7. Types of licence enforcement notices available to licencing bodies. Modified from Defra (2011a).

Type	Notice	Notes
Enforcement notice	**Compliance notice**	Can be used in less serious situations to compel a person to come back into compliance.
	Remediation notice	May require a person to take specific steps to put right or compensate for any harm they may have caused.
	Stop notice	An emergency notice which can be used to stop seriously harmful activities urgently, including before the harm is caused.
	Emergency safety notice	Can be used to compel a person to make safe a serious navigational safety hazard.
Notices to change the status of enforcement notices	**Revocation notice**	May be used for the withdrawal of a compliance, remediation, stop or emergency safety notice that has already been served.
	Variation notice	Can be used to extend the period in an existing compliance, remediation, stop or emergency safety

Notices to change the status of an existing marine licence	**Revocation notice**	Revokes an existing marine licence in specific, limited circumstances which include instances of non- compliance
	Variation notice	Varies the conditions of a marine licence in specific, limited circumstances which include instances of non-compliance
	Suspension notice	Suspends a marine licence for a specified length of time in specific, limited circumstances which include instances of non-compliance.

The MMO (2011a) notes that its enforcement processes will be on line with the Macrory and Hampton Reviews. The Hampton Review outlines a series of key principles to be applied throughout regulatory processes including transparency, accountability, proportionality, consistency and helping to target action on cases where action is needed (MMO, 2011a). Significantly, the reviews also recommend the application of flexible tools, enabling proportionate responses in cases of regulatory non-compliance (MMO, 2011a). Hence this approach is potentially valuable in those cases where environmental risks and uncertainties result in licensing issues that may necessitate enforcement actions (e.g. mammal collisions triggering stop notices).

Flexibility and Adaptive Management

Marine licensing processes contain mechanisms that potentially allow for flexibility and adaptive management-based approaches in the light of uncertain environmental risks associated with marine renewable energy developments. Examples of such provisions include:

- **Stakeholder concerns in the absence of evidence –** for example, the MMO has processes to address situations where stakeholders raise serious concerns regarding a licence. However, whilst such processes are potentially valuable, the MMO notes that *'concerns will only be taken forward in the absence of substantiating evidence if such concerns could significantly alter the licence decision'* (MMO, 2011a).
- **Licence variations and amendments –** marine licence holders are able to submit variation requests resulting in licence amendments, although such requests commonly require consultation with primary advisors and consultees (MMO, 2011a).
- **Review of active licences –** for example, the MMO annually reviews a sample of high risk licences issued for at least 5 years to check that there are no grounds for varying, suspending or revoking the licence (MMO, 2011a). This review includes the submission of monitoring reports to assess the impacts proposed in the initial application, together with consultation with primary advisors regarding the adequacy of the licence (MMO, 2011a).
- **Consideration of new evidence –** licensing authorities are able to consider the potential implications of new evidence for licences, with the MMO (2011a) noting that:

'If new evidence on a licence either (a) comes to light through the review process; or (b) is submitted to the MMO outside this review process, the MMO will assess whether such evidence would significantly alter the original decision on granting the licence because of any reason given under Section 72(3) of the Marine and Coastal Access Act. The MMO may consult with the Licence Holder and primary advisors on the significance of the new evidence'.

In addition, the MMO (2011a) highlights that within a licence construction window it may by notice vary, suspend or revoke a licence it has granted under the Marine and Coastal Access Act. Significantly, in relation to Marine Renewable Energy developments, situations when this might occur include changes in circumstances relating to the environment or human health, increased scientific knowledge relating to either the environment or human health, or for any other reason deemed relevant (MMO, 2011a).

In addition to marine licensing provisions, marine spatial planning processes also have the potential to enable flexible management of uncertain environmental risks. Examples identified during the review process include:

- **Flexible approaches –** there is a recognition that marine planning may be spatially and temporally prescriptive, requiring both flexible and adaptable approaches and regular review and revision (Defra, 2011c). Significantly, Defra (2011c) note that Marine Plans should not only consider current but future and emerging activities and their impact on the marine environment. In addition, it is recognised that flexible licensing decisions, that may depart from the Marine Plan, may be necessary (Defra, 2011c). Examples of such situations, relevant to the development of Marine Renewable Energy, include:
    - The results from any Habitats Regulations Assessment or EIA undertaken as part of the decision making process, which may reveal information additional to or different from the relevant Plans
    - Dynamism of and/or changes and/or new discoveries within the marine environment
    - Scientific and significant technological advances
    - Appropriate and effective ways to respond to emergency situations (Defra, 2011c).

- **Learning from mistakes –** Defra (2001c) recognise that systems should be in place to enable those involved in marine planning to learn from mistakes. In particular, they note that problems should be documented and assessed to enable them to be mitigated during the next round of plan-making (Defra, 2011c).

- **The need for a marine planning evidence base –** in recognition of the changing evidence base Defra highlight the need for a robust and up-to-date evidence base (Defra, 2011c). This includes monitoring and implementation reports, that can be used to review Marine Plan review processes (Defra, 2011c).

- **Monitoring and indicators –** there is awareness that monitoring and indicators have a potentially important role in both the identification and mitigation of adverse effects (Defra, 2011c).

Habitat Regulations and the Precautionary Principle

A key challenge for the development of marine renewable energy developments is that projects or plans may have the potential to affect designated sites such as Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Sites of Special Scientific Interest (SSSIs) and Ramsar sites. Those sites designated as SACs and SPAs (known as Natura sites) under the European Union (EU) Habitats and Birds Directives will require a Habitats Regulations Assessment (HRA) (MMO, 2011a). In cases where the HRA concludes that the project or plan has a Likely Significant Effect (LSE) on a Natura site then an Appropriate Assessment (AA) will be required (MMO, 2011a). Other designations, such as SSSIs may require the development to have consent and permissions potentially with conditions regarding the local environment.

The HRA process poses a number of significant challenges for marine renewable energy developments. In particular, in cases where the AA assessment is inconclusive, then the precautionary principle is adopted, with the application treated as being likely to have a significant effect (MMO, 2011a). This is clearly an issue for the development of the marine renewable energy industry because the environmental risk uncertainties potentially represent challenges when wishing to determine LSE.

Consultees and Scientific Advice

Many of the marine licensing processes reviewed explicitly include provisions for scientific advice and input from external consultees. For example, in relation to licensing application consultation the MMO states that:

'The MMO may consult any person or body it deems fit, in cases involving any matter in which that person or body has particular interest or expertise. The MCAA does not specify statutory consultees that the MMO must consult before deciding an application. This is to enable all potential consultees to be on equal footing (none are more or less important than others, to ensure that organisations or individuals consulted are relevant to the project' (MMO, 2011a)

Such processes are potentially valuable when organisations such as the Marine Management Organisation and Marine Scotland are faced with making decisions regarding highly uncertain issues. However, whilst the availability of consultation processes should be commended, a number of potential issues are apparent with such practices, particularly when seeking to address uncertain environmental risks. These include:

- **Evidence-based decision-making supported by transparent frameworks –** whilst it is recognised that marine licensing decisions should be based on a robust evidence-base *'drawing on different, identifiable lines of evidence'* (Defra, 2011c), this may not be possible in the case of marine renewable energy technologies for which evidence of impacts may be unavailable or highly uncertain. This potentially poses challenges for licensing authorities that may be tasked with making decisions under uncertainty. It also highlights the importance of transparent frameworks and processes to ensure clarity and evidence-based rather than subjective decision-making.
- **Provision of scientific advice –** whilst Defra highlights the importance of using different lines of evidence, it also notes that *'CEFAS will remain the Secretary of State's and the MMO's main source of scientific advice'* (Defra, 2011b). However, there may be benefits associated with broadening the range of organisations involved in providing scientific advice to organisations involved in marine licensing.

This is particularly important given the complex and interdisciplinary nature of the environmental risks and accompanying uncertainties associated with the development of marine renewable energy developments. Indeed the development of expert panels could prove valuable in future as they would enable a consensus on uncertainties to be formed.

- **The precautionary principle –** in light of uncertainties the precautionary principle may be adopted by default by some organisations involved in the licensing process. One clear example of this is where a Likely Significant Effect on a European Site has been identified, the MMO notes that it will consult the statutory nature conservation body and have due regard to any representations (MMO, 2011). This is potentially of concern because Statutory Nature Conservation Bodies are likely to apply the precautionary principle in those cases where uncertainties exist

2.8 Uncertainty

When considering marine renewable energy there is much about the marine environment that is uncertain. A review of the scientific research associated with marine renewable energy highlights that specific projects are improving the knowledge base but they are limited in scope because they focus on one species and one stressor at a time (Boehlert & Gill, 2010).

A summary of the review for the environmental impact topics of underwater noise, organism collision and Electromagnetic fields (EMF) emitted by subsea cables is shown in Table 8. For studies of marine anthropogenic noise the focus has been on pile driving because of its high intensity and predicted injurious effects on receptor organisms such as cetaceans or fish. Organism collisions (either fatal or injurious) with moving parts of a renewable energy device have also been a specific topic where there has been much research activity.

Table 8 highlights that specific species are the focus for research into environmental impacts and only some of these studies actually assist with providing data applicable to the reduction of uncertainty. The majority of studies have come from the offshore wind sector and tend to be aimed at marine mammals, birds or to a lesser extent fish when considering underwater noise and collision. Interestingly, for the little known environmental effects, such as Electromagnetic Fields (EMF), there has been less research activity and it has been directed towards fish, even though many other taxa have the potential to detect and respond to EMF (Gill *et al.*, 2005; Boehlert & Gill, 2010). The approaches taken for all the environmental impact studies reviewed depend on the organisms and they vary from direct quantification through on site monitoring (Petersen *et al.,* 2006) to modelling the potential effects of a particular hazard (e.g. Wilson *et al.*, 2007, cetacean, bird and fish collision risk models). They all provide some way to help the determination of organisms that could be affected and hence reduce uncertainty. The limitation that exists usually relates to lack of data and they tend to focus on species of conservation importance, because of legislative requirements, or they are in the public eye.

Table 8 indicates that the focus is on marine mammals for noise and birds in relation to collision. Interestingly fishes are the focus for EMF, not because they have particular conservation concern or designation but purely because they are regarded as the most EM-sensitive. This does not mean other organisms should not be considered. Also the basis of the evidence comes mainly from reviews or models (with many assumptions) rather than direct research, hence the uncertainty around this topic is not directly addressed, which renders the evidence base relatively static compared to the other research activities such as device performance and operation. Regardless, the argument that these studies can be used for assessing ecological effects remains very much hypothetical at present. There is a significant way to go to address the knowledge gaps evident when considering actual ecologically relevant impacts.

Table 8. Summary of studies of MRED interaction with receptors in the marine environment, the type of study and the country that the studies were associated with. The table highlights the percentage split between the main categories identified during the review.

SECTOR	**Noise (%)**	**Collision (%)**	**EMF (%)**
Marine Environment – general	30	-	31
Offshore wind farms	40	81	54
Wave and Tidal	-	19	-
Boat noise/traffic	5	-	-
Subsea piling	15	-	-
Experimental studies	10	-	15
Marine Organisms			
Cetacea	50	14	9
Pinnipeds	18	-	-
Fishes	9	5	73
Turtles	5	-	9
Birds	-	72	-
Other	18	9	9
Purpose			
EIA	60	55	-
General effects	30	19	-
Policy/planning	10	26	100
Method			
Quantitative	45	33	-
Qualitative	10	13	-
Modelling	-	46	22
Review	45	8	78
Country			
UK	33	40	50
EU	17	50	20
USA	39	5	20
Other	11	5	10

The studies that are shown in Table 8 provide evidence for a general issue that was encountered within the literature reviewed. It has been clearly shown above that the EIA process has been used as a poor determinant for risk. This was evident in the published studies reviewed and this was exacerbated by the fact that different risk definitions are used and have a huge variation in the determination of uncertainty associated with the environmental impact (or risk) considered. Table 6 provides some evidence for this in that most studies were linked to EIAs or marine policy/planning associated with environmental impact and monitoring.

Some potential hazards to particular receptors are considered as likely (Table 8), even though the evidence does not actually exist (e.g. SNH, 2010 – assumptions on bird collision modelling). There is a lot of effort that has gone into trying to estimate such things as collision mortality but again the basis for defining this as a high priority risk comes down to some form of expert opinion and perception that some organisms should be afforded protection. This is unfortunately to the expense of other organisms that may have a greater, as yet, unquantified or little understood risk present. The level of uncertainty is central to which organisms are considered.

There are signs of more widely applicable methods for reducing uncertainty. These hinge on the fact that they are generic enough to address several receptor types e.g. noise effects on organisms can be assessed through understanding the sound source characteristics in relation to the received level of sound. This works for many receptors. The receptor specific research can then provide the detail needed to assess the level of effect. In terms of noise this is species specific audiograms. Expert judgement can use the audiograms to provide an assessment of the auditory capability of an organism and then the received sound with its individual characteristics can be overlaid on the audiogram to determine the extent of overlap (if any) within the range of detectability of the receptor. The next step is then determining what the effect may be. In the case of porpoises the sound characteristics overlap with the auditory ability of the porpoise and the effect is recorded as a movement away from the area where pile-driving is occurring (Brandt *et al.*, 2011).

Whilst this addresses the uncertainty surrounding the effect it does not transfer to understanding the impact of the environmental stressor on the receptor and hence does not provide the necessary knowledge on which to assess the risk of impact on the receptor. An impact would have to show that the porpoises were ecologically compromised to some degree. For example, do they avoid feeding areas which could result in slower growth rates or weight loss owing to reduced energetic intake, thereby decreasing the resources allocated to reproduction which is then manifest as a change in the reproductive output and hence a shrinking of the species population. The latter represents an impact which would be understandable and actionable by policy and decision makers. However the time scale that this will occur over is probably years to decades owing to the long gestation time, the parental care investment and then the knock-on reduction in breeding individuals through time. Political timescales do not follow ecological timescales hence there needs to be a clearer acknowledgement of this limitation and a better cross-consideration between the disciplines.

3 RISK AND UNCERTAINTY IN OTHER MARINE SECTORS

3.1 Review and synthesis of information on relevant risk and uncertainty assessment methods and tools

To supplement the review of the existing information relating to MRE risk and uncertainty we also undertook a literature search and review of other marine sectors environmental risk assessment. The objective here was to ascertain whether any existing methodologies for the other sectors were suitable for transfer or adaptation for MRE risk assessment and uncertainty determination.

The sectors considered were:

- Oil and gas
- Marine aggregates
- Mining
- Climate Change
- Seismic surveys
- Subsea cables/pipelines

The review focussed on UK based material unless there was an obvious gap, in these cases the search was widened to the international community. The material reviewed was deemed the most appropriate, but does not represent all available information on the topic.

3.2 Methods

Information Resources
Searches were carried out in the following areas:

- Web of Science databases - Science Citation Index (SCI-EXPANDED), Social Science Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI) and Conference Proceedings Citation Index – Science (CPCI-S).
- SciVerse SCOPUS/ScienceDirect - Physical Sciences, Social Sciences and Life Sciences subject areas.
- Online information sources including the web sites of UK, EU and US government agencies, environmental consultancies, and other relevant bodies

Table 9. Review of other marine sectors environmental risk related reports and publications accessed (see Appendix J for detail).

Industry Sector	UK	EU	USA/Other
Oil & Gas	9	1	3
Cable/ Pipeline	3	4	4
Mining	-	-	1
Marine Aggregates	2	-	-
Marine General	2	1	-
Climate Change	12	-	1
Journal articles			
Oil & Gas	12		
Other	4		

3.3 Risk definition by sector

During the review of other marine sectors a problem of variability in what was termed risk became apparent. Either the risk was not properly understood or environmental impact was considered as a proxy for risk. This mistake has been repeated in the marine renewable energy sector as highlighted in Section 2. For risk to be properly assessed there must be a consideration of the source-pathway- receptor, the magnitude or extent of exposure to a hazard and the likelihood of the hazard occurring.

There were however some sections of other marine industries that were more specific and were useful in defining risk and promoting some methodology by which the risk could be assessed. The important attributes and most promising methods are highlighted in the next section.

3.4 What can be learnt from the other sectors

The Institute of Environmental and Ecological Management (IEEM) recently published Ecological Impact Assessment (EcIA) guidance, where they suggest that likelihood be assessed to identify which issues merit mitigation. The guidance states that '...it is important to consider the likelihood that a change or activity will occur as predicted and also the degree of confidence in the assessment of the impact on ecological structure and function.' The document provides a meaningful scale for assessing likelihood and confidence. For issues related to offshore development where evidence is scarce expert judgment may be relied upon to provide objective assessment of likelihood and confidence.

An example of a likelihood scale is:

- Certain/near-Certain: probability estimated at 95% chance or higher.
- Probable: probability estimated above 50% but below 95%.
- Unlikely: probability estimated above 5% but less than 50%.
- Extremely Unlikely: probability estimated at less than 5%.

As IEEM have acknowledged it is important to understand the question of 'Why is it important to assess risk?' In some instances the impact of the hazard may be high whilst the likelihood of such an event is low. In essence, following the EIA process that considers only the worst case scenarios creates a list of impacts that can be characterised as low likelihood high impact events (bottom right in Figure 5). This approach takes the focus away from the risk that are the most likely to be high priority because some low impact and low likelihood risks (i.e. lower priority; Figure 5) are not explicitly recognised in the EIA. The risk literature contains guidance on how to manage these types of risks compared to, for example, low impact high likelihood events which require a different approach (Figure 6). The response to the risks can be very different depending on the assessment of the risk (Figure 6) By linking the risk assessment to the management strategy, decision makers can begin to understand the residual or remaining risk they are left with (Pollard *et al.*, 2004).

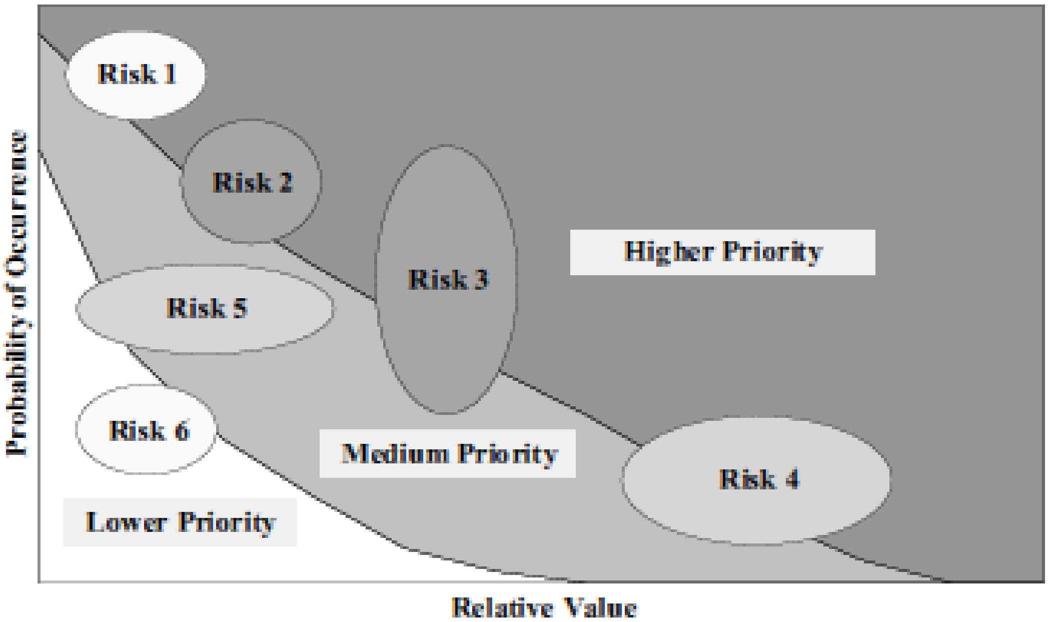


Figure 5. Probability-value-response schematic. Emphasis is placed on high probability – high value risks, with distinction between risks of comparable value and probability being provided by social responses to risk. The ellipses are indicative of the relative uncertainty in probability or value.

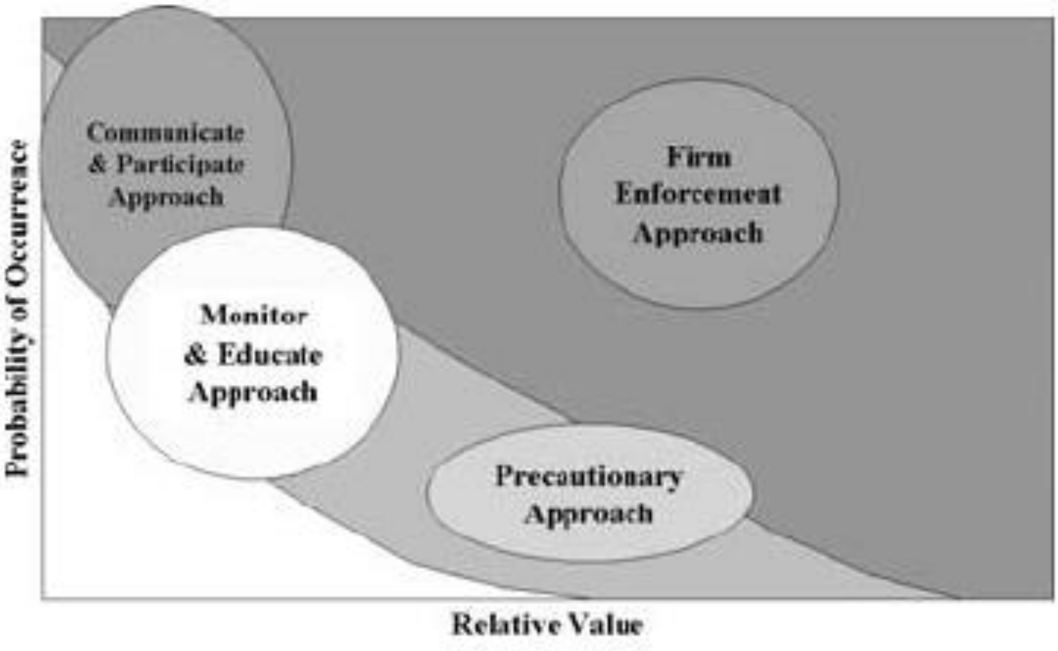


Figure 6. Policy tools for risk management mapped onto probability – relative value – social response schematic.

In the Offshore Sector health and safety applies the ALARP principle (As Low As Reasonably Possible) to manage risk. This principle relies upon a robust assessment of realistic risk, not simply worst case scenarios, and then determines how this risk can be managed (Figure 7).

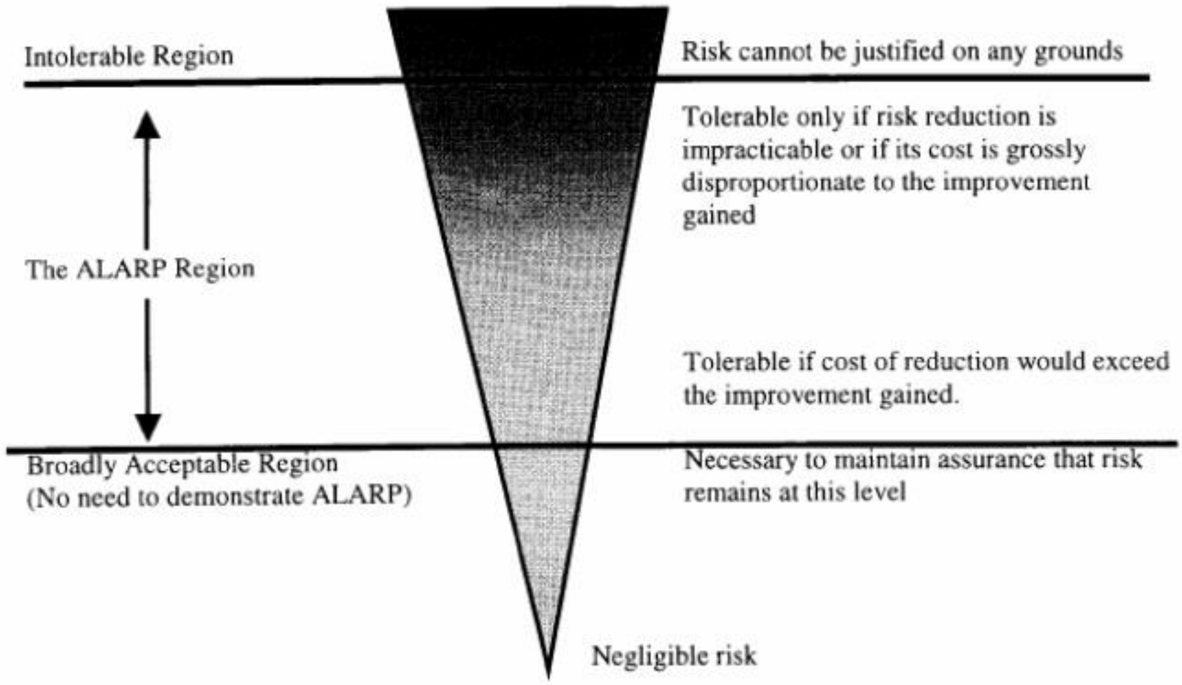


Figure 7. HSE framework for decisions on the tolerability of risk.

Within the UK, offshore safety regulations apply an integrated risk based approach that begins with feasibility studies and extends through the life cycle of the installations. In a risk based approach, early considerations are given to those hazards which are not foreseeable to design out by progressively providing adequate measures for prevention, detection, control and mitigation and further integration of emergency response.

The aim of offshore safety analysis is to make safety based design/operation decisions at the earliest stages when the cost of making any necessary changes is low. This is not to say that modifications may be necessary later in the process to ensure ALARP principles.

Traditionally, when making safety based design/operation decisions for offshore systems, the cost of a risk reduction measure is compared with the benefit resulting from reduced risks. If the benefit is larger than the cost, then it is cost-effective, otherwise it is not. This kind of cost benefit analysis based on simple comparisons has been widely used as a general principle in offshore safety analysis.

3.5 Climate Change Risk and Uncertainty

The risks associated with climate change represent a significant uncertainty for decision-makers. However, whereas the consideration of risks and uncertainties by the marine renewable energy sector is in its relative infancy, awareness of climate change risks and uncertainties and their management is more mature. Indeed, a considerable body of literature is now available on the subject of uncertainties and their management, and a wide range of tools and approaches are available for those wishing to assess and manage uncertain climate change risks. For example, at the international level, the Intergovernmental Panel on Climate Change (IPCC) has published a simple typology of uncertainties that includes examples of the differing types of approaches and considerations available to those wishing to consider climate change uncertainties (IPCC, 2005).

Table 10.. A simple typology of uncertainties (IPCC, 2005).

Type	**Indicative examples of sources**	**Typical approaches or considerations**
Unpredictability	Projections of human behaviour not easily amenable to prediction (e.g. evolution of political systems). Chaotic components of complex systems.	Use of scenarios spanning plausible range, clearly stating assumptions, limits considered, and subjective judgements. Ranges from ensembles or model runs.
Structural uncertainty	Inadequate models, incomplete or competing conceptual frameworks, lack of agreement on model structure, ambiguous system boundaries or relationships wrongly specified or not considered.	Specify assumptions and system definitions clearly, compare models with observations for a range of conditions, assess maturity of the underlying science and degree to which understanding is based on fundamental concepts tested in other

		areas.
Value uncertainty	Missing, inaccurate or non-representative data, inappropriate spatial or temporal resolution, poorly known or changing model parameters.	Analysis of statistical properties of sets of values (observations, model ensemble results, etc.); bootstrap and hierarchical statistical tests; comparison of models with observations.

In this section a range of approaches, aimed at addressing the challenges posed by climate change risks and their uncertainties are described, as the marine renewable energy sector could learn much from them. Clearly, whilst a wide range of approaches for addressing climate change uncertainties are available (e.g. Table 10), our review focused on those deemed as most appropriate for those within the marine renewable energy undertaking risk assessments. For an in-depth discussion of approaches to managing climate change uncertainties the reader should consult Manning *et al.*, (2004), United States Climate Change Science Program (US CCSP) (2009), HM Treasury and Defra, (2009) and Willows and Connell (2009).

3.5.1 Scenarios and Projections

A range of climate change scenarios and projections are available for use by decision-makers to assess climate change risks and uncertainties. In the UK the UK Climate Projections (UKCP) provide detailed projections of climate change for a number of scenarios (UKCP, 2012). Until relatively recently deterministic scenarios were used to address uncertainties, with UKCP02 providing four scenarios (Low Emissions, Medium-Low Emissions, Medium-High Emissions and High Emissions) available for use in risk assessments and scenario analysis. However, user demands for further information regarding uncertainty has resulted in the development of the UKCP09 probabilistic projections that are available for three greenhouse gas emissions scenarios (High, Medium and Low).

Whilst the shift to probabilistic projections has a number of advantages, including allowing users to make more robust decisions and making uncertainty more transparent, it has raised significant challenges. In particular, the projections are more complicated for users, who can become overwhelmed by the complexity of the probabilistic projections and the volume of data available (Figure 8). This has had knock-on implications for organisations, such as the UK Climate Impacts Programme (UKCIP) and Department for Environment Food and Rural Affairs (Defra) regarding the provision of training and user support. Furthermore, and of potential importance to the MREKE Programme, there is emerging evidence that the explicit nature of uncertainties associated with the projections can pose a barrier to adaptation in some organisations (Defra, 2012). However, it is recognised that this is primarily an organisational risk management issue.

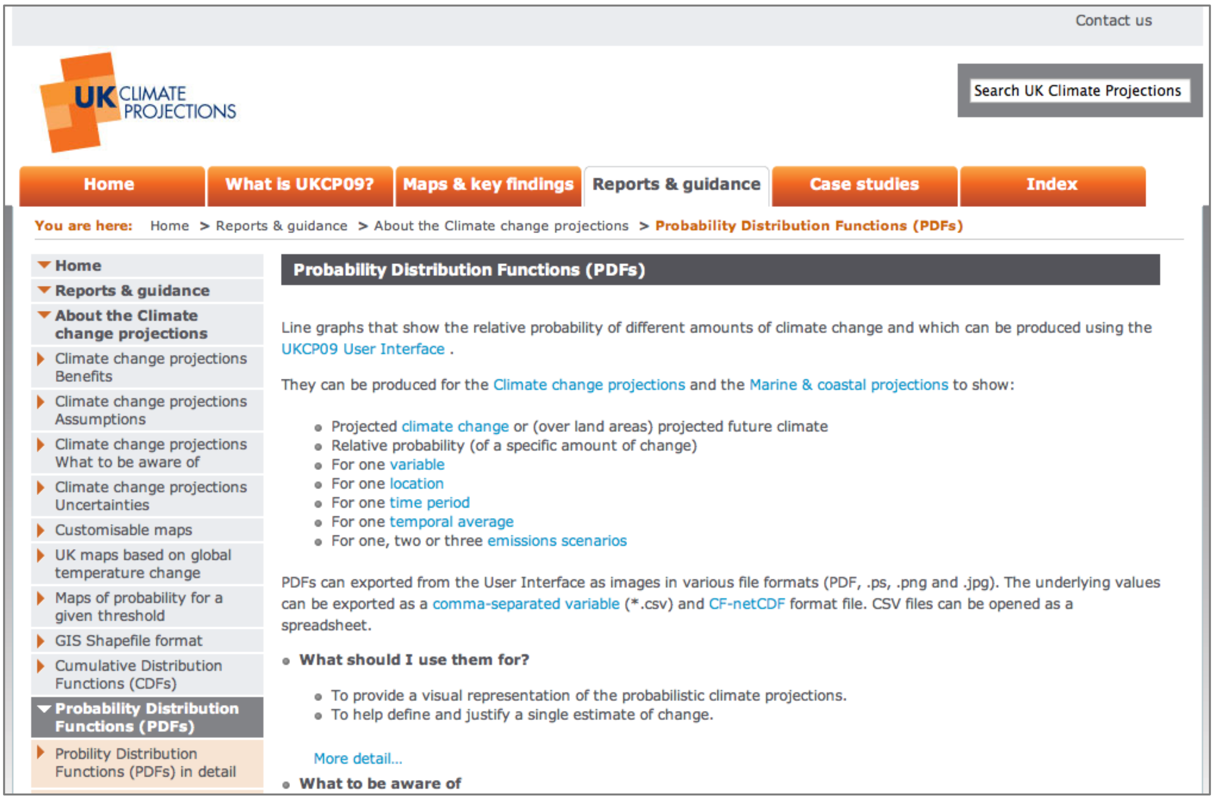


Figure 8. The UKCP09 website includes a wide array of data products, ranging from key findings to maps and probability distribution functions, alongside custom weather generator and threshold detector tools.

3.5.2 Critical Questions for those Dealing with Risk Uncertainty

Whilst it may initially appear obvious to those with experience of assessing and managing uncertain risks, the US CCSP's (US CCSP, 2009) Best Practice Approaches for Characterising, Communicating, and Incorporating Scientific Uncertainty in Climate Decision Making report provides sound and fundamental advice that is highly relevant to those assessing and addressing marine renewable energy risks. In particular, it states that when involved in the characterisation and management of climate change uncertainties you *'must always think critically and ask themselves questions such as'*:

- Does what we are doing make sense?
- Are there other important factors that are equally or more important than the factors we are considering?
- Are there key correlation structures in the problems that are being ignored?
- Are there normative assumptions and judgements about which we are not being explicit?
- Is information about the uncertainties related to research results and potential policies being communicated clearly and consistently? (US CCSP, 2009).

3.5.3 Characterising and Communicating Risk Uncertainty

The explicit consideration, characterisation and communication of uncertainty are approaches that are commonly used by those addressing uncertain climate change risks.

In particular, the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2005; 2010) highlights two key attributes, which are important when making judgements on climate change:

1. The amount of evidence available to support the judgement being made
2. The degree of scientific consensus within the scientific community about that judgement (US CCSP, 2009).

This has resulted in the categorisation of knowledge (Figure 9) and the relationship between evidence, the level of agreement, and its relationship with confidence (Figure 10), with increasing scientific agreement or consensus and more evidence resulting in improved confidence (US CCSP, 2009; IPCC, 2010). In practice, this approach for classifying and communicating confidence has been adopted my numerous organisations. For example, the UK Marine Climate Change Impacts Partnership (MCCIP) present the level of confidence associated with its assessment of the climate change risks facing the marine environment (Figure 11). However, as can be seen in Figure 11, there lacks a clearly defined confidence classification, thus making it difficult for users to interpret. Elsewhere, the Environment Agency has applied a more detailed and robust confidence classification as part of its recent Adaptation Reporting Power Adaptation Report (Table 11).

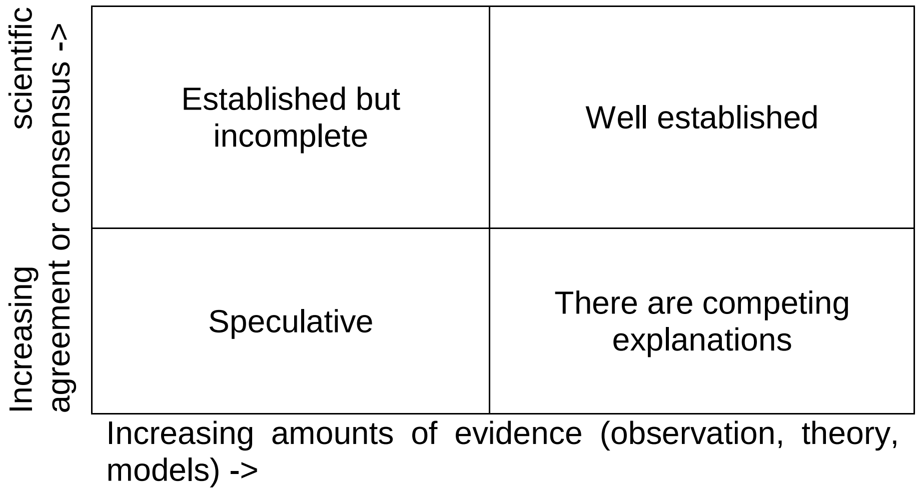


Figure 9. The categorisation of the various states of knowledge that may apply in different aspects of climate and related problems (US CCSP, 2009).

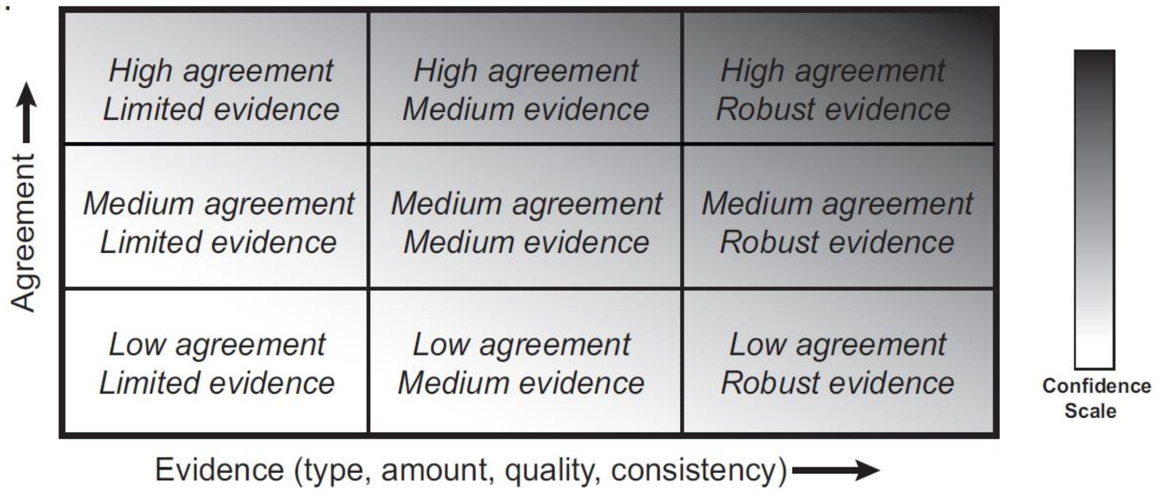
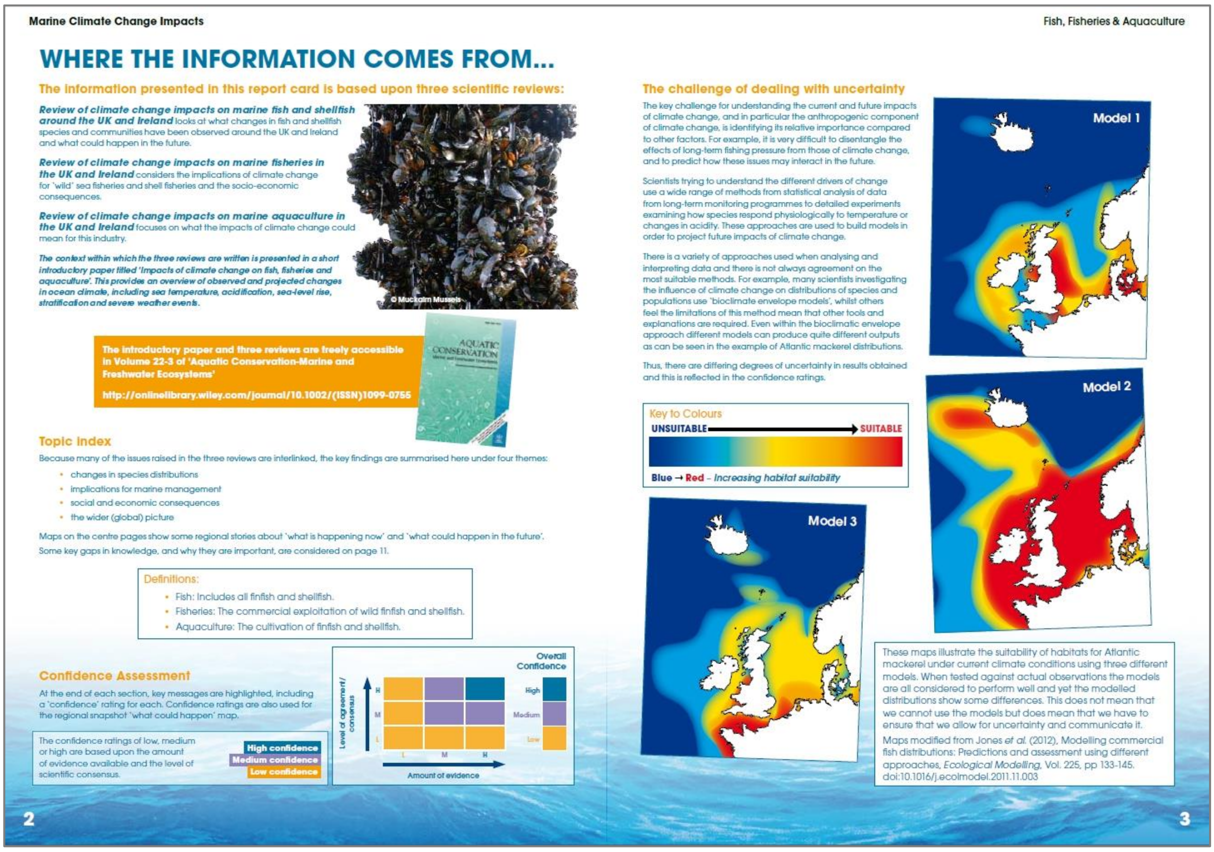


Figure 10. A depiction of evidence and agreement statements and their relationship to confidence. Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence (IPCC, 2010).


Marine Climate Change Impacts

Fish, Fisheries & Aquaculture

WHERE THE INFORMATION COMES FROM...

The information presented in this report card is based upon three scientific reviews:

Review of climate change impacts on marine fish and shellfish around the UK and Ireland looks at what changes in fish and shellfish species and communities have been observed around the UK and Ireland and what could happen in the future.

Review of climate change impacts on marine fisheries in the UK and Ireland considers the implications of climate change for 'wild' sea fisheries and shell fisheries and the socio-economic consequences.

Review of climate change impacts on marine aquaculture in the UK and Ireland focuses on what the impacts of climate change could mean for this industry.

The context within which the three reviews are written is presented in a short introductory paper titled 'Impacts of climate change on fish, fisheries and aquaculture'. This provides an overview of observed and projected changes in ocean climate, including sea temperature, acidification, sea-level rise, stratification and severe weather events.

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The introductory paper and three reviews are freely accessible in Volume 22-3 of 'Aquatic Conservation-Marine and Freshwater Ecosystems'

http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1099-0755

AQUATIC CONSERVATION

Topic Index

Because many of the issues raised in the three reviews are interlinked, the key findings are summarised here under four themes:

- changes in species distributions
- implications for marine management
- social and economic consequences
- the wider (global) picture

Maps on the centre pages show some regional stories about 'what is happening now' and 'what could happen in the future'. Some key gaps in knowledge, and why they are important, are considered on page 11.

Definitions:

- Fish: Includes all finfish and shellfish.
- Fisheries: The commercial exploitation of wild finfish and shellfish.
- Aquaculture: The cultivation of finfish and shellfish.

Confidence Assessment

At the end of each section, key messages are highlighted, including a 'confidence' rating for each. Confidence ratings are also used for the regional snapshot 'what could happen' map.

The confidence ratings of low, medium or high are based upon the amount of evidence available and the level of scientific consensus.

High confidence
Medium confidence
Low confidence

Level of agreement / consensus
H
M
L
L M H
Amount of evidence
Overall Confidence
High
Medium
Low

2

The challenge of dealing with uncertainty

The key challenge for understanding the current and future impacts of climate change, and in particular the anthropogenic component of climate change, is identifying its relative importance compared to other factors. For example, it is very difficult to disentangle the effects of long-term fishing pressure from those of climate change, and to predict how these issues may interact in the future.

Scientists trying to understand the different drivers of change use a wide range of methods from statistical analysis of data from long-term monitoring programmes to detailed experiments examining how species respond physiologically to temperature or changes in acidity. These approaches are used to build models in order to project future impacts of climate change.

There is a variety of approaches used when analysing and interpreting data and there is not always agreement on the most suitable methods. For example, many scientists investigating the influence of climate change on distributions of species and populations use 'bioclimate envelope models', whilst others feel the limitations of this method mean that other tools and explanations are required. Even within the bioclimatic envelope approach different models can produce quite different outputs as can be seen in the example of Atlantic mackerel distributions.

Thus, there are differing degrees of uncertainty in results obtained and this is reflected in the confidence ratings.

Key to Colours
UNSUITABLE → SUITABLE
Blue → Red – *Increasing habitat suitability*

Model 1
Model 2
Model 3

These maps illustrate the suitability of habitats for Atlantic mackerel under current climate conditions using three different models. When tested against actual observations the models are all considered to perform well and yet the modelled distributions show some differences. This does not mean that we cannot use the models but does mean that we have to ensure that we allow for uncertainty and communicate it.

Maps modified from Jones *et al.* (2012), Modelling commercial fish distributions: Predictions and assessment using different approaches, *Ecological Modelling*, Vol. 225, pp 133-145. doi:10.1016/j.ecolmodel.2011.11.003

3

Figure 11. Marine Climate Change Impacts Partnership's marine climate change impacts, Fish, Fisheries and Aquaculture Summary Report that explicitly considers the level of confidence in key messages (MCCIP, 2012a).

Table 11. Confidence assessment criteria used by the Environment Agency's climate change Adaptation Report (Environment Agency, 2011).

Confidence in the evaluation of importance and proximity	
Very low	Based on expert judgement or weak evidence only
Low	Based on few, incomplete, inconclusive impact studies
Medium	Based on expert interpretation of a number of (potentially conflicting) impact studies
High	Based on impact studies that give a consistent picture but do not explore uncertainty fully
Very high	Based on many impact studies that give a coherent picture and explore uncertainty fully
Confidence in the evaluation of resource and inertia	
Very low	We do not have sufficient understanding of the impact to be able to suggest a possible response
Low	We do not have a good understanding of our response
Medium	We understand the nature and scale of the response required (for example, change of policy, major legislative intervention etc.)
High	We have scoped the feasibility of specific responses
Very high	We have scoped the feasibility of specific responses and have developed policy for best practice

The examples provided by the MCCIP Summary Report and the Environment Agency's Adaptation Reporting Power Adaptation Report illustrate the importance of explicitly and clearly communicating uncertainties. Indeed, the US CCSP (2009,) emphasise that *'the real issue is the framing of uncertainty in familiar and understandable terms'*. In the field of climate change, this has led to the IPCC producing guidance notes for its lead authors of its Assessment Reports (IPCC, 2005; 2010) to ensure that uncertainties are handled in a consistent manner. For example, the guidance note for the Fourth Assessment Report (IPCC, 2005), included qualitatively calibrated levels of confidence (Table 12), whilst recently published guidance for consistent treatment of uncertainties in the Fifth Assessment Report (IPCC, 2010) includes clearly defined terminology for likelihoods (Table 13).

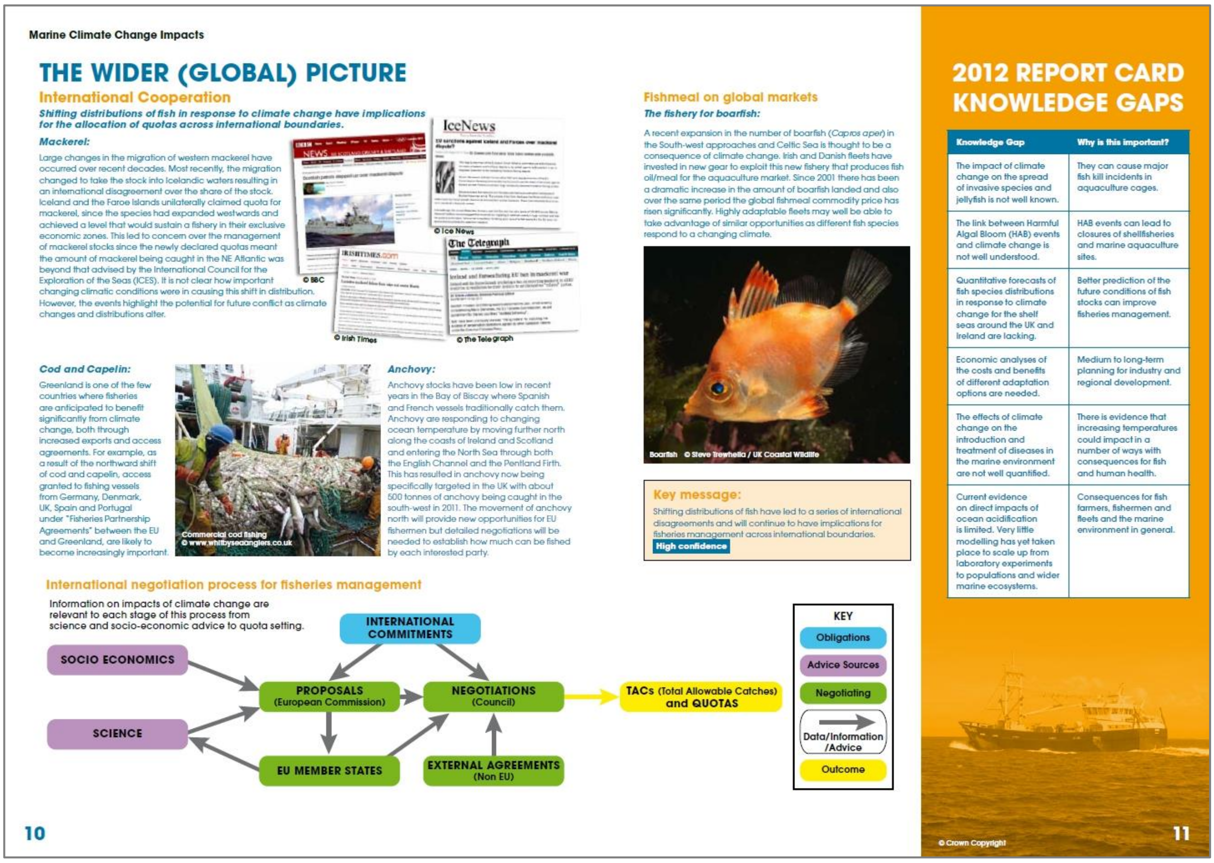
Table 12. Quantitatively calibrated levels of confidence (IPCC, 2005).

Terminology	**Degree of confidence in being correct**
Very High confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Table 13. Likelihood scale used by the IPCC (IPCC, 2010).

Term	Likelihood of the Outcome
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33-66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

Alongside the communication of confidence in the supporting information, some organisations provide explicit details of the information gaps affecting climate change risks. One good example of this is from the MCCIP Report Cards (MCCIP, 2012a) that use short high-level messages to describe each knowledge gap (Figure 12) and why they are important. Furthermore, MCCIP have published a standalone Knowledge Gaps Report (MCCIP, 2012b) in which each knowledge gap 'type' is classified and the timescale provided using a simple, easily interpreted classification (Table 14).


Marine Climate Change Impacts

THE WIDER (GLOBAL) PICTURE

International Cooperation

Shifting distributions of fish in response to climate change have implications for the allocation of quotas across international boundaries.

Mackerel:

Large changes in the migration of western mackerel have occurred over recent decades. Most recently, the migration changed to take the stock into Icelandic waters resulting in an international disagreement over the share of the stock. Iceland and the Faroe Islands unilaterally claimed quota for mackerel, since the species had expanded westwards and achieved a level that would sustain a fishery in their exclusive economic zones. This led to concern over the management of mackerel stocks since the newly declared quotas meant the amount of mackerel being caught in the NE Atlantic was beyond that advised by the International Council for the Exploration of the Seas (ICES). It is not clear how important changing climatic conditions were in causing this shift in distribution. However, the events highlight the potential for future conflict as climate changes and distributions alter.

© BBC © Ice News © Irish Times © The Telegraph

Cod and Capelin:

Greenland is one of the few countries where fisheries are anticipated to benefit significantly from climate change, both through increased exports and access agreements. For example, as a result of the northward shift of cod and capelin, access granted to fishing vessels from Germany, Denmark, UK, Spain and Portugal under "Fisheries Partnership Agreements" between the EU and Greenland, are likely to become increasingly important.

Commercial cod fishing © www.whitbyseaanglers.co.uk

Anchovy:

Anchovy stocks have been low in recent years in the Bay of Biscay where Spanish and French vessels traditionally catch them. Anchovy are responding to changing ocean temperature by moving further north along the coasts of Ireland and Scotland and entering the North Sea through both the English Channel and the Pentland Firth. This has resulted in anchovy now being specifically targeted in the UK with about 500 tonnes of anchovy being caught in the south-west in 2011. The movement of anchovy north will provide new opportunities for EU fishermen but detailed negotiations will be needed to establish how much can be fished by each interested party.

International negotiation process for fisheries management

Information on impacts of climate change are relevant to each stage of this process from science and socio-economic advice to quota setting.

Fishmeal on global markets

The fishery for boarfish:

A recent expansion in the number of boarfish (*Capros aper*) in the South-west approaches and Celtic Sea is thought to be a consequence of climate change. Irish and Danish fleets have invested in new gear to exploit this new fishery that produces fish oil/meal for the aquaculture market. Since 2001 there has been a dramatic increase in the amount of boarfish landed and also over the same period the global fishmeal commodity price has risen significantly. Highly adaptable fleets may well be able to take advantage of similar opportunities as different fish species respond to a changing climate.

Boarfish © Steve Trewhella / UK Coastal Wildlife

Key message:

Shifting distributions of fish have led to a series of international disagreements and will continue to have implications for fisheries management across international boundaries.

High confidence

2012 REPORT CARD KNOWLEDGE GAPS

Knowledge Gap	Why is this important?
The impact of climate change on the spread of invasive species and jellyfish is not well known.	They can cause major fish kill incidents in aquaculture cages.
The link between Harmful Algal Bloom (HAB) events and climate change is not well understood.	HAB events can lead to closures of shellfisheries and marine aquaculture sites.
Quantitative forecasts of fish species distributions in response to climate change for the shelf seas around the UK and Ireland are lacking.	Better prediction of the future conditions of fish stocks can improve fisheries management.
Economic analyses of the costs and benefits of different adaptation options are needed.	Medium to long-term planning for industry and regional development.
The effects of climate change on the introduction and treatment of diseases in the marine environment are not well quantified.	There is evidence that increasing temperatures could impact in a number of ways with consequences for fish and human health.
Current evidence on direct impacts of ocean acidification is limited. Very little modelling has yet taken place to scale up from laboratory experiments to populations and wider marine ecosystems.	Consequences for fish farmers, fishermen and fleets and the marine environment in general.

© Crown Copyright

10 11

Figure 12. Explicit consideration of the level of confidence in key messages and knowledge gaps in the 2012 MCCIP Marine Climate Change Impacts on Fish, Fisheries and Aquaculture Summary Report (MCCIP, 2012a).

Table 14. MCCIP knowledge gap classification methodology (MCCIP, 2012b).

Information gaps classification	Description
+	where it is clear that the gap has more than one 'type'
->	gaps of one type that are of a consequence of a limited understanding of others
Current gaps	gaps that can refine our understanding of what is happening now or in the past
Future gaps	gaps that relate to increasing our understanding of what could happen in the future
Evidence (E), planning (P) and / or regulation (R	Relevance to policy areas

3.5.4 Decision-Making Strategies

A number of approaches for making decisions in the light of climate change uncertainties exist that may be of value to those wishing to address uncertainties in the marine environment. For example, the US Climate Change Science Program (US CCSP, 2009) and the UK's HM Treasury and Defra (HM Treasury and Defra, 2009) highlight the following broad adaptation approaches:

1. **Decision analysis** – can be used to identify optimal strategies in the face of uncertainty. In particular, if it is possible to identify alternative strategies and identify and estimate the probability of key uncertain events and specify preferences among the range of possible outcomes, then the US CCSP (2009) note that such tools can assist in framing and analysing complex decisions in a consistent and rational way.
2. **Resilient strategies –** approaches that will continue to function across a range of future circumstances.
3. **Flexible/adaptive strategies –** that may enable adjustment or incremental adaptation in response in future to effects that are different to those originally anticipated.
4. **Identification of low-regrets and win-win measures -** low-regrets options have relatively low costs, and relatively large benefits (that are mainly realised under projected future climate change). Win-win measures address climate change risks, but also deliver other benefits (HM Treasury and Defra, 2009).

Resilient and adaptive strategies are commonly used by organisations when adapting to climate change and the use of Real Options Analysis as an example of an adaptive strategy is provided below. The US CCSP (2009) also notes that the **precautionary principle** can also be used to address uncertainty. However, they also highlight the key limitation of adopting such an approach – that it can prevent adaptation or change. In particular, there are examples of organisations being paralysed by uncertainty because they have embraced the precautionary principle. Indeed, the risk management challenges currently facing the marine renewable energy sector partly stem from the adoption of the precautionary principle.

Alongside this range of different approaches, there is an accompanying recognition that underlying support frameworks are necessary to underpin and deliver adaptation, and this is highly relevant to the management of uncertainties in the marine renewable energy sector. In particular, HM Treasury and Defra's (2009) Supplementary Green Book Guidance on Accounting for the Effects of Climate Change in the development, appraisal and evaluation of policies, programmes and projects, identifies the need to:

1. **Set the right underlying framework for effective adaptation** – for example through the provision of codes and guidance on accounting for uncertainty.
2. **Creating information needed to make effective decisions** – through research, education, information, training, key thresholds and interdependencies. Also, learning from experience through monitoring progress, collecting data and evaluating outcomes (HM Treasury and Defra, 2009).

The Green Book Supplementary Guidance also highlights that **a mix of adaptation measures may be necessary** and that **decisions that would be either difficult or expensive to revise in future should receive additional scrutiny**. In addition, the guidance also outlines a number of principles of good adaptation that are equally applicable to the management of marine renewable energy risks. These are that adaptation measures should be:

1. **Effective**
    - Reducing risks whilst not introducing additional negative effects.
    - Incorporating flexibility to account for future change.
    - Not restricting future adaptation options.
2. **Efficient**
    - The reduction in risk should justify the adaptation costs.
    - Correctly timed. For example, adaptation measures should be flexible to prevent lock-in or maladaptation.
3. **Equitable**
    - The distributional consequences of adaptation options should be considered.

3.5.5 Real Options Analysis

The Supplementary Green Book Guidance (HM Treasury and Defra, 2009) describes the application of Real Options Analysis as a means of incorporating climate change uncertainties and flexibility into decision-making, and represents an example of an adaptive management approach. In Real Options Analysis a 'Real Option' is an alternative or choice that becomes available through an investment opportunity or action (HM Treasury and Defra, 2009).

Real Options Analysis acknowledges that our understanding of uncertainty will change in future in light of new information or learning from experience. If an activity, such as an adaptation measure, is designed to be flexible, then it is possible for it to be modified as our understanding evolves. However, the flexibility of the activity, does not affect its performance if it is not required. As a result, HM Treasury and Defra (2009) highlight the potential value of adopting the Real Options Analysis approach for policies, programmes or projects that include:

1. Uncertainty
2. Flexibility
3. Potential for learning

The Supplementary Guidance (HM Treasury and Defra, 2009) outlines the use of Real Options Analysis both as a qualitative and quantitative tool. In its qualitative form, Real Options Analysis can utilise decision trees, using them to map and understand the sequence of actions, decision points and events associated with an activity. When used quantitatively, information regarding the costs, benefits, and probabilities associated with different options is added to the decision tree. Furthermore, sensitivity analysis can be used to explore alternative scenarios when undertaking Real Options Analysis. Figure 13 illustrates the use of Real Options Analysis, whilst Figure 14 introduces the concepts of identifying thresholds, lead times and decision points, which are key elements of the use of Real Options Analysis in decision-making.

Whilst Real Options Analysis enables the identification of options for addressing the management of long-term and uncertain risks, and has been used successfully in decision-making processes such as the Thames Barrage (HM Treasury and Defra, 2009; insert EA TE2100 report), it can be hampered by a desire to wait for new information. In addition, HM Treasury and Defra (2009) identify a number of practical issues associated with the approach, including:

1. **Enforceability –** an option will only have value if it can be enforced or undertaken. This may be constrained by the degree of managerial discipline or other public commitments.
2. **Time frames –** the time frame available before exercising the option affects its value. With more time for useful information to become available, the greater the scope for the value of an option to vary.
3. **Information –** gathering information on costs, benefits and probabilities associated with options can be resource intensive.

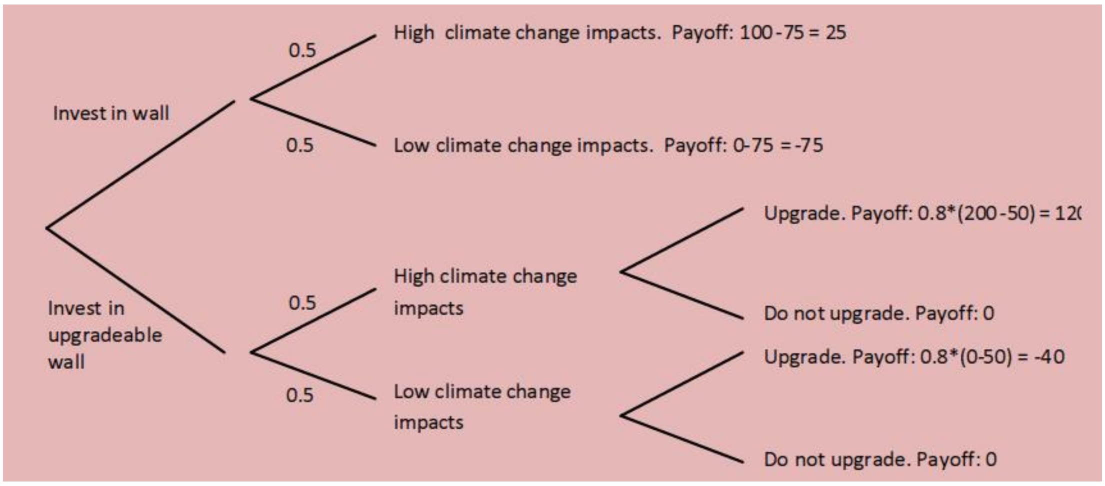


Figure 13. An example of using decision-trees in Real Options Analysis (HM Treasury and Defra, 2009)

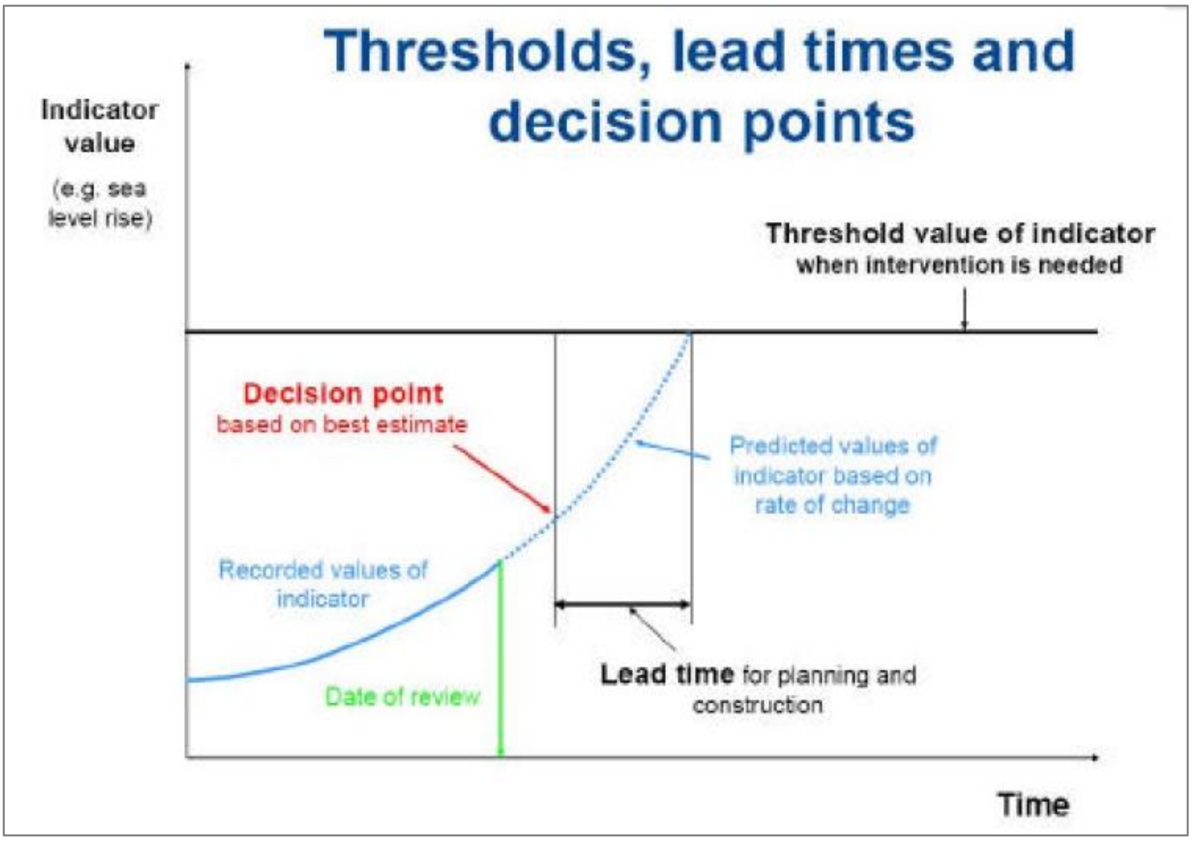


Figure 14. The identification of thresholds, lead times and decision-points are key elements of the Real Options Analysis approach to decision-making under uncertainty (HMT and Defra, 2009).

3.5.6 Adaptation Framework to support decision-making in the face of climate change risk

In the UK the UK Climate Impacts Programme (UKCIP), Department for Environment Food and Rural Affairs (Defra) and the Environment Agency (EA) have developed a climate change risk-uncertainty-decision-making framework to support climate change risk decision-making (Willows & Connell, 2003). The framework, outlined in Figure 15, offers a flexible, iterative approach for decision-making and has three key attributes. In particular, it is:

- **Circular –** promoting adaptive management with decisions being reviewed and revisited as new information becomes available.
- **Iterative –** feedback and iteration enable the refinement of the problem, decision-making criteria, risk assessment and options, and the development of robust decisions.
- **Tiered –** initial identification, screening and prioritisation of risks and options occur before detailed risk assessments and options appraisals are undertaken.

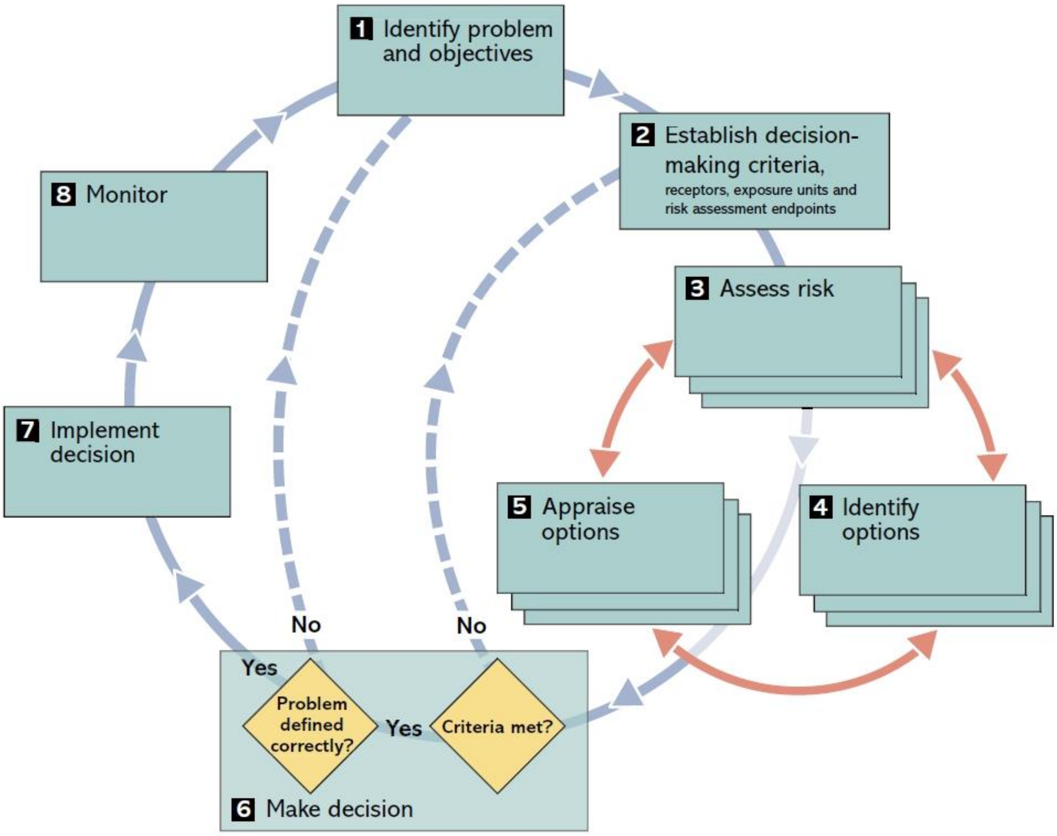


Figure 15. UKCIP Adaptation Framework to support decision-making in the face of climate change risk (Willows & Connell, 2003).

Each stage of the framework is accompanied by a series of questions helping decision-makers to understand the issues involved and to aid decision-making. The framework emphasises the need for a formal process or audit trail, enabling the recording and review of decisions, and states that the decision-maker should:

1. Provide clear reasoning for each answer
2. State any significant assumptions
3. Be explicit about the choice of decision criteria and policy strategies
4. Where appropriate state the degree of confidence in the answer
5. Identify any major uncertainties
6. State any information sources, literature, methods and tools used in arriving at the answer (Willows & Connell, 2009).

Furthermore, the framework also highlights the importance of communicating the uncertainties and their potential influence on decisions. In particular, it notes that the following information should be provided to address the potential risk of climate change risks and uncertainties being misunderstood:

- An appreciation of the overall degree of uncertainty and variability and confidence that can be placed in the analysis and its findings
- An understanding of the key sources of variability and uncertainty and their impacts on the analysis

- An understanding of the critical assumptions and their importance to the analysis and findings; this should include details of any such assumptions which relate to subjective judgements of the analysts performing the analysis
- An understanding of the unimportant assumptions and why they are unimportant
- An understanding of the extent to which plausible alternative assumptions could affect any conclusions
- An understanding of key scientific controversies related to the assessment and a sense of what difference they might make regarding the conclusion (Willows & Connell, 2009).

A key element of the framework, which is of particular importance to the marine renewable energy sector, is stage 8 – Monitor, evaluate and review. Here, the need to identify quantitative targets and indicators for monitoring decisions is emphasised alongside the accompanying requirement for research and monitoring to identify trends and reduce uncertainties associated with risk characterisation (Willows & Connell, 2009).

3.5.7 Useful outputs for MREKE in the future

The UKCP09 projections and UKCIP illustrate a number of benefits and challenges that may be of value to the NERC MREKE Programme and the development of their work:

- **Centralised portals –** UKCP09 website provides the climate projections and support whilst UKCIP's website provides further support on climate change.
- **Multiple and tiered products –** both the UKCP09 and UKCIP websites contain a wide range of data products, tools and publications for different users and requirements. This ranges from the provision of key headline messages, to downloadable datasets, including Geographical Information System (GIS) data, and advanced analysis tools.
- **Freely available centralised support –** until recently UKCIP provided support and training on climate change although this has recently transferred to the Environment Agency.
- **Cost –** the provision of probabilistic projections and support is costly.

4 ORGANISATIONAL RISK APPETITES - PERCEPTION AND HANDLING OF RISKS AND UNCERTAINTIES

4.1 Background to organisational risk appetite

As highlighted in the previous sections, the review element of this project has identified that risk assessment and uncertainty estimation methods for supporting decision-making for marine renewable energy projects are currently lacking. Whilst this is a significant finding, it only represents one element of the risk management challenge facing the marine renewables industry, with another key issue being how industry and individual organisations perceive the handling of environmental risks and uncertainties. Significantly, this is an area that has received very little attention to-date, despite its potential importance in providing insights into the handling of risks and uncertainties by the sector, and potential solutions. As such, very little is currently known about the extent to which environmental risks and uncertainties are impacting on the development of the marine renewables sector. To address this research gap, a preliminary assessment of how organisations and the wider marine renewables sector perceive the handling of environmental risks and uncertainties was conducted. We term this 'organisational risk appetites' and believe that it provides valuable insights for both the development of future risk assessment tools and methods and the NERC MREKE programme.

In the risk management literature risk appetite is defined as set of explicit statements defining an organisations' desired level of risk and risk tolerance thresholds (COSO, 2004). It can also refer to a broader set of values and beliefs that affect individual propensity for taking and avoiding risk within an organisation (IRGC, 2009). Risk appetite is seen as a key factor achieving a balanced approach to risk, that is, one that is neither excessively risk seeking or risk averse (IRGC, 2009). For example, enterprise risk management frameworks require that an explicit 'risk appetite' for each risk be centrally determined and communicated to the rest of the organisation, where it is intended to inform local risk management practice (COSO, 2004). However, such a narrow, technical definition of risk appetite has been criticised for ignoring the role of human behaviour in determining risk appetite (Power, 2009). Power (2009) argues that the definition and assessment of risk appetite must include the wider social and situational factors that affect risk behaviour. Therefore, in this scoping study we explored the wider perception of risk within the marine renewables sector as it related to risk seeking and risk avoidance. The specific objectives of this study were to explore the marine renewable energy sectors':

1. *Perception of relative significance of risks and uncertainties*. For example, environment risk may be viewed as more important than reputational risk by the sector.
2. *Perception of the purpose and role of risk management.* For example, how risk management fits into core organisational objectives or everyday organisational functions of organisations involved in the development of the marine renewable energy industry.
3. *Perception of relative weighting of upside and downside risk.* For example, is risk primarily associated with opportunity or as a negative to be avoided – in particular is the marine renewable energy sector risk seeking or risk averse?
4. *Positivist versus constructivist perceptions of risk.* For example, does the sector and individual organisations (for example device manufacturers) view environmental risks as a technical problem to which a single solution can be found, or, is risk viewed as a

product of stakeholder (for example regulators) perceptions requiring stakeholder involvement to manage?

4.2 Methodology

The survey utilised a series of open-ended questions designed to provide insights into environmental risks and uncertainties and the manner in which they are affecting the marine renewable energy industry and its development. This approach was chosen because it provided flexibility and potentially deeper insights than closed questions. This was important given the sensitive nature of the issues being explored by the study. In particular, it allowed respondents to both raise particular issues of concern to their organisation or not respond to any questions that they did not wish to answer (for example on commercial grounds).

Initially a series of 23 questions (Appendix 1) were identified, based on previous research investigating risk appetites and the findings from the NERC/Defra RESPONSE project risk scoping workshop. These were subsequently refined to 11 questions (Table 13) following initial responses to the survey that suggested that a more succinct set of questions may prove beneficial.

Table 13. The open-ended questions used in the survey.

1. What are the main risks facing your organisation?
2. Where does the largest uncertainty reside in your risk management activities?
3. Are there any environmental risks of strategic concern in your organisation?
4. What future risks do you expect to emerge as the sector expands to meet the UK renewable energy targets?
5. How does risk management link to your corporate strategy for the mid-to-long term?
6. How do you engage with commercial partners regarding risk?
7. What are the implications of the uncertainties regarding risks faced by your organisation?
8. In which areas do you think your organisation's exposure to risk is too high? [Please give examples]
9. In which areas do you think your organisation is being too cautious regarding risk? [Please give examples]
10. What are the main factors limiting your organisation's ability to manage risk (identify, assess and mitigate risk)?
11. Do you feel that your current risk management practices will be sufficient to meet future challenges as the sector expands? [If not, how might they need to be developed?

The scoping nature of this element of the project and resource constraints associated with transcribing of recordings precluded face-to-face or telephone interviews. Instead, an e-mail-based survey was utilised, targeting key organisations from across the marine renewable energy industry. Organisations invited to participate in the study included key wave and tidal device manufacturers, utilities/developers actively developing wave and tidal devices and projects, together with a range of representatives from the wider marine sector involved in marine renewable energy projects (e.g. contractors and consultants). In addition, the two UK wave and tidal test sites – the European Marine Energy Centre (EMEC) and WaveHub were also approached to gain their perspectives on environmental risks and uncertainties.

Organisations and key individuals approached to participate were initially identified from existing contacts from across the industry. This list was subsequently expanded following a literature and internet search to identify those organisations actively developing devices/technology and sites. Finally, a number of contacts were made at the All-Energy Exhibition, held in Aberdeen during May 2012.

A range of information on the characteristics of each organisation was collated to ensure that the survey targeted a representative-cross section of the industry (e.g. early-stage versus more mature organisations) involved in the development of marine renewable energy, and the challenges that environmental risk and uncertainty pose to them. This included information detailing the size, age and nationality of the organisation. In addition, information regarding the maturity of their technology, customers and deployment, together with investors, to assist the analysis of the results was collated.

In total 42 organisations with a wide, technical and commercial set of attributes/characteristics were approached to participate. Upon receipt, survey responses were anonymised and respondents contacted to thank them for their participation in the study. The responses were subsequently stored in NVIVO (QSR International, 2012), enabling the coding of responses and the identification of key themes and supporting/representative quotes using a structured mixed methodology approach.

4.3 Results

In total six responses to the survey were received with one of these being an e-mail rather than full survey response. Despite the low response rate, a representative cross-section from the industry was received (Table 14), with responses being provided by a range of organisations from device manufacturers, utilities/developers and test sites. Furthermore, respondents not only included organisations from the UK but also at the European level, thus providing an international perspective on the issue of environmental risk and uncertainty.

Table 14. Characteristics of survey respondents.

Respondent	Technology			Stage		
	Wind	Wave	Tidal	Research and development	Testing/readying for commercialisation	Building and operating commercially
A						
B						
C						
D						
E						
F						

The analysis of the responses has identified a number of key issues associated with the survey questions, and these are outlined below. Example quotes and the number of respondents identifying such issues are provided.

4.3.1 The main risks facing organisations

A range of main risks were identified by the survey respondents and these are outlined in Table 15. It is clearly evident from the analysis that the consenting risks dominate respondents' concerns. In particular, the current consenting process was identified as a risk due to the lengthy consenting process, which can impact upon organisation's ability to secure commercial deals. Furthermore, there is concern that regulators are overly cautious with regards new technology, therefore restricting research and development.

> *"…we do believe that the regulator and its key statutory consultees are too cautious in dealing with new technologies, even in light of demonstrable evidence (sic)."*

In addition, concerns were also raised regarding the impact of future regulation and marine protected areas (MPAs) upon organisation's ability to gain and retain consents (Table 15).

Table 15. The main risks facing organisations.

Survey question	Responses from survey participants	Example quote	Number of respondents
What are the main risks facing your organisation?	Future regulation that will impact commercial environment.	*"…uncertainties in the renewable obligation certificate post 2017 is increasing risk to projects (especially arrays which are likely to begin operation in 2017), as investors for these projects require a level of certainty on their return which currently cannot accurately achieved."*	2 (B, F)
	The current consenting processes.	*"…immaturity of the consenting process. It is an evolving process that is hampered by a lack of regulatory capacity and experience (i.e. Marine Scotland need more personnel)."*	2 (B,C)
	Lack of EIA and environmental monitoring guidelines	*"… no international standard for marine energy environmental assessment, thus need to prove ourselves with demo projects and licensing in each and every region."*	2 (B,C)
	Unforeseen regulatory constraints due to marine protected areas.	*"Inability to develop commercially viable sites due to Environmental Designations (SPA's and SAC's) – From a consenting perspective, there is a correlation between the numbers of environmental designations to good wave energy sites."*	3 (A,B,F)
	Risk to gaining consent due to uncertainty regarding impact on marine life.	*"…marine mammal collision or disturbance effects that are currently unknown and in turn result in long consenting processes which delay a projects manufacture and installation."*	2 (B,F)
	Difficulty securing funding	*"…lack of funds for project developers."*	3 (A,C,F)
	Employee health and safety	*"Health, Safety and Environment risks to personnel."*	3 (A,B,F)
	Future consenting and regulatory environment.	*"The ultimate threat to the organisation is that the technology being developed cannot be installed in the water due to consents not being secured or due to inappropriate conditions placed upon developers as part of the consents or licences that are permitted."*	2 (A,F)

A second area of concern to respondents was the lack of guidelines on environmental impact assessment and monitoring. This was identified as posing a risk because the lack of guidance is resulting in costly monitoring burdens for organisations (Table 15). Such concerns were also coupled with a frustration caused by a perceived inability to demonstrate the low environmental impact of devices:

> *"The main issue is the inability to demonstrate how a marine energy device interacts with sensitive species in an environmentally sensitive site. Logic would say that you start small, or in a less sensitive site, to demonstrate interactions and if acceptable show a gradual build up. However the risk remains (and has materialised) that irrespective of where devices have demonstrated "no impact", the results cannot be transferred or are considered not representative for an SPA or SAC (sic)."*

Perception of risks relating to environmental impacts predominantly concerned the impact on gaining consent, *i.e.* the impact of environmental issues on commercial and technological development. Concerns regarding the impact on the marine environment itself were not apparent (Table 15). Survey responses suggested that the risk of negative impacts on the natural environment was perceived as being low:

> *"Our product doesn't create any significant environmental risk. Practically all materials used are recyclable and harmless to nature. Should an accident happen the site and environment could relatively easily be brought back to original shape (sic)."*

Other significant risks identified by respondents were health and safety risks to their employees and difficulty in gaining project finance (Table 15):

"The technology can also be held up from being deployed due to financing risks / uncertainties. For pre-commercial arrays to be installed at least £40-50m is being sourced by technology developers to consent, build and operate these projects in a weak financing climate (sic)."

4.3.2 Uncertainties

The main sources of uncertainty reported by respondents reflected the main risks reported (Table 15). The main sources of uncertainty affecting respondents' organisations were impacts on marine life, and the future consenting and regulatory environment (Table 16). Other sources of uncertainty were only identified by one respondent, these included: gaining project funding; environmental impact at commercial scale; managing subcontractors; turbulent flow loading; and 'unknown unknowns'.

Table 16. The main sources of uncertainty facing respondents' organisations.

Survey question	Responses from survey participants	Example quote	Number of respondents
What are the main sources of uncertainty facing your organisation?	Impact on marine life.	*"Absence of data from actual device/array deployments to provide sufficient evidence that there are no significant impacts to the environment or wildlife."*	2 (B,F)
	Future consenting and regulatory environment.	*"The ultimate threat to the organisation is that the technology being developed cannot be installed in the water due to consents not being secured or due to inappropriate conditions placed upon developers as part of the consents or licences that are permitted."*	2 (A,F)

4.3.3 Future Risks

Survey participants were asked to identify risks that they expected to emerge as the marine renewables sector expanded to meet UK renewable energy targets, and a wide range of possible future risks were highlighted (Table 17). Of these only two were identified by more than one respondent, these being increased conflict between users of marine resources or space and reduced political support for offshore renewables (Table 17):

Table 17. Future emerging risks.

Survey question	Responses from survey participants	Example quote	Number of respondents
What future risks do you see emerging as the marine renewables sector matures?	Reduced political support	*"…premature ending of schemes like ROC's, policy uncertainty (sic)."*	2
	Conflict of use with other marine resource or space users.	*"…conflicts of use, particularly with the fishing, oil and gas and maritime sectors (sic)."*	2
	Conflict between site specific and global environmental values at risk.		1
	Hydraulic fluid leakage.		1
	Increased public resistance.		1
	Cumulative impact from multiple projects and commercial arrays		1

4.3.4 Limiting factors

Survey respondents identified a number of factors which limited their ability to effectively manage risk. The most commonly reported limiting factors were the lack of in-house expertise on risk issues and a lack of resources (financial and manpower) that limits risk management activities (Table 18):

Table 18. Resource challenges identified.

Survey question	Responses from survey participants	Example quote	Number of respondents
What are the main factors limiting your organisation's ability to manage risk (identify, assess and mitigate risk)?	Lack of resources (financial and manpower).	*"As a small team, the formal risk management procedures can often be overlooked due to other key tasks that may take priority at the time (sic)."*	3
	Limited in-house expertise		2
	Lack of cooperation between devise developers.		1

4.3.5 Poor Response Rate

Although 42 organisations from across the marine renewables sector were invited to participate in the survey, only six responses were received (Table 14). This is despite all invitees being asked to complete the survey on three or four occasions, both by e-mail and in person at the All-Energy event, and repeated assurances that survey responses would be provided. Whilst this low response rate is highly disappointing, in some cases we were given a reason for the reluctance to complete the survey which provide valuable insights into the sector. For example, the main reason was that respondents were very busy:

> *"I am so sorry not to have undertaken the survey yet but we are locked in a very hectic business deal and I have simply not had time to address it (sic)."*

In addition there was evidence that some respondents were unwilling to complete the survey due to issues of commercial confidentiality. This may be indicative of the commercial sensitivities and competitive nature of the sector, which is still in its infancy, as identified by one respondent:

> *"Cooperation with competitors in developing the market: tidal developers generally very protective over their environmental and technical test experiences/data (sic)."*

4.4 Discussion

The overall picture from this initial scoping study is that the MRE sector views commercial risks arising from the current and future consenting process as the greatest risk it faces. Interestingly, environmental risks appear to be viewed as being low, except for those relating to consenting. This emphasis on the consenting process is reflected in the main motivations for research into environmental impacts, expressed by participants, which were to (i) demonstrate the low environmental impact of renewable energy devices and (ii) reduce the burden of monitoring and EIA for consenting. However, the apparently low level of concern regarding the potential environmental impacts associated with marine energy devices and developments, and the risk that the environment poses to them, is of concern. Indeed, this is both a surprising and potentially significant finding arising from this research. In particular, it suggests that there may be a lack of awareness of the risks that environmental processes (for example extreme events, sedimentary processes, mammal collisions) may pose to devices and developments (for example physical or reputational damage), despite the experiences from the development of offshore wind, which have highlighted the vulnerability of offshore infrastructure to such risks.

The marine renewable energy industry is currently in its infancy and it is clear that a number of challenges associated with uncertainties are manifesting themselves. In particular, the research suggests that uncertainties surrounding potential impacts on marine life and the future consenting and regulatory environment currently dominate thinking in the sector, particularly because consenting represents a key barrier to commercial development. However, a number of other observations can be made from the results that relate to the early-stage of development of the sector:

- **The organisations sampled are best characterised as risk seeking and entrepreneurial.** The organisations sampled viewed the risks produced by their marine renewable technologies as minimal. Rather, the main risks perceived by the organisations sampled were those that affected their commercial and technological development. This likely reflects the entrepreneurial nature of such a new and dynamic, emerging sector.
- **There appears to be a lack of awareness of environmental risks across the sector.** This may be explained by the current engineering and commercial focus of the industry, which centres on proving the technology, which in turn is underpinned by the requirement to gain consents. As noted by some respondents, this has the potential to result in risk management being overlooked – a particular issue in the relatively small-size of organisation's invited to participate in the study.
- **Risk management across the sector is currently immature**, with the industry hampered by a lack of resources and in-house expertise. Similarly regulators are viewed as lacking clear EIA and risk management guidance, and being perceived as being inexperienced.
- **Concerns regarding reputational risks do not appear to have begun to emerge.** The findings suggest that environmental risks are yet to be viewed as representing a potential reputational risk for the sector at present. However, it is possible that such concerns may emerge as the sector moves from the technology innovation and testing stage to full-scale deployment of devices and arrays.
- **Knowledge gaps and uncertainties**, for example, the potential impacts on marine mammals appear to be exacerbated by the lack of clear guidance from regulators and the inexperience across the sector. Such issues subsequently appear to impact upon the consenting process.
- **Commercial sensitivities are potentially hampering the development of a community of practice.** The findings from the survey suggest that the significant commercial pressures associated with the development of the

fledgling marine renewable energy industry are accompanied by a level of commercial secrecy. This in turn is hampering the potential for co-operation and shared learning across the sector.

It is suspected that many of these challenges will gradually be addressed as the sector matures, with technologies converging and a smaller number of commercial device manufacturers emerging. As the sector matures, and organisations become more established they may become less risk seeking. Indeed, Table 15 indicates that this evolution is beginning to occur, with large multi-national companies, such as ABB and Siemens investing in the sector. Such changes will potentially result in formal risk management processes gaining importance both within individual organisations and at the sector level. It may also address the issues of limited resources and expertise currently hampering risk management capability. Furthermore, the involvement of large, established power and engineering organisations may result in the involvement of risk assessment and management specialists in marine renewable energy. Indeed, it will be interesting to observe such changes alongside the emergence of new forms of risk as the industry evolves and shifts from device testing to the deployment of devices, and ultimately large arrays.

Whilst the research has provided unique insights into the risk management challenges facing those involved in the development of marine renewables, engaging the sector proved difficult because of the time and resource pressure that potential respondents were under. Furthermore, they may have been reluctant to share environmental and technical knowledge. Such issues are not solely limited to this research and have been encountered in other studies, involving the marine renewable energy industry, which the research team has been involved in.

4.5 Summary

While only a preliminary scoping study, this work was required owing to the paucity of existing understanding and practice within the MRE sector with regards to risk assessment. The study has provided valuable insights into the perception and handling of environmental risks and uncertainties by the marine renewable energy industry. Furthermore, the findings have a number of potentially important implications that the NERC MREKE programme may wish to consider:

- **There is a clear and potentially urgent need to raise awareness of environmental risks across the sector.** In particular, the development of understanding of the full breadth of environmental risks that potentially may affect the industry, not just those associated with short-term consenting issues. In particular, it appears that the marine renewable energy industry is yet to learn from the challenges that environmental risks have posed to the development of offshore wind.
- **EIA and risk management tools, training and guidance are required to support and up-skill both the industry and regulators.** Increased availability of EIA/risk tools and improved risk literacy are required to address current consenting challenges relating to lack of regulator clarity on

required risk management/EIA processes, and industry expertise in carrying out and interpreting those processes.

- **Knowledge gaps and uncertainty need to be addressed –** targeted research addressing key uncertainties and knowledge gaps is required. Such research needs to consider both physical effects and impacts alongside 'softer' organisational processes. In particular, increased clarity of the risks involved, with help identifying and streamlining EIA / risk management processes required to manage risks to an acceptable level. This would reduce industry uncertainty (and resulting nervousness) regarding how environmental aspects may affect their development/survival.
- **Engaging the sector is challenging.** The difficulties encountered when trying to engage with organisations across the sector was both disappointing but understandable given organisations' resource constraints and the commercial sensitive nature of the issues under discussion. However, it was pleasing to note that some respondents were extremely keen to be engaged with the research. This experience has potential implications for the MREKE programme because limited engagement may occur if it is felt that participation in projects will add to workloads. Thus, the MREKE programme may wish to consider whether co-ordinated approaches to engaging stakeholders may prove beneficial in future to ensure that stakeholder fatigue does not set it. Similarly, it may wish to consider possible approaches for building trust and effective working relationships with both individual organisations and the wider marine renewable energy industry. In particular the MREKE programme may wish to learn from the types of approaches that have been successfully applied in research involving other highly sensitive issues such as the Adaptation Reporting Power and Shoreline Management Planning (SMP) processes.
- **Information sharing and the development of a community of practice are required.** The MREKE programme may wish to consider means by which the sector could be encouraged to share information and develop a community of practice. Such an effort would however, have to be sensitive to the commercial interests of the parties involved.

5 GAP ANALYSIS

As is evident from the preceding sections there are a number of issues relating to risk and uncertainty in the MRE sector and these translate to problematic decision making and policy formulation. To draw together the findings from this review and highlight where future developments and research should be directed we have undertaken a simple gap analysis. Through the gap analysis we have considered a) the current situation regarding risk and uncertainty, b) where the topic should be in the future, and c) what needs to be done to get there – known as the 'bridges' (Fig. 16).

Recommended Scenario		Current Scenario
Well defined protection goals exist	1	Little high-level guidance on the acceptable balance between energy provision and protection exists.
A consistent definition of risk exists	2	Definitions of risk are inconsistent. Often, environmental impact is confused with "risk".
A structured approach to risk assessment is employed across the board, which includes (1) problem formulation with stakeholders (2) risk assessment (3) identification of management options (4) risk management	3	No structured approach to risk assessment amongst the MRE community. Heavy reliance on EIAs which (mostly) fail to consider: likelihood, social/economic/ other non-environmental impacts, pathways for impact Given they do not consider the "risk" in its entirety, EIA's also fail to facilitate informed prioritisation.
Risk assessment consistently considers: 1) source identification 2) hazard identification ("what") 3) pathway identification ("how") 4) receptor identification ("who" or "what" is affected) 5) conceptual model development 6) a realistic assessment of consequences (as opposed to the "worst case" scenario) 7) location/ distribution ("where") 8) timescale ("when") 9) likelihood of hazard/ event occurring 10) likelihood of exposure 11) likelihood of exposure having an impact on the receptor (is the receptor sensitive?) 12) overall risk	4	Few organisations are currently able (or required) to provide this information. As such, decision-making is based on incomplete information with no real view of the level of risk posed by devices. In particular, EIA's
Uncertainties are identified in all risk assessments, and assessed and communicated using a standard framework. Where possible, this is includes sensitivity analysis.	5	Much current reporting fails to acknowledge the type/ source of uncertainty (e.g. lack of data/ natural variability); A lack of sensitivity analysis also means it is currently not possible to know whether the level of uncertainty has a real impact on possible level of risk.

	Recommended Scenario	Current Scenario
6	Where probabilistic modelling is employed, the outputs are user friendly, and communicated using existing frameworks (e.g. section 3.5)	The complexity of probabilistic methods has overwhelmed decision makers in many organisations, creating a barrier for adoption.
7	Sufficient knowledge is available to assess the likely impact of hazards on receptors	Only a select few organisms are fully characterised in terms of sensitivity to hazards. This leads to an undue focus on “known” species and fails to highlight risks to other species/ environmental assets.
8	ALARP approaches are employed. Risks are reduced as low as reasonably possible, without exceeding cost-benefit thresholds	Whilst not widely employed in MRE, the offshore health and safety sector uses this approach regularly.
9	Regulators and industry engage with a range of experts to feed into and critique A) assessment frameworks and B) the assessments themselves.	There is a lack of engagement between regulators, academia, industry and the third sector. Failure to engage is likely to result in less-informed frameworks, assessments, and decisions. Valuable data and opinions must be better extracted from these communities and shared.
10	Risk assessment is consistent across the industry	A lack of standard reporting procedures means that risks are incomparable and therefore it is not possible to prioritise.

Link	Recommended Scenario	Current Scenario
11	Risk appetite and 'scales' are well defined and inform the risk matrix. This in turn allows simple prioritisation of risks.	There is no industry standard definition on what is considered to be "high, medium or low" risk to key receptors. i.e. the loss of one marine mammal may be interpreted as very high, or very low, dependant upon the person assessing the issue.
12	The risk assessment process is iterative.	Risk assessments are conducted prior to instalment, but are not reviewed afterwards. Any re-assessments are currently unlikely to change practice.
13	Horizon scanning is integrated into assessments.	Industry does not currently consider the emerging issues or stressors that may change the results of a risk assessment.
14	Risk assessment takes a systemic and integrated modelling approach that recognises cumulative risk.	Current approaches do not employ bottom-up approaches which detect drivers of exposure, interdependencies, possible areas of cumulative risks, and areas for intervention (either at pathways or nodes in the system). Popular methods are: • Expert models – top-down in approach; do not fulfil the requirements of the risk assessment, not always ;successful in identifying pathways. • Scenario models – resource and time consuming; restricted number of pathways analysed; subject to bias; less able to pick up emerging issues.
15	The industry is aware of the environmental risks, and the impact this might have on reputational risk	Risks from marine renewables are seen as minimal, with the focus on internal organisational risks. Organisations also fail to consider the reputational risks associated with environmental issues.
16	Regulators and industry work towards a mature risk management capability	The lack of proper frameworks, awareness, communication mechanisms, and culture
17	Industry, regulators and academia work together as a true community of practice	Information sharing is limited by commercial sensitivities and links between sectors are not typically strong.

Figure 16. Gap analysis highlighting current scenario based on the MREKE review (right column) and recommended scenario (left column) for addressing the risk and uncertainty KE gaps for MRE sector. The numbered links represent where action is required i.e. the 'bridges' (see Section 8 Recommendations).

6 AN INTEGRATED CONCEPTUAL FRAMEWORK

As a result of the review that we have undertaken it is clear that in order to ensure that the MRE sector take into account risk and uncertainty some form of integrated assessment is necessary. The current document provides the evidence that this is not currently happening; there is a real and significant imbalance to the way in which the MRE sector is set up to deal with risk and uncertainty in whatever form. Here we suggest that the development of an integrated risk framework is key to addressing the issue.

An integrated framework is a logical structure that enables organisations to assess a variety of different risks and issues from a common perspective. The ability to assess risk from a common structure is important for providing consistent and relevant risk information to decision makers. The aim of the framework is to provide a means for comparing different risks in a fair and transparent manner.

Comparing different risks is very challenging due to the variability of their character and the different values stakeholders may place on an issue. This can lead to subjective bias, difficulties in reproducing comparison and consequently poor decision making. Notwithstanding these difficulties, a comparison of risk decisions must be made and invariably these comparisons will be made implicitly. Hence, there is real value in including a stage of risk comparison so that organisations can aim to prioritise their risks and thus maximise their efforts and resources by targeting the risks that pose the greatest threat to the organisation. Here we present a basic framework for integrated risk assessment that explicitly includes risk comparisons and the inherent uncertainty.

6.1 An Integrated Risk Assessment Framework

Risk principles for managing industrial systems have evolved over the years. In the beginning industrial systems (e.g. waste facility) were considered as being self-contained and risks were identified and managed from within the system boundaries. This approach did not consider the wider impacts a system may have on the environment or society as a whole. Although this approach greatly improved the level of safety for many industry systems it neglected to consider that many impacts (e.g. environmental and social) do not subscribe to the boundaries of a property or a nation. This desire to address the broader risk beyond the system boundaries led to the development of integrated frameworks that take a holistic approach to risk and consider the environmental, social and economic impact of activities in the broader sense. Further developments in the field have begun to address the risk posed by an organisation itself. Consideration is given to an organisations risk management culture, its maturity, its record and its long term intentions. Moving away from being a tick-box exercise, risk management is quietly becoming a means for the operator, the public and the regulator to understand the risks posed by an industrial process in its entirety.

Frameworks that attempt to provide a holistic assessment of risk have been implemented in the chemical and waste sector. The EU Seveso II Directive was aimed at the chemical industry and guided the development of integrated frameworks that not only prevented major accidents but also aimed to limit the impact these accidents have on the wider society and the environment. Subsequently in the UK, the Control of Major Accident Hazard Regulations 1999 (COMAH) were developed, which incorporated an integrated framework to consider risk beyond the traditional boundaries of the industrial system and brought together multiple regulatory bodies (e.g. Health and Safety Executive and the Environmental Agency).

A more recent example of implementing an integrated framework occurred in the offshore sector. Although the UK offshore sector has a strong record and culture of safety (driven by the development of Safety Cases; a response to the Piper Alpha accident) the use of Safety Cases has been criticised as not providing a holistic response to risk, namely the integration between safety and environmental regulation. In October 2011 the EC published the 'Proposal for a Regulation of the European Parliament and of the Council on safety of offshore oil and gas prospection, exploration and production activities' which highlighted two main problems with offshore safety across the EU:

1) 'The risk of a major offshore oil or gas accident occurring in Union waters is significant and the existing fragmented legislation and diverse regulatory and industry practices do not provide for all achievable reductions in the risks throughout the Union'.

2) 'The existing regulatory framework and operating arrangements do not provide for the most effective emergency response to accidents wherever they occur in Union waters, and the liabilities for clean-up and conventional damages are not fully clear'.

Proposition of this regulation was intended to harmonise regulation in the EU and to ensure operators consider every possible risk, both environmental and operational. The intention was to: a) ensure consistent use of best practices for major hazards associated with offshore operations; b) introduce best regulatory practice across all EU jurisdictions; c) strengthen the EU's preparedness and emergency response; and d) improve clarification of existing EU liability and compensation provisions.

Within the emerging marine renewable sector there does not exist a cohesive strategy for assessing and managing risk. Though aspects of this sector are regulated the guidance is disjointed and unbalanced and there is high uncertainty when considering the environmental risks. Therefore, we propose that the sector requires an integrated framework, similar to those in the hazardous chemical and offshore sectors that provides a holistic perspective of risk and brings together multiple stakeholders.

The outline framework, shown in Figure 17, links sector specific risk assessments with larger, systems oriented analysis which then feeds into a risk comparison and strategy development. Importantly, the framework requires that no risk assessment be completed in isolation. Rather, the risks posed by an activity should be considered in the broader operational context of the organisation, no matter their magnitude, to ensure that risk management strategies developed are both appropriate and cost effective.

The framework is not purely linear and includes a series of feedback loops that enable stakeholders and decision makers the opportunity to reassess decisions in the event that further information is made available (i.e. an adaptive framework). In this respect the framework becomes a living document that requires continual update and evaluation. Such an approach provides more value to the decision makers and stakeholders than a static, snap-shot assessment of risk that, once completed, ends up on the shelf never to be viewed again.

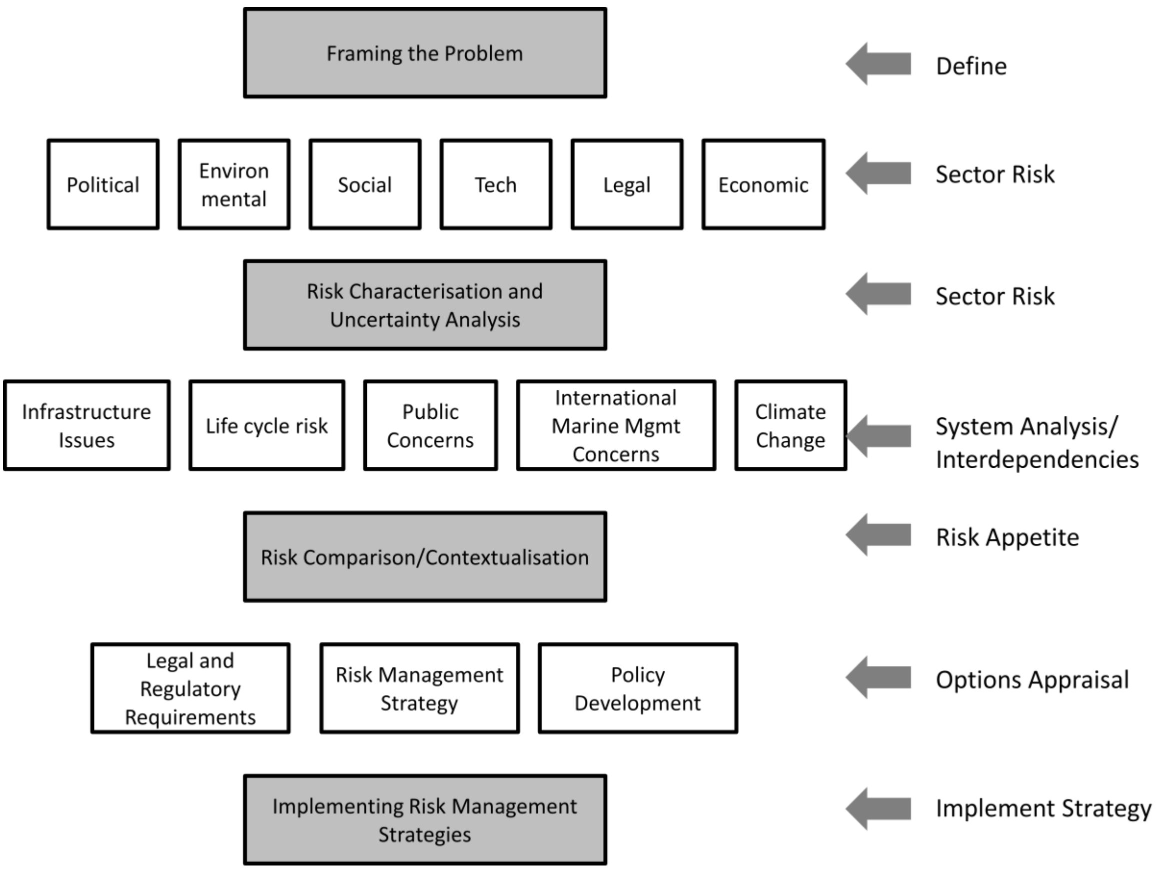


Figure 17. Adapted framework for integrated risk assessment and analysis (based on Ram, 2009).

7 CONCLUSIONS

The review presented here demonstrates the current status of risk and uncertainty understanding and approaches applied within the MRE sector. The main conclusions are:

In the review of the risk baseline for UK MRE the overriding picture was that risk assessments were sparse and generally supplemented or substituted with the outputs of the environmental impact assessment (EIA) process. An EIA considers the effects an activity may have on the environment, the spatial and temporal variability of those effects, the cumulative nature of the effects and the sensitivity of the environment to the threat. Numerous guidance documents for conducting EIAs for marine renewable energy development exist. They are prescriptive and systematic intended to provide developers and decision makers a comprehensive understanding of potential impacts. However, of the guidance reviewed, few suggest an assessment of risk when considering strategies for mitigating impacts. The EIA does not provide an understanding of the risks derived from a particular activity. Of the EIA guidance that does provide some form of assessment of likelihood of adverse effects it is often insufficient to inform a complete assessment of risk.

Some guidance suggests that the EIA should consider the likely worst case variations within a project. These may then be assessed according to significance and then prioritised (i.e. the Rochdale Envelope). However, assessing and prioritising worst case scenarios with no concept of their likelihood to occur may lead to disproportionate mitigation.

Most EIA guidance takes a structured, repeatable approach not unlike risk frameworks, which provide similar clarity and rigour to investigating an issue. However, the difference is that risk frameworks enables decision makers to address those issues that pose the greatest risk or threat, rather than manage all issues regardless the likelihood of their occurrence.

Based on the review, it appears that currently the UK MRE industry does not possess a clear, well-articulated framework for assessing risk. Assessing the quality, reliability and relevance of experimental or empirical evidence, and the underpinning conceptual model, is an important part of risk assessment and related management decision making.

Some of the MRE stressor-receptor relationships appear to be well researched whilst others have very little research evidence. The greater the knowledge we have on stressors then the more confident we can be about the type of effects we might expect to find. We can then look for receptors that are considered vulnerable or likely to respond to the stressor. However, determining this is highly dependent on our knowledge of which organisms or processes are vulnerable to change.

Reviewing other marine sectors raised a problem of variability in what was termed ‘risk’. Either the risk was not properly understood or environmental impact was considered as a proxy for risk. This mistake has been repeated in the marine renewable energy sector. For risk to be properly assessed there must be a consideration of the source-pathway- receptor, the magnitude or extent of exposure to a hazard and the likelihood of the hazard occurring.

There were however some approaches applied in other marine industries that were useful in defining risk and promoting some methodology by which the risk could be assessed. When assessing the ecological impact it is important to consider the likelihood that a change or activity will occur as predicted and also the degree of confidence in the assessment of the impact on ecological structure and function. Scales for assessing likelihood and confidence are the main method applied. For issues related to offshore development, where evidence is scarce expert, judgment may be relied upon to provide objective assessment of likelihood and confidence.

In the Offshore Sector health and safety applies the ALARP principle (As Low As Reasonably Possible) to manage risk. This principle relies upon a robust assessment of realistic risk, not simply worst case scenarios, and then determines how this risk can be managed.

The risks associated with climate change represent a significant uncertainty for decision-makers. A range of approaches, aimed at addressing the challenges posed by climate change risks and their uncertainties are an important source of lessons that are relevant to the marine renewable energy sector. The explicit consideration, characterisation and communication of uncertainty are approaches that are commonly used by those addressing uncertain climate change risks. The result has been a categorisation of knowledge and the relationship between evidence, the level of agreement, and its relationship with confidence with increasing scientific agreement or consensus and more evidence resulting in improved confidence.

A variety of methods are available to communicate confidence and many explicitly highlight the information gaps that exist. The main objective is to identify optimal strategies in the face of uncertainty, make strategies resilient and adaptive and identify low regret but large benefit measures.

The precautionary principle is also highlighted as a way to address uncertainty; however, it is key to acknowledge the limitation of adopting the precautionary approach is that it can prevent adaptation or change.

Alongside the range of different approaches, there is an accompanying recognition (such as from Defra) that underlying support frameworks are necessary to underpin and deliver adaptation. Furthermore, the right information is needed to make effective decisions and a mix of adaptation measures may be necessary and when decisions may be either difficult or expensive to revise in future they should receive additional scrutiny. Adaptation measures should be effective, efficient and equitable.

Whilst risk assessment and uncertainty estimation methods for supporting decision-making for marine renewable energy projects are currently lacking, another challenge facing the marine renewables industry, is how industry and individual organisations perceive the handling of environmental risks and uncertainties, termed here as ‘organisational risk appetites’.

Following a scoping survey with an open-ended questionnaire, a number of key issues were raised (although based on a small number of respondents). The most prevalent issue was consenting risk, particularly the length of the process and concerns regarding the impact of future regulation and marine protected areas (MPAs) upon an organisation’s ability to gain and retain consents. A second area of concern to respondents was the lack of guidelines on environmental impact assessment and monitoring.

Other significant risks identified by respondents were health and safety risks to their employees and difficulty in gaining project finance. The main sources of uncertainty reported by respondents reflected the main risks reported namely impacts on marine life, and the future consenting and regulatory environment. With regards to the future, increased conflict was a concern between users of marine resources or space and reduced political support for offshore renewables. A number of factors which limited ability to effectively manage risk were the lack of in-house expertise on risk issues and a lack of resources (financial and manpower) that limits risk management activities. The low response rate to the survey was either because of time or commercial sensitivity.

There is a clear and potentially urgent need to raise awareness of environmental risks across the sector. EIA and risk management tools, training and guidance are required to support and up-skill both the industry and regulators. Knowledge gaps and uncertainty need to be addressed. Engaging the sector is challenging; information sharing and the development of a community of practice are required.

8 RECOMMENDATIONS

It is evident from the review that the disparate nature of the environmental risk and uncertainty relating to the MRE sector has to be dealt with effectively to ensure that the current problems and constraints that exist are appropriately considered and addressed.

Based on the gaps identified in through this review project we have a number of recommendations. The numbered bridges in Fig. 16 link to our main recommendations.

Bridges 2-4, 10, 11, 14: Methods
There is a real and significant imbalance to the way in which the MRE sector is set up to deal with risk and uncertainty. What is required is the **development of an integrated risk framework developed for the MRE sector,** employed uniformly across government, industry and academia. Such a framework would ensure the **consistent use of terminology, method, and assessment criteria**. The proposed integrated framework (Fig. 17), based on those developed in other more risk mature sectors should be considered as a starting point from which to develop a balanced and integrated approach to dealing with environmental risk and uncertainty.

The aim of the framework is to provide a **structured means for assessing and comparing the variety of risk issues that impact the MRE sector** (e.g. environmental, economic, social). The integrated framework will extend the process boundaries to consider both direct and indirect impacts across multiple levels. This needs to be achieved in a fair and transparent manner to provide consistency and comprehensiveness to environment risk and uncertainty assessment.

The integrated framework will **provide the structure for which evidence may be incorporated to address and mitigate environmental risk and uncertainty**. By providing a logical, organised pathway for assessment, decision makers can identify areas where further research and evidence is necessary. In addition, this provides opportunity for targeted allocation of research resource as well as indicating the appropriate tools at the appropriate scales to reduce uncertainty.

The framework can then become the focal point for industry, decision makers and the public and as new knowledge becomes available it can be added into the framework. The **framework will also guide research needs**, likely highlighting requirements for research conducted with an industry relevant context, for example research investigating the interface between MRE and marine organisms. This will provide policy relevant evidence that should stimulate debate and provide decision makers the confidence they require to make decisions under conditions of uncertainty.

From the **industrial perspective, an integrated framework will indicate the focal points they have to manage in terms of their own assessment of environmental risk**; will suggest the monitoring that they have to implement and will improve the quality of environmental risk assessments by making explicit the expectations of the regulator.

Bridges 5-6: Uncertainty

There is a **distinct need to develop robust, yet simple and understandable ways to communicate uncertainty**. Official guidance which draws on the wide range of existing frameworks would be useful in achieving this goal. However, we note that in order for these tools to be utilised by decision makers, **it is crucial to build capacity and confidence in uncertainty methods**. Currently, uncertainty acts as a barrier to progress/ decisions in many sectors. We believe a combination of **training**, and the use of robust methods with simple outputs, will raise the utility of uncertainty assessments. Critically, we believe **sensitivity analysis answers the "so what" question** to uncertainty, and allows decision makers to see whether the level of uncertainty is important to their decision.

Bridge 7: Lack of knowledge

The quality of a risk assessment is to some extent, reliant on the quality and availability of data, information, and knowledge. **The current lack of evidence must be addressed by conducting research in a balanced way, across all stressors and receptors**. Undue focus on particular receptors will ultimately encourage risk assessments to be narrow in scope, with a great deal of uncertainty about the true impacts of risks to the system as a whole.

More directed funding is needed, not only to generate increased knowledge, but also to ensure that it is shared widely and incorporated into risk assessments throughout the industry. Critically, this information should be accessible and not published in academic journals alone.

State of the art knowledge, which moves the agenda forward, must be incorporated into risk assessment frameworks as it becomes available. In doing so, decision makers will have timely access to supporting evidence.

To facilitate this knowledge uptake, we recommend **the generation of an online "MRE evidence base**" service which aims to **regularly review new published evidence in the field, and translate this knowledge into short, useable "evidence snippets" which are uploaded to an online system**. Individuals undertaking a risk assessment could then access the database, and quickly access existing information relating to likelihood, modelling studies, receptor impacts/ sensitivity and more. We envisage **such a tool would be useful to regulator, industry, and academic users, and could include a monthly/ quarterly newsletter service alerting it's users to new evidence** and research. Based on the experience of the research team, it is important to ensure that the organisation tasked with this important knowledge exchange activity has the capacity to develop such tools.

Bridges 8, 15-16: Awareness raising and capacity building

In order to raise awareness of the environmental risks associated with the MRE industry, a **programme of intense knowledge exchange** is required. A targeted combination of conferences, free online webinars, secondments, guidance documents, e-newsletters, online resources, and face to face meetings are likely to enhance the level of awareness amongst developers and operators. **Evidence of environmental impacts should be communicated in an open forum** between industry, academia and government with the overall goal of working together to facilitate a sustainable industry.

Only when these organisations incorporate all types of risk (particularly environmental risk) into their management activitie, can they work to achieve a mature risk management capability and generate value from this activity Good risk management offers competitive advantage by increasing resilience, improving corporate social responsibility initiatives, providing a degree of 'reputational protection'. We envisage that the development of matrure risk management practice across the community could be achieved through the **provision of training and workshops** (free to the regulated community, in addition to practical guidance documents which provide step-by step tutorials on how good risk management van be incorporated into existing practices.

Bridges 17 and 9: Engagement

True communities of practice are mostly self-organising communities with shared goals and resources, who regularly engage in a common practice. The community members continuously learn together through mutual engagement, which requires open engagement of regulators and industry with a range of experts to assess, critique and update current frameworks and the risk assessments. There is also a critical need to specifically address the issue of information sharing, which is currently limited by commercial sensitivities and lack of links between those involved in the MRE sector.

Additional recommendations

A further key recommendation is that whilst the existing regulations and policies appear to allow for the handling of uncertainties and consultation regarding them, at the moment the decision making processes is rather opaque. Hence, there is a **critical need for transparent and risk based processes** to accompany them.

In addition, because the knowledge base is so patchy and unbalanced it is important that the **decision makers draw on a wide set of expertise**, such as through an expert panel.

Innovative risk communication tools – the research has highlighted the need to develop new methods for communicating and comparing the uncertain environmental risks associated with marine renewable energy developments. In particular, innovative approaches for communicating uncertainties and visualising the marine environment are urgently required. Such tools are of importance if the potential risks and opportunities relating to the future growth in marine renewable energy are to be discussed in the types of participatory decision-making processes that will be required if the envisaged expansion of the industry is to be realised.

To address this challenge, a preliminary exploration of interactive methods for communicating risks and uncertainties using tablet devices has been undertaken as part of this project (Fig. 18). This has already illustrated the potential of such technology, which may prove valuable in a range of situations, from discussions between scientists, policy-makers and developers, to engagement with local communities. Indeed the research team is already planning pursue further funding to develop this exciting area of research.

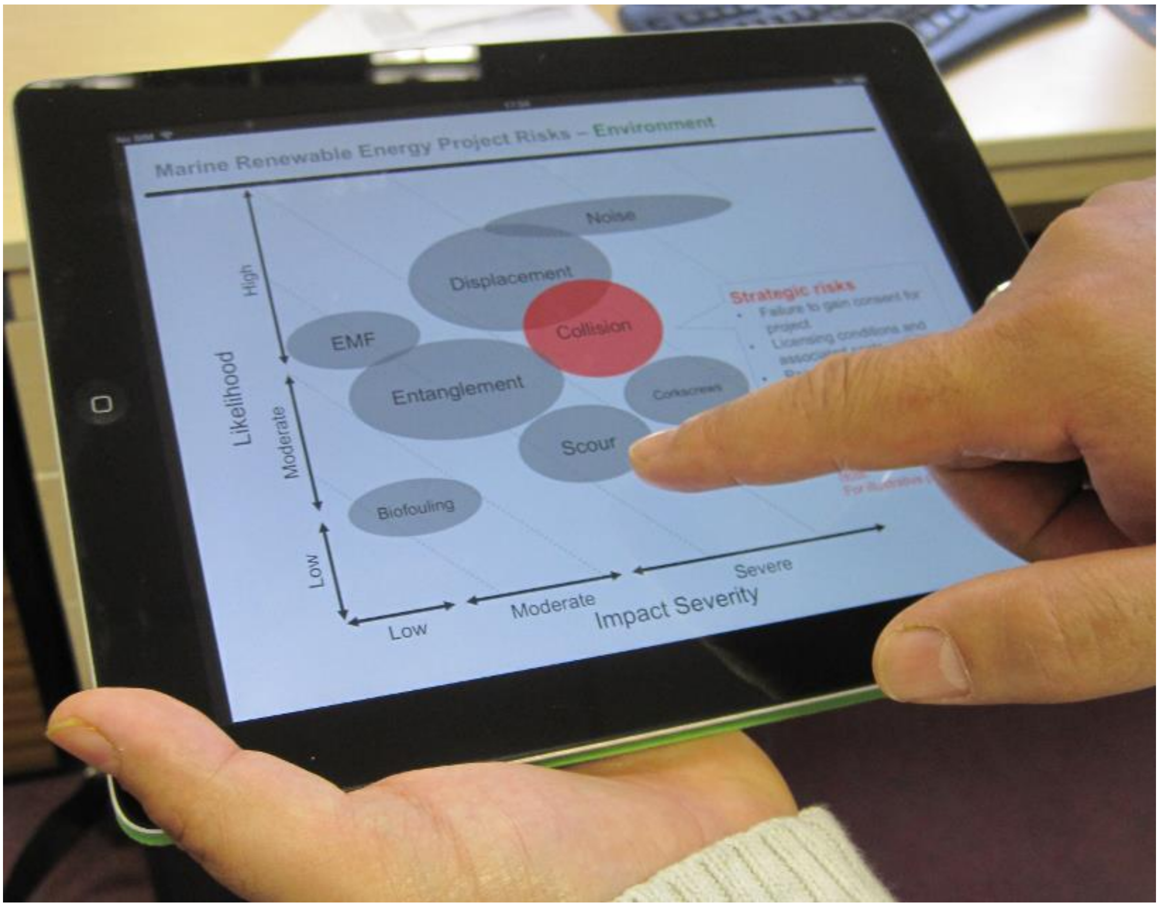


Figure 18. An example of ppreliminary exploration of interactive methods for communicating risks and uncertainties using a tablet device.

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10 APPENDICES

10.1 Literature Review Tables

[TO BE ADDED or CD-ROM?]

10.2 Survey Questionnaire

[TO BE ADDED or CD-ROM?]