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# Development of risk profiling

# Deliverable 3.3


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# RiCORE Project Synopsis

The aim of the RiCORE project (Risk based Consenting for Offshore Renewable Energy) is to establish a risk-based approach to consenting where the level of environmental survey required is based on the environmental sensitivity of the site, the risk profile of the technology and the scale of the proposed project. The project, which has received funding from the European Union's Horizon 2020 research and innovation program, will run between January 1$^{st}$ 2015 and June 30$^{th}$ 2016.

The consenting of offshore renewable energy is often cited as one of the main non-technical barriers to the development of this sector. A significant aspect of this is the perceived uncertainty inherent in the potential environmental impacts of novel technologies. To ensure consents are compliant with EU and national legislation, such as the Environmental Impact Assessment Directive (85/337/EEC) and Habitats Directive (92/43/EEC), costly and time consuming surveys are required even for perceived lower risk technologies in sites which may not be of highest environmental sensitivity.

The RiCORE project will study the legal framework in place in the partner Member States to ensure the framework developed will be applicable for roll out across these Member States and further afield. The next stage of the RiCORE project is to consider the practices, methodologies and implementation of pre-consent surveys, post consent and post-deployment monitoring. This will allow a feedback loop to inform the development of the risk-based framework for the environmental aspects of consent and provide best practice. The project will achieve these aims by engaging with the relevant stakeholders including regulators, industry, and EIA practitioners, through a series of expert workshops and developing their outcomes into guidance.

A key objective of the project is to improve consenting processes in line with the requirements of the Renewable Energy Directive (2009/28/EC) (specifically Article 13-1) to ensure cost-efficient delivery of the necessary surveys, clear and transparent reasoning for work undertaken, improving knowledge sharing and reducing the non-technical barriers to the development of the Offshore Renewable Energy sector so that it can deliver clean, secure energy.

# Executive Summary

The main aim of the RiCORE project is to ensure the successful development of Offshore Renewable Energy (ORE) in the EU Member States by reducing the cost and time taken to consent projects of low environmental risk through the development of a risk based approach to the consenting of projects which standardises the assessment of key components of environmental risk from ORE deployment.

The starting point will be the “Survey, Deploy and Monitor Licensing Policy Guidance” (SDM) that was pioneered by Marine Scotland[1], and the project will look separately at the potential utility of a risk based approach to reduce time and cost when securing consents during both pre- consent surveying and post- deployment monitoring. The SDM policy is a tool to provide regulators and developers with an efficient risk-based approach for taking forward wave and tidal energy proposals, facilitating a phased/staged development approach (avoiding sensitive environments).

This deliverable aims to contribute to the further development of the Survey, Deploy and Monitor (SDM) policy guidance, pioneered by Marine Scotland, acting as a guide for users wishing to apply a risk based approach at a Member State level. For this, a review and further development of the three main pillars on which this approach is based has been undertaken: (i) environmental sensitivity of the site, (ii) the risk profile of the technology and (iii) the scale of the proposed project.

Section 3 reviews the approach undertaken in Scotland for environmental sensitivity assessment with a view to informing consideration of those aspects other Member States may wish to further develop.

Section 4 address the identification of the main impact pathways of MRE developments over the marine environment based on the technology identification undertaken by Deliverable 3.2 (Mascarenhas *et al.*, 2015).

[1] http://www.gov.scot/Topics/marine/Licensing/marine/Applications/SDM

Section 5 refine or improve the parameters used to describe the scale of the project introducing the physical scale of the project (area of occupation and generation capacity) and the duration of the project parameters.

Section 6 develops the methodology for the overall assessment of the risk posed by a project, based on assessments of environmental sensitivity, project scale, and technology risk according to the proposal undertaken in previous sections.

# 1. INTRODUCTION

As the world turns increasingly toward renewable energy sources, the **potential risks of renewable energy development** to various ecological receptors will require approaches that can both predict potential harm and be used to identify key research needs to understand and tolerate the risk to eco-receptors before and during operations. **Risk** is basically a measure of the probability and the magnitude of adverse consequences of an event (Suter and Barnthouse, 1993). According to ISO 31000[2], **risk assessment** includes three different steps (Figure 1):

1. *Risk identification* involves the identification of risk sources, areas of impacts, events (including changes in circumstances) and their causes and their potential consequences.

2. *Risk analysis* involves the processes to comprehend the nature of risk and to determine the level of risk, providing the basis for risk evaluation and decisions about risk treatment.

3. *Risk evaluation* involves the processes of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude are acceptable or tolerable, assisting in the decision about risk treatment.

**Ecological Risk Assessment (EcoRA)** is a *flexible* process for organising and analysing data, assumptions, and uncertainties to evaluate the likelihood (probability) of adverse ecological effects that may have occurred or may occur as a result of exposure to one or more stressors related to human activities (Hope, 2006). Ecological risk assessment is increasingly seen as a way to integrate science, policy, and management to address the wide array of ecological impact assessment problems (Cenr, 1999).

[2]ISO 31000:2009(E). Risk management — Principles and guidelines, ISO copyright office, Geneva, Switzerland, www.iso.org, p 34.

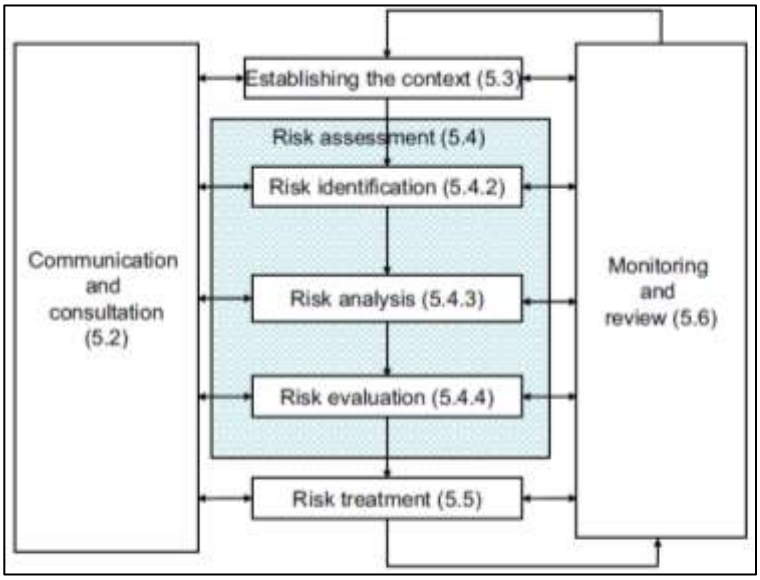


**Figure 1.** Risk management process (from ISO 31000[1]).

The *advantages* of following an ecological risk assessment framework are two-fold: (a) it provides a framework for gathering data and evaluating their sufficiency for decision-making and (b) recognises, considers, and reports uncertainties in estimating adverse effects of stressors (due to natural variation of ecosystems and species populations, uncertainty is always present to some extent) (Chapman and Wang, 2000).

Moreover, EcoRA is an *iterative process* that consists of three phases (Usepa, 1998) (Figure 2):

1. Problem formulation
2. Analysis
3. Risk characterization.

According to Harman *et al*. (2004) the results of an ecological risk assessment can be used to: (i) determine the risk to the environment posed by energy development activities; (ii) whether those risks require remediation; and (iii) to develop potential remedial responses.

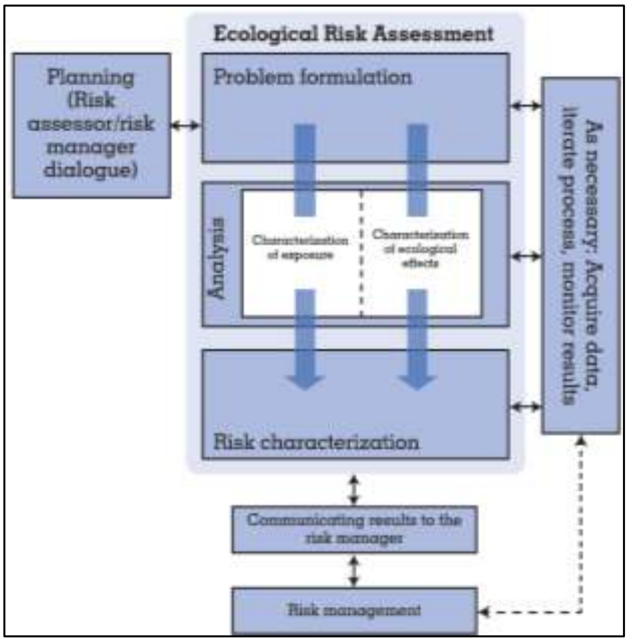


**Figure 2.** Ecological Risk Assessment process (from USEPA 1998).

Some challenges facing EcoRA include the following:

- Integrating the concerns of stakeholders and risk managers with the scientific knowledge of risk assessors.
- Conducting risk assessments that encompass large areas and involve multiple stressors.
- Moving beyond effects on individual organisms and species to predicting changes in populations and ecosystems.
- Communicating ecological risks to stakeholders.

EcoRA is a *well-founded method*, that, in addition to its many applications on land, has been used in marine renewable energy (Nunneri *et al.*, 2008; Boehlert and Gill, 2010; Stelzenmüller *et al.*, 2010; Burger *et al.*, 2011; Chou and Ongkowijoyo, 2014; Hammar *et al.*, 2014). It has been proved as a suitable tool for structuring the complexity and uncertainties associated with ecosystem-based assessments of emerging ocean energy technologies. Hammar *et al*. (2014) applied an EcoRA on an offshore wind farm project to ensure an environmentally acceptable development and help regulatory authorities to make informed decisions. It can be used to allow developers to take responsibility for decisions on pre-application data gathering, to fully understand the rationale behind any proposed data collection and understand the costs and benefits of any survey work. It allows developers to understand the risks of not collecting sufficient information to inform an adequate EIA and the subsequent restrictions which might result, in the form of mitigation measures and other license conditions (Sparling *et al.*, 2015).

Apart from using the information gathered from an EcoRA for making decisions about managing offshore exclusion zones, it can be also used for establishing public policies (Burger *et al.*, 2011). In this context, Scottish Government adopted **a risk-based approach to consenting** prototype and first iteration devices and arrays in their receiving environments through the development of the **Survey, Deploy and Monitor (SDM) Policy**[3] for wave and tide harnessing projects. SDM aims to enable flexibility in the Marine Scotland approach to site characterisation and monitoring in relation to the environmental impacts of marine devices. Regulators, and statutory advisors such as Scottish Natural Heritage (SNH), are able to discuss the relative risks associated with different developments in different locations, and take a balanced and proportionate view of the significance of the environmental issues raised in each case. With the growing and competing demands for marine resources, it aims to reduce the complexity of marine management and ultimately improve the regulatory framework for marine renewables.

[3] http://www.gov.scot/Topics/marine/Licensing/marine/Applications/SDM

## 2. OBJECTIVES

The general objective of this deliverable is to contribute to the further development of the Survey, Deploy and Monitor (SDM) policy guidance, pioneered by Marine Scotland, acting as a guide for users wishing to apply a risk profiling approach at a Member State level. Conclusions are presented in the format of a checklist of the issues where scope for further development of risk profiling has been identified by the RiCORE project.

In order to achieve this general objective, the present deliverable uses the SDM approach developed in Scotland as a case study. Consideration is given to where the SDM approach is considered best practice and where further development of risk profiling is recommended for each of the following:

a) **Environment**: developing the risk profile for environmental sensitivity. Through review of the profiling of environmental risk undertaken by Marine Scotland, options for refining the approach at a Member State level are considered.

b) **Technology**: developing the risk profile of the novel technologies identified in Deliverable 3.2 and improving the profiling for wave and tidal technology with international experience to ensure robust basis for decision making under the policy. This section reviews current state of knowledge with respect to important impact pathways between stressors and receptors. The content can be used to inform technology risk profiling undertaken at Member State level, recognizing that the evidence base for the significance of impact pathways is likely to change over time.

c) **Scale**: agreeing commitment to what constitutes small, medium and large scale for the different technology types. This is previously defined for wave and tidal as <10MW, 10-50MW and >50MW. New recommendations are provided.

These tasks will take on recommendations from: (i) task 2.3 (D2.3) to ensure the risk profiling will be universally recognised and accepted; (ii) task 3.1 (D3.1) which undertook a review of the of the SDM policy in order to set the basis for the further development of the policy to other novel technologies and the insertion into partner Member State policies and (iii) task 3.2 (D3.2) which undertook a review of novel technologies currently in development, focusing on TRL 5 – 9 but ensuring the scope includes the next tranche of technologies that are being developed, in particular to expand to include the range of emerging floating wind technologies.

The deliverable builds on the findings coming from Expert Workshop 3 held in Dunkeld, Perthshire (UK) on 9-10$^{th}$ November 2015.

# 3. ENVIRONMENTAL SENSITIVITY

## 3.1 Background

This section reviews the approach undertaken in Scotland with a view to informing consideration of those aspects other Member States may wish to further develop. In developing the Survey, Deploy and Monitor (SDM) policy, Marine Scotland created a map based profile of environmental sensitivities. Environmental sensitivities were characterized for wave energy, tidal energy as well as offshore wind energy devices. The methods used are set out in scoping study documents for each set of technologies and are published in the Scottish Marine and Freshwater Science Report services (Davies and Watret, 2011). The data used to create individual sensitivity layers were considered the best available at the time and were largely held by the Crown Estate in their in-house geographic information system called Marine Resource System (MaRS) (Davies *et al.*, 2012).

The scoping studies that informed the development of the SDM policy environmental sensitivity mapping was undertaken on a grid scale of 1.8 km which reflected the scale at which the resource areas had been mapped. The reports acknowledge that those resource areas and associated sensitivities that occur at smaller spatial scales may have been poorly represented. This is most likely to be the case for tidal stream resource owing to the large number of small areas around Scotland that can have powerful flows. These include areas at headlands, and areas around sills at the entrances to sea lochs (and separating basins within sea lochs), and in channels and sounds between islands and between islands and large land masses. For similar reasons, the mapping undertaken may not have included very localised environmental sensitivities, emphasizing the indicative nature of the exercise.

The scoping studies undertaken in 2011 updated a previous report published in 2010 (Harrald *et al.*, 2010), incorporating new information on the environment, together with updates in the way underlying data were handled. This reflects a policy strategy to continually use the best available scientific evidence, particularly in relation to interactions with novel devices whose potential impacts have associated scientific uncertainties that are likely to reduce through time. This is recommended as best practice because conclusions are sensitive to technical factors, such as the categorisation of environmental data layers as either representing complete or partial constraint on location of marine renewable energy, the weighting applied to the layers, and the classification system used to create the overall scores.

## 3.2 Approach

In creating a mapped representation of environmental sensitivity to inform the SDM policy it was necessary to make a number of decisions regarding data and their use in models that will apply equally to any similar exercise. These decisions included:

- Specification of the factors that require consideration with respect to the potential impacts of the energy devices, and the availability of spatial data that can be included;
- Whether particular sensitivities should be considered as incompatible with the presence of energy devices, or whether the sensitivities should be considered as presenting gradations of limitation to the presence of devices (e.g. high, medium and low);
- The relative importance (weighting and scoring) that should be applied to different sensitivities in the final integration of overall environmental sensitivity;
- The relative quality, reliability and overall robustness of data layers.

The SDM policy created maps of combined sensitivities for each of socio-cultural sensitivities, environmental sensitivities, and human activities (including industrial and commercial fisheries). The combined environmental sensitivities layer was made up of a total of 19 individual layers (or factors), each of which was weighted and scored to calculate the potential relative influence within the overall sensitivity (Table 1).

**Table 1.** Environmental Sensitivities used for tidal energy in SDM policy: weighting, scoring and relative influence.

| Data layer | Weight | Maximum score | Potential relative influence |
|---|---|---|---|
| Bird reserves | 800 | 80 | 64000 |
| Important Bird Areas | 500 | 50 | 25000 |
| Local nature reserves | 800 | 80 | 64000 |
| Special Areas of Conservation | 1000 | 100 | 100000 |
| Special Protection Areas | 1000 | 100 | 100000 |
| Sites of Special Scientific Interest | 900 | 100 | 90000 |
| Offshore candidate SACs and SPAs | 1000 | 100 | 100000 |
| Offshore draft SACs and SPAs | 1000 | 100 | 100000 |
| Offshore possible SACs and SPAs[4] | 1000 | 100 | 100000 |
| RAMSAR sites | 1000 | 100 | 100000 |
| Possible seal haul out sites[5] | 900 | 90 | 81000 |
| Areas of importance to basking sharks | 700 | 70 | 49000 |
| Nursery areas for commercial fish species | 300 | 55 | 16500 |
| Spawning areas for commercial fish species[6] | 300 | 55 | 16500 |
| Areas of search for potential Marine Protected Areas (MPAs)[7] | 600 | 60 | 36000 |
| Areas of search for seabird aggregations | 400 | 40 | 16000 |
| Areas of importance to breeding sea birds | 800 | 145 | 116000 |
| Areas of importance to sea birds in winter | 500 | 50 | 25000 |
| Areas of importance to marine mammals | 800 | 145 | 116000 |

An overall environmental sensitivity layer for each tidal, wave and floating wind technologies, reflecting the fact that each technology has its own impact pathways. Therefore, the relative importance of particular sensitivities differs between the technologies. As an example, though diving birds are relevant to all technologies, their presence is more significant with respect to tidal technologies (because of the potential for sub-surface collisions) and so this factor is given greater weighting in the tidal sensitivity map than that prepared for wave power and floating wind

[4] http://www.gov.scot/Topics/marine/marine-environment/mpanetwork/SACmanagement
[5] In Scotland these were designated in June 2014 under the *The Protection of Seals (Designation of Haul-Out Sites) (Scotland) Order 2014* (http://www.gov.scot/Topics/marine/marine-environment/species/19887/20814/haulouts).
[6] Coull, K.A., Johnstone, R., and Rogers, S.I. (1998). Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd., Aberdeen, 58 pp.
[7] http://www.gov.scot/Topics/marine/marine-environment/mpanetwork

developments. Landscape value or character, on the other hand, while important for site selection, was not considered to have any bearing on the length of time over which site characterisation surveys should be conducted, and therefore was not included. It is anticipated that for any risk-based characterization, the environmental sensitivities would follow a similar process of identifying the individual factors that could potentially be impacted, and adoption of a scoring system to classify the relative importance of each factor to the overall environmental sensitivity. The specification of factors will be dependent on available information and expert opinion regarding the potential for impact. This specification is likely to vary between Member States. The overall purpose of the scoring system is to ensure that those environmental sensitivities that are considered to be more important for decision making are given relatively more influence (potential relative influence column of Table 1). The system of scoring and weighting adopted by Marine Scotland was specified for statistical reasons to be associated with MaRS, and would not necessarily apply to other datasets.

With respect to the mapping of overall environmental sensitivity under the SDM policy a classification of constraint levels was provided in map form (Figure 3). This enables areas of relatively higher and lower sensitivity to be distinguished. In developing the SDM policy, Marine Scotland chose to consider the maps as indicative only (i.e. it is possible that at a local scale specific sites may have a relatively greater or lower sensitivity than is shown). Developers/applicants must take this information and use the best available site specific information to help determine what additional data may be required to undertake EIA/HRA (where necessary) to meet the requirements of the Directives i.e. identify and describe potential significant effects. Additionally, they are relevant only to marine renewables (wave and tidal power) development and those factors which might influence the duration of site characterisation studies. They are neither an overall assessment of a site's environmental richness or biodiversity nor of its complete environmental sensitivity or sensitivity to other forms of development. The stated intention under the SDM policy is for the maps to be subject to revision and upgrade as more datasets become available and/or existing ones renewed.

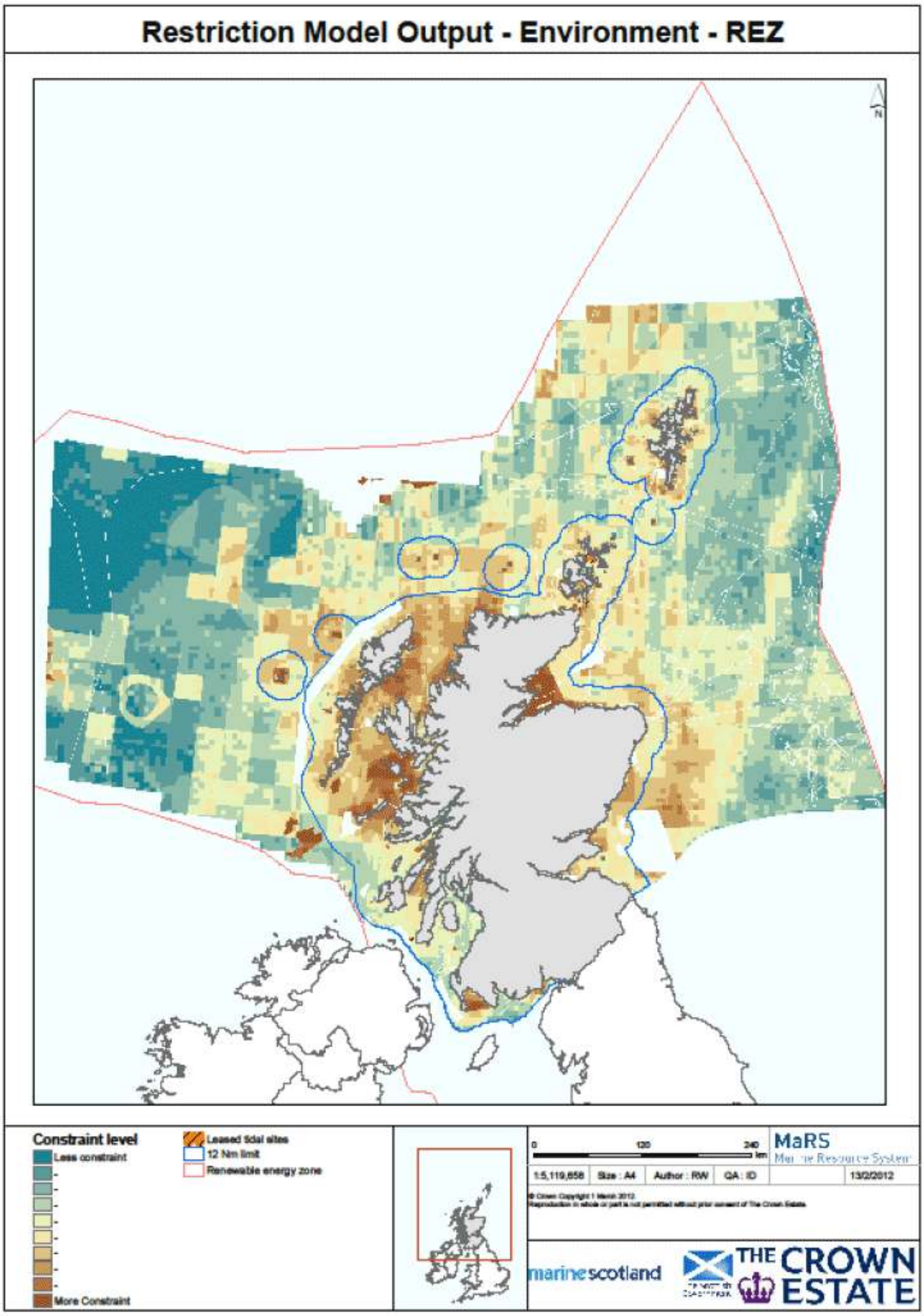


**Figure 3.** Output from the Environmental Restriction model for tidal stream energy development in Scottish waters. Taken from Davies *et al*. (Davies *et al.*, 2012).

## 3.3 Developing environmental risk profiles

Following consultation, Marine Scotland assigned an overall assessment of High, Medium or Low environmental sensitivity to specific areas being considered for development. This qualitative approach at the end of the process for scoring the overall environmental sensitivity was adopted at the time for a number of reasons:

- Because of concern that more quantitative approaches for discriminating between the environmental sensitivity layers could give a false sense of robustness to what was ultimately a subjective exercise;
- The preference for an approach that was quick to apply;
- It enabled a further degree of flexibility in the process, allowing consensus to build around the evidence that was available at the time of decision making;
- By giving weight to expert opinion it allowed for pragmatic interpretation of the available evidence.

Further development of more quantitative approaches should give consideration to the extent to which they can be confident of improving risk profiling.

The factors considered as environmental sensitivities under SDM reflected general concerns that habitats and species afforded protection under the Birds and Habitats Directives, or under national legislation should be prioritised. Other Member States undertaking this exercise for the first time may choose to weight the factors differently, or choose additional or alternative factors.

The method used to combine individual environmental risk factors to arrive at overall environmental risk will entail quantification that is ultimately based on a series of expert judgements reflecting the value likely to be ascribed to each environmental factor under the licensing regime for project proposals. In Scotland the FEAST tool enables assessment of the sensitivity of receptors to pressures (http://www.marine.scotland.gov.uk/FEAST/), with a particular focus on determining the management requirements of Marine Protected Areas. Existing work of this type can inform expert judgement. Delphi techniques could also be applied when assessing the vulnerability of environmental factors (Certain *et al.*, 2015). A key consideration for Member States developing the risk profile for environmental sensitivity is that they may not have access to datasets that can be used to spatially map the relative importance of the marine environment. This issue has been identified during expert workshops, and is believed to be a potential constraint affecting the development of SDM in Portugal, Spain and Ireland in particular. Concerns regarding data quality also applied during the development of the SDM policy in Scotland, with observers noting the age of some datasets, and the limited spatial coverage associated with others. The recommendation is to use the best available evidence. Where no data from the local marine environment exist (e.g. no attempts have been made to monitor seabirds at sea) reference to existing published literature can often be used to inform a mapping exercise. In the example of seabirds, literature on the foraging ranges of seabirds from colonies could be used if no local data exists. Finally, if the exercise is repeated in Scotland there are various new pieces of additional information that could be used that were not previously available. Recently identified marine protected areas, and seal haul-out sites around the coastline are examples.

# 4. TECHNOLOGY RISK PROFILING

The identification of the main impact pathways of MRE developments over the marine environment has been one of the conclusion points of the Expert Workshop 3 held in Dunkeld, Perthshire (UK). Defining an appropriate risk assessment approach involves consideration of potential impacts. Therefore, it follows that survey requirements should be determined by the potential significant impacts that could arise from a proposed development. These impacts will depend on the characteristics of a project including the type of energy generation technology, support vessels and infrastructure to be used. According to the Deliverable 3.2 (Mascarenhas *et al*., 2015), 11 technology types have already reached a level of maturity enabling them to immediately benefit from the risk-based approach proposed by the RiCORE project. A number of them are in the floating wind category (Table 2).

**Table 2.** MRE technology types identified in Deliverable 3.2. Adapted from Mascarenhas *et al.* (2015).

| Technology category | Technology type | TRL |
|---|---|---|
| Tidal | Tidal impoundment | 9 |
| | Tidal stream - Horizontal axis turbine | 8 |
| | Tidal stream - Enclosed Tips (Venturi) | 8 |
| Wave | Attenuator | 8 |
| | Point Absorber | 7 |
| | Oscillating Wave Surge Converter | 8 |
| | Oscillating Water Column (OWC) | 7 |
| Floating Wind | Spar-horizontal axis WT | 7-8 |
| | Semi-submersible platform - Horizontal axis WT | 8-9 |
| | Semi-submersible platform - Vertical axis WT | 7 |
| | Tension leg - submerged platform | 7 |

All of them have common aspects that are subject to act as **stressors** (action of the project that can generate impacts) over different **receptors** (environmental factors that can be affected by the project actions) of the marine environment. According to Boehlert and Gill (2010), the main stressors of MRE developments are associated with:

a) The **physical presence of the devices.**

b) The **physical presence of moorings, mooring lines and supporting structures**.

c) The **dynamic components of the devices**: the moving parts of the devices can lead to “blade strike”.

d) The **chemicals** used in the devices (hydraulic fluids, anode erosion and anti-fouling paints) and the pollutants’ leaking from vessels during deployment, routine servicing, and decommissioning.

e) The **acoustic effects** during deployment, routine servicing and operation of devices, and decommissioning.

f) The **electromagnetic field** generated during transmission of the produced electricity through the submarine cables during the operation of devices.

In the following sections, the different impact pathways of the MRE technology types identified in Deliverable 3.2 are described. The objective is to provide the needed criteria to the experts in charge of the risk analysis of these technologies so they will be able to assign a value of Low, Medium or High risk according to the expected impacts.

## 4.1 Physical presence of devices

As stated by Boehlert and Gill (2010), the mere physical presence of new structures in marine ecosystems results in fundamental changes to the habitat, both above and below the water surface.

### 4.1.1 Icthyofauna

Generally speaking, any artefact located in the sea may cause an attraction effect on fish communities, especially if it is floating. Similar effects have been observed by Morrisey *et al.* (2006) in relation to floating structures for aquaculture (fish cages, mussel mesh, etc.). Such attraction can favour changes in species composition in the study area and alter the relation predator-prey (Boehlert, 2008). This presence of MRE devices on the seafloor or suspended in the water column can act as Fish Attractant Devices (FAD), attracting certain marine animals as it has been observed for some fish species such as cod, flatfish, sand eels, etc. (Dempster and Taquet, 2004; Wilhelmsson *et al.*, 2006; Fayram and De Risi, 2007; Kramer *et al.*, 2015).

At the sea surface, some wave devices may take up significant areas that may need to be considered for migratory surface dwellers in terms of a physical barrier. Furthermore, shoreline and estuarine devices may represent large immovable and impassable objects for migratory species (Boehlert and Gill, 2010).

Thus the key impact pathways of the physical presence of devices over fish communities could be the following:

- IP1: Changes in fish behaviour; may act as fish aggregation devices.
- IP2: Barrier to movement (a real or perceived obstacle to normal movement of sea life during migration or day to day activities).

All these effects will manifest during the operation phase of the MRE projects

### 4.1.2 Marine mammals

The attraction of fish described in section 4.1.1 can in turn entice other marine species like marine mammals (cetaceans and pinnipeds) attracted by the feeding opportunity.

As with fish, at the sea surface, some wave devices may take up significant areas that may affect migratory surface dwellers in terms of a physical barrier or promote displacement from the area, keeping them from important feeding, breeding, nursery, or resting habitats, or from vital movement and migratory corridors. Even if Barrier effects could be more related with noise being produced from both wave and tidal devices, however, physical barriers will become more of an issue with array deployment. Furthermore, shoreline and estuarine devices may represent large immovable and impassable objects for migratory species (Boehlert and Gill, 2010).

Thus the key impact pathways of the physical presence of devices over marine mammals communities could be the following:

- IP3: Changes in marine mammal behaviour; may act as aggregation devices.
- IP4: Barrier to movement (a real or perceived obstacle to normal movement of sea life during migration or day to day activities), and displacement of activities such as feeding, mating, rearing, or resting habitats.

### 4.1.3 Birds

According to Copping *et al*. (2013), if the devices have surface expression, birds may be attracted to the device or may avoid large numbers of devices. However, there is no evidence that seabirds are likely shown avoidance or an extreme change in distribution as a result of the presence of a Wave Energy Converter (WEC) (Lees *et al.*, 2016).

In the case of offshore wind, the energy used by marine birds that are displaced is an impact of concern (Masden *et al.*, 2009). For adult birds that have dependent young it may be the additional time costs of displacement that are the critical factor for survival of chicks. Energetic costs to adults may be a lesser impact upon the population. The potential impacts on long distance migrating birds are considered to be small, but for daily commuting birds, long-term habitat fragmentation and extended routes could have moderate effects on assemblages (Wilhelmsson *et al*., 2010). Evidence to date suggests that birds avoid wind turbine structures and are well able to navigate through the array of turbines (Desholm and Kahlert, 2005).

With respect to collision risk, avoidance rates are likely to be species specific (depending upon a range of factors such as behavioural response and maneuverability in flight), although early assessments of collision risk using the 'Band model' adopted a fixed 95% avoidance rate for all species (Band, 2012; 2014).

Thus the key impact pathways of the physical presence of devices over marine birds could be the following:

- IP5: Displacement.

- IP6: Collision risk with turbine blades.

### 4.1.4 Landscape

The effects on landscape during the commissioning stage are mainly caused by the presence of floating structures, machinery and land equipment for fixed structures in the area of future occupation of the infrastructure. During the operation stage, the impact on landscape derives from the presence of the structures themselves (both infrastructures of floating devices and marker buoys usually necessary for fixed structures). Regarding this impact it is important to mention that most of WECs are located at water surface level, therefore their visual impact is expected to be minimal, but in the case of floating or fixed wind farms these structures can reach more than 100 m height and rotor diameter between 100 and 130 m. In the case of offshore facilities, like tidal impoundment and OWC technologies, the modification of onshore landscape can be very significant.

Thus the key impact pathways of the physical presence of devices over **landscape** could be the following:

- IP7: landscape alteration due to the presence of devices.

## 4.2 Physical presence of supporting structures

Below water, devices will include buoys, cabling systems, hard-fixed structures (such as monopoles or jackets), rock scour protection, anchors, electrical cables, etc.

### 4.2.1 Benthic communities

Moorings leads to a change of **benthic communities** over the footprint of where it is placed (Energi and Elsam, 2005). The lost surface and consequently, total affected biomass will depend on the total number of structures installed at the bottom and their sizes.

On the other hand, whenever a new material is submerged in the sea it will become colonised by marine organisms. Particularly in soft bottom habitats, but to some extent also on hard bottom dominated areas, the addition of hard substrata, like mooring foundations, increases habitat heterogeneity and the biodiversity of sessile organisms (Wilhelmsson *et al.*, 2010). Typical colonising species include sponges, cnidarians, bryozoans and polychaetes and mobile invertebrates (such as crab, shrimp, squid, etc.) that are prevalent in an area (Langhamer, 2010, 2012). This is a well-documented effect, especially for wind and wave technologies, but also in coastal defences, oil and gas structures, etc. (Page *et al.*, 1999; Petersen and Malm, 2006a; Vaselli *et al.*, 2008; Wilhelmsson and Malm, 2008; Langhamer and Wilhelmsson, 2009; Langhamer *et al.*, 2009; Langhamer, 2010, 2012; Krone *et al.*, 2013a; Krone *et al.*, 2013b; Munari, 2013; Wehkamp and Fischer, 2013a; Wehkamp and Fischer, 2013b; Broadhurst *et al.*, 2014).

MRE devices thus can provide hard substrata in regions and at depths often dominated by soft bottom habitats. This could fill gaps between natural areas of hard substrata and so change the biogeographic distribution of species within a region (Bulleri and Airoldi, 2005) and also the possibility of being a possible entry point and stepping-stones for invasive rocky shore species brought in as larvae by ballast water (Airoldi *et al.*, 2005; Glasby *et al.*, 2007; Villareal *et al.*, 2007; David and Gollasch, 2008; Hulme *et al.*, 2008; Simkanin *et al.*, 2009). Also, the devices itself can provide a substrata for biofouling processes with similar effect as those above mentioned.

Thus the key impact pathways of the physical presence of supporting structures over the **benthic communities** could be the following:

- IP8: increases of sea bottom habitat heterogeneity and biodiversity of sessile and mobile benthic organisms due to the addition of hard substrata coming from moorings, foundations and cables.
- IP9: changes in biogeographic distribution of hard substrata species and introduction pathway of invasive species.

### 4.2.2 Icthyofauna

The installation of MRE devices may also provide opportunities for creating and enhancing habitats increasing the number of fish in an area as they reef around the supporting structures of the devices (searching for protection, food availability and using the structures as reference points for spatial orientation), and create *de facto* marine protected areas as other human uses, such as trawling (which is one of the most severe threats to the marine environment including both benthic and fish assemblages), are avoided in the vicinity or inside the areas of MRE development. This reefing effect has been documented and hypothesized for tidal (Broadhurst *et al.*, 2014; Broadhurst and Orme, 2014) and wind and wave developments (Page *et al.*, 1999; Petersen and Malm, 2006b; Vaselli *et al.*, 2008; Wilhelmsson and Malm, 2008; Inger *et al.*, 2009; Langhamer and Wilhelmsson, 2009; Langhamer *et al.*, 2009; Lindeboom *et al.*, 2011; Krone *et al.*, 2013a; Munari, 2013; Kramer *et al.*, 2015). If not buried, the physical presence of power cables could also provide shelter for benthic fish, especially juveniles (Wilhelmsson *et al.*, 2010).

Thus the key impact pathways of the physical presence of supporting structures over fish communities could be the following:

- IP10: reefing effect.

### 4.2.3 Marine mammals

Large marine animals such as marine mammals may also be at risk from colliding with or becoming entangled in mooring lines and cables. As stated by Boehlert and Gill (2010), for those devices with cables and moorings, the nature of mooring cables (slack or taut, horizontal or vertical, diameter) is critical to entanglement issues. Nevertheless, according to Benjamins *et al*. (2014), for most megafauna, MRE device moorings are unlikely to pose a major threat.

Thus, the key impact pathways of the physical presence of supporting structures over **marine mammals** could be the following:

- IP11: entanglement and collision with cables and mooring lines.

### 4.2.4 Seafloor integrity

During the commissioning stage, the effects on sediments are mainly associated with re-suspension during anchoring and installation of fixed devices to the bottom, thus being an extremely temporary impact in nature and with a rapid recovery (Bald *et al.*, 2010).

During the operation stage, dragging or rubbing of materials such as chains, wires, ropes or cables across the seabed could be expected. Kristof and Linfoot (2012), carried out a study of the scouring effect on bottom sediments and consequent disruption of benthic habitats of a typical (height 19 m, diameter 16 m, mass 900 tonnes) wave energy converter (WEC) of an oscillating water column (OWC) type with a three point mooring installed in 40 m of water depth and wave regime conforming to regular waves between 2 and 6 m height with 8 s period. The results of the study showed that in regular waves of 6 m height and 8 s period, the area of benthic habitats adversely affected by the mooring lines may exceed 60 $m^2$. Also, moorings dragged after an exceptionally severe storm may affect rocky structures, making rocks and stones rotate, and also the sedimentary bottom of the installation area, if present. According to Fairley *et al.* (2015), the installation of tidal turbines in sites with mobile sediments can lead to changes in sediment transport regime and also to the morphology of sandy areas.

Another effect derived from moorings involves the artificialisation of substratum. If anchor points are mainly located on sedimentary bottoms, an accumulation of anchors may lead to a significant change in proportion of hard/soft substratum in the installation area (Bald *et al.*, 2010).

Thus the key impact pathways of the physical presence of supporting structures over seafloor integrity could be the following:

- IP12: dragging or rubbing of materials such as chains, wires, ropes or cables across the seabed and changes in sediment transport regime and the morphology of sandy areas.

- IP13: artificialisation and change in proportion of hard/soft substratum in the installation area.

## 4.3 Dynamic effects of devices

Dynamic components of MRE devices (rotating tidal turbine blades, the various wave devices that oscillate, attenuate, and move as waves pass by and blades of offshore wind devices) can interact with marine environment. As stated by Boehlert and Gill (2010), moving parts of MRE technologies can lead to "blade strike". Because of the wide variety of MRE technologies, dynamic components of these technologies can be located above or below the sea surface and their potential environmental impacts may vary.

In-water turbines, such as current or tidal energy devices, generally move at slower speeds and thus the likelihood of blade strike is lower. However, the speed of the tip of some horizontal axis rotors could be an issue for cetacean, fish, or diving birds (Wilson *et al.*, 2007). The potential for marine animals to collide with the moving parts of tidal devices, particularly the rotors of horizontal-axis tidal stream turbines, is a primary concern for consenting and licensing of projects (Sparling *et al.*, 2015).

In the case of wind energy devices, the interaction between birds and wind turbines is the most thoroughly investigated environmental concern relating to wind power. This collision risk/blade strike is much more likely to be an environmental concern for offshore wind compared to tidal stream.

### 4.3.1 Icthyofauna

Several field studies focused on evaluating the potential risk for fish to collide with wave and tidal technologies have indicated a low probability of co-occurrence of fish with a rotating turbine when currents were stronger than 1 m/s, however this behaviour can be species-specific and the risk can be greater with larger fish (Hammar *et al.*, 2013; Broadhurst *et al.*, 2014; Viehman and Zydlewski, 2015). Laboratory and semi-controlled field studies suggest high survival rates (>95%) of fish after passing through turbine rotor-swept areas (Amaral *et al.*, 2015; Castro-Santos and Haro, 2015). Other studies have included the use of numerical models (Romero-Gomez and Richmond, 2014; Hammar *et al.*, 2015) suggesting a 1 to 10% of probability of collision. This risk increases as a function of turbine diameter and current speed.

Thus the key impact pathways of the dynamic effects of devices over **fish communities** could be the following:

- IP14: collision with structures and moving parts.

### 4.3.2 Marine mammals

Although advances have been made on the modelling front (Wilson *et al.*, 2007; Carlson *et al.*, 2014; Band, 2015), empirical data describing the behavior of marine mammals around operational tidal turbines is still lacking limiting the understanding and prediction of how MRE developments could affect marine mammals. Current uncertainty about the nature and magnitude of collision risk is curtailing the rate of development of the tidal energy industry in some parts of the world.

Few studies of the consequence of an animal colliding with an MRE device have been completed. Much of the work on marine mammals in tidal environments has focused on the harbor porpoise (Pierpoint, 2008; Marubini *et al.*, 2009; Embling *et al.*, 2010; Wilson *et al.*, 2014; Macaulay *et al.*, 2015). All these studies underlined the importance of baseline density and behavior (diurnal variation on depth) of marine mammals as an important predictor of collision risk. Direct observations of marine mammals were made at Marine Current Turbine s' (MCT's) SeaGen in Strangford Lough, Northern Ireland, and at OpenHydro's open-center turbine at the European Marine Energy Centre (EMEC), Orkney, Scotland. At SeaGen, no impacts on marine mammals from the tidal turbine were observed (Keenan *et al.*, 2011; Savidge *et al.*, 2014). At Open Hydro's open-center turbine, no direct interactions between marine mammals and turbines were observed, and there were frequent observations of marine mammals (seals, porpoises, and small whales) around the turbine (Copping *et al.*, 2013).

Modelling of collision show that risk of collision will vary across the tidal cycle as a result of variations in rotor speed with current speed, approach velocities of animals, etc., as well as any variation in animal abundance over the tidal cycle (Wilson *et al.*, 2007; Pierpoint, 2008; Wilson *et al.*, 2013; Carlson *et al.*, 2014; Sparling *et al.*, 2015; Thompson *et al.*, 2015b).

Thus the key impact pathways of the dynamic effects of devices over marine mammals could be the following:

- IP15: collision with structures and moving parts.

### 4.3.3 Birds

#### a) Wind turbines

Marine wind energy device impacts on birds have been addressed in several studies (Chamberlain *et al.*, 2006; Larsen and Guillemette, 2007; Wilson *et al.*, 2007; Minerals Management Service, 2008; Masden *et al.*, 2009; Wilhelmsson *et al.*, 2010; Band, 2012; Band, 2014; Grant *et al.*, 2014; Henkel *et al.*, 2014). It has been broadly suggested that collision risks at offshore wind turbines would cause minimal mortality within populations. However, there are still considerable research gaps (e.g. the cumulative collision risks exposure associated with long-distance migration). A recent offshore wind farm study indicated that the majority of collisions occur on a few days per year, when bird navigation is hampered by bad weather, which weakens predictions (Wilhelmsson *et al.*, 2010).

According to Desholm (2009), it is important to note that both collision rates and impacts of increased mortality on populations vary greatly with species. Including both on- and offshore facilities, estimated rates of mortality for different bird species range from 0.01 to 23 mortalities per wind turbine per year (Drewitt and Langston, 2006), with an average across bird species of 1.7 collisions per turbine per year according to an ongoing scientific synthesis (M. Green, personal communication on synthesis in progress 2009 in Wilhelmsson *et al*., 2010). In conclusion, most studies indicate small impacts of bird collisions on assemblages as a whole for most species studied and the few areas considered, although any effects would be long-term. The temporal and methodological limitations in most studies and variability among species call for further clarification (Wilhelmsson *et al.*, 2010).

Thus the key impact pathways of the dynamic effects of devices over **birds** could be the following:

- IP16: collision with wind turbines

### b) Tidal turbines

For diving seabirds, collisions with tidal turbines represents a potential way in which tidal energy developments may cause population-level impacts, especially in shallow depths. However, there are few empirical data available on collision impacts of seabirds with underwater MRE devices. Furness *et al*. (2012) related the tidal turbine collision risk with mean and maximum diving depth and the use of tidal races for foraging. Grant *et al*., (2014) developed a Exposure Time Population Model (ETPM) to assess collision risk of diving seabirds. The model explores the collision rate required to achieve a critical level of additional mortality by estimating (i) thresholds of additional mortality for the population at risk of collision (via population modelling) and (ii) the potential time that each individual within the population is at risk of collision (via exposure time modelling). Wade (2015) has incorporated uncertainty data in an attempt to highlight areas and species where more targeted research was required. According to Furness *et al*. (2012), it is acknowledged that even the highest risk of collision due to structures would represent a relatively low risk for seabirds. In this regard, Wade (2015) suggests that highly energetic tidal channels may not be an attractive foraging habitat for most species of seabirds, implying that only a small number of bird species are likely to be at elevated risk of collision with devices. This would be in accordance with the results of the SeaGen tidal energy convertor

Environmental Monitoring Programme (Keenan *et al.*, 2011). Data collected from shore-based surveys conducted during the installation and operation of the tidal device suggested that SeaGen had little impact of ecological or conservation significance on the bird species investigated.

Thus the key impact pathways of the dynamic effects of devices over **birds** could be the following:

- IP17: collision with tidal turbines

### 4.3.4 Marine dynamics

Marine renewable energy devices operate by removing kinetic energy from water (or air in the case of offshore wind). This energy withdrawn from air, water, or waves may also have potential effects at both near- and far-field scales.

According to Copping *et al*. (2013) nearfield changes in the water column are not likely at the small pilot scale, but they could occur at large scale. For devices at sea or in estuaries, the resultant reduction of energy may lead to downstream effects. In the water column, modifications to water movement energy could lead to changes in turbulence and stratification, potentially altering vertical movements of marine organisms and resulting in prey and predator aggregation. In the far field, energy reduction could lead to changes in currents and subsequent alterations in sediment transport.

Tidal energy devices may result in local acceleration and scouring in some cases, but have the potential to decrease tidal amplitude in downstream areas. Field studies carried out by O'Laughlin and Proosdij (2013) and O'Laughlin *et al*. (2014), found that a decrease in the tidal amplitude due to energy removal by tidal turbine arrays may decrease the cumulative export capacity of tidal channels over time, potentially leading to a gradual infilling of tidal creeks. Modelling studies of simulated arrays undertaken by Martin-Short *et al*. (2015), Robins *et al*. (2014) and Mulligan *et al*. (2013), among others, showed in general an alteration of the sediment transport in the nearfield close to the array (sediment accumulation within the array with reduced velocities) and the surrounding area (scour to the sides of the array). Studies undertaken by means of a three-dimensional model by Sanchez *et al*. (2014) showed that there are no significant differences between the impacts caused on the general circulation by floating and bottom-fixed tidal stream turbines. Also, studies based on marine radar undertaken by McCann and Bell (2014) has showed promising capabilities for the study of marine currents and consequently the application of this methods for further studies of the impact of tidal energy devices on marine dynamics.

Shadow effects of wave energy devices may alter sediment transport and deposition as well as have an effect on beach processes (Millar *et al.*, 2007; Largier *et al.*, 2008). Numerical models simulating changes in wave energy extraction have looked for impacts on the nearshore areas, particularly the focusing of energy nearshore that could cause changes in shorelines (Iglesias and Carballo, 2014) and beach erosion profiles (Abanades *et al.*, 2014). Calculations made in trial installations like the ones by Wave Hub in England, estimate a reduction of 5% in wave height in the worst case (equivalent to ~10% of energy) being re-established at an approximate distance of 5 km (Halcrow_Group_Ltd, 2006). A case study at Perranporth Beach, Cornwall, UK (a small array of 11 devices), expected a wave energy flux reduction by up to 12% (Abanades *et al.*, 2014). A recent example of a shadow area assessment for the installation of a floating wave harnessing devices in the Biscay Marine Energy Platform (BIMEP) in Arminza, Basque Country (Bald *et al.*, 2008) is based on propagation of a series of waves from the most energetic directional sectors with the average direction in that sector, achieving a series of associated shady areas. The global percentage of energy decrease reaches a maximum of 9% in some areas of the nearshore. This decrease can have direct effects over some marine species which have a strong relationship with wave energy. This is the case of the goose barnacles (*Pollicipes pollicipes*). According to the biomass-wave energy relationship established by Borja *et al*. (2006), the 9% of wave energy decrease in BIMEP can derive in a 0,47 to 0,66 $kg \cdot m^{-2}$ biomass decrease, which represents approximately a 25% of existing biomass in the affected area.

Energy removal by devices in water, as well as blockage effects, can lead to localized changes in water movement energy and turbulence—these changes, in turn, can cause benthic sediment scouring and resultant habitat changes. In the water column, modifications to water movement energy could lead to changes in turbulence and stratification, potentially altering vertical movements of marine organisms and resulting in prey and predator aggregation. In the far field, energy reduction could lead to changes in currents and subsequent alterations in sediment transport.

Thus the key impact pathways of the dynamic effects of devices over **marine dynamics** could be the following:

- IP18: Scour processes affecting the movement of previously stable sediment due to accelerated flows and turbulence induced by structures on or near seabed. Sedimentation processes affecting accumulation of previously mobile or suspended sediments due to reduced flows or turbulence arising downstream or in the shadow of structures.
- IP19: Dissipation of wave energy due to the presence of marine energy devices leading to calmer waters or less exposed coastlines.
- IP20: Change in tidal flows and fluxes (changes in the velocity, direction, quantity and or duration of flows).
- IP21: reducing or more likely increasing turbidity in the water column through the release or mobilisation of fine particles.

## 4.4 Chemical effects

In most cases, the effects of chemicals used in marine renewable energy will differ little from other marine construction projects. During deployment, routine servicing, and decommissioning, the expected risks associated with marine vessel operations will be encountered. In normal operations, the potential for spills exists, particularly for those devices that use a hydraulic fluid. Continuous leaching of chemicals may occur if anti-fouling paints are used to minimize biological fouling of devices (Boehlert and Gill, 2010).

Concerning water quality, the greatest potential risk from chemicals associated with marine energy development could be leaks of hydrocarbons, oil or other fluid leakage as well as the continuous leaching of anti-fouling paints from installation, maintenance, and decommissioning of devices (Arvidsson and Molander, 2012; Sotta, 2012). The largest risks of negative physical environmental impacts from pollution would probably arise from dredging of sediments containing pollutants (Nendza, 2007), and although these effects are likely to be local and/or temporary, caution is needed when constructing many turbines over a longer time (U.S. Department of Energy, 2009).

Concerning the biological environment, chemicals that are accidentally or chronically released from ocean energy installations could have toxic effects on aquatic organisms. Such events are unlikely but could potentially have a high impact (Boehlert *et al*. 2008). On contact with accidental release of oil, marine animals die most often through external contamination that destroys their protection against the cold and water, or by toxic poisoning through ingestion (Sotta, 2012). On the other hand, chronic releases of dissolved metals or organic compounds used to control biofouling in marine applications would result in low, predictable concentrations of contaminants over time. Even at low concentrations that are not directly lethal, some contaminants can cause sublethal effects on sensory systems, growth, and behavior of biological environment; they may also be bioaccumulated on predators such as young fish, seabirds and marine mammals (U.S. Department of Energy, 2009; Sotta, 2012; Witt *et al.*, 2012).

In conclusion and according to Wilhelmsson *et al*. (2010), serious pollution does not seem likely, and if pollution does occur effects on biotic assemblages should be local and overall effects thus small, provided that there are no large oil spills. The risk of stirring up polluted seabeds and variability in construction methods among developers bring in some uncertainty, but evidence from existing research is otherwise good.

Thus the key impact pathways of the chemical effects over physical and biological environment could be the following (U.S. Department of Energy, 2009):

- IP22: releases of contaminants from oils and other operating fluids and anti-biofouling coatings deriving in toxicity due to the exposure to contaminants; potential bioaccumulation of metals and other compounds and effects on behavior.

## 4.5 Acoustic effects

Noise can be generated by vessel traffic as well as the installation, operation, and decommissioning activities required for MRE devices. Potential impacts of anthropogenic underwater noise on marine life are wide ranging: it can cause species to avoid areas with significant anthropogenic sound, possibly disrupting feeding, breeding or migratory behaviour, cause permanent or temporary damage to marine organisms, mask communications, or even cause death (Clark *et al.*, 2009; Oestman *et al.*, 2009; Halvorsen *et al.*, 2012a; Halvorsen *et al.*, 2012b; Hammar *et al.*, 2013; Rossington *et al.*, 2013; Viehman and Zydlewski, 2015).

The loudest and most disruptive noise levels are associated with construction phase (Thomsen *et al.*, 2006). Construction of foundations and the laying of cables in offshore wind projects have showed that they can generate considerable acute noise, Peak 260 dB re: 1µPa and Peak 178 dB re: 1µPa respectively (Mccauley *et al.*, 2003; Gill, 2005; Madsen *et al.*, 2006). This is especially clear for pile driving associated with monopile for offshore wind devices and some tidal turbines and other devices that require small piles for securing jacket foundations. Pile driving can generate very-high-intensity, wide bandwidth (20 Hz to 1 kHz) (Greene and Moore, 1995), but relatively short-duration noises (Boehlert and Gill, 2010). Less is known about noise generated during construction of tidal and wave devices (Copping *et al.*, 2016). However, Thomsen *et a*l. (2015) surmise that construction activities may produce sound levels similar to those of wind farm construction activities, when similar activities are implemented. However, few wave and tidal installations are likely to drive full size piles into the ocean floor, as is carried out for offshore wind development; the resulting noise levels for MRE installation are likely to be less than those for offshore wind (Copping *et al.*, 2016).

During the operational phase, devices with subsurface moving parts could generate noise and vibration. Sound generated by wave and tidal devices is likely to range from 116 to 170 dB SPL (sound pressure level) at 1 m from the source, with most energy being below 1 kHz (Polagye *et al.*, 2010; Bassett *et al.*, 2012; Beharie and Side, 2012; Lepper *et al.*, 2012; Haikonen *et al.*, 2013; Cruz *et al.*, 2015). Despite the seemingly extensive number of existing studies reviewed by Robinson and Lepper (2013), these authors conclude that actually few datasets of the quality necessary to characterize noise radiation from MRE devices exist, which presents serious challenges for making impact assessments.

In the case of offshore wind, vibrations in the tower cause underwater noise with frequencies in the range of 1-400 Hz and 80-110 dB re: 1µPa and is likely to increase as a function of the number of turbines (Nedwell *et al.*, 2003).

### 4.5.1 Icthyofauna

Fish species hear at low frequency (typically 10 Hz to 1000 Hz) (Enger and Andersen, 1967; Chapman and Sand, 1974; Sand and Karlsen, 1986), but there is considerable variation in fish hearing abilities, both in terms of threshold and frequencies of perceptible sounds, which are linked to particular anatomical adaptations (Hawkins, 1981; Hastings and Popper, 2005; Lovell *et al.*, 2005; Madsen *et al.*, 2006; Thomsen *et al.*, 2006) and life cycle stage, species and body size as well (Nedwell *et al.*, 2003). It has generally been agreed that fish can be divided into two groups – hearing generalists (or “non-specialists”) and hearing specialists. These groups are not related to the taxonomic relationship between fishes. Instead, both hearing specialists and generalists are found distributed through many fish taxonomic groups (Hastings and Popper, 2005). Hearing specialists have special adaptations that enhances their hearing bandwidth and sensitivity. Examples of specialists include goldfish, catfish, some squirrelfish, herrings and relatives, and many other taxonomically diverse species. Quite often, hearing specialists will detect signals up to 3,000 – 4,000 Hz, with thresholds that are 20 dB or more lower than the generalists. The majority of fishes do not have specializations to enhance hearing and are therefore called hearing generalists (Hastings and Popper, 2005). It might be argued that the only fishes that would be affected by anthropogenic sounds are species that make and use sound for communication (Popper, 2003). However, while any species do not make sounds or use sound for intraspecific communication (e.g., goldfish), all species are likely to obtain a good deal of information about their environment from the overall acoustic milieu (Popper, 2003)

According to Wilhelmsson *et al*. (2010), displacement of fish during pile driving for the construction of a single wind-farm can be very broad, but should be short-term, and severity of impacts of local fish assemblages should generally be small. If the construction of several wind farms succeeds each other in the same region effects will be longer term. According to the same authors, during operation there is no evidence of fish avoiding wind farms and based on current knowledge, any impacts should be very local. Studies on juvenile fish and larvae exposed to seismic shooting and explosions showed an impact on survival in these groups, although these results cannot be directly translated into possible effects of pile driving due to the difference between the sound sources (Popper and Hastin, 2009)

Robinson and Lepper (2013) note there have been 29 studies related to noise and wave and tidal energy development activities, and of these, 17 have measured noise during construction and/or operational phase. Despite the seemingly extensive number of studies, Robinson and Lepper (2013) conclude there are actually few datasets of the quality necessary to characterize noise radiation from MRE devices which presents serious challenges for making impact assessments. Haikonen *et al*. (2013) reported that at a distance of 20 m from a WEC, the maximum value for a single pulse was 133 dB re 1 µPa with an average of 129 dB re 1µPa, which suggests that many marine animals will be able to detect the noise from the operating WEC, but that the noise is not sufficient to cause fish to change their behaviour or be physically injured at the site. In the long term, the severity of impacts on fish assemblages as a whole is considered small.

Thus the key impact pathways of underwater sound over icthyofauna could be the following:

- IP23: disturbance and avoidance behaviour during construction stage due to underwater noise generated.

### 4.5.2 Marine mammals

Although there is considerable variation in the hearing abilities of marine mammals, the published data suggest that, in general, they are able to perceive a wider range of frequencies and to lower levels than fish (Nedwell *et al.*, 2012).

Consequently, the effects on marine mammals behaviour can extend far beyond the farm area during pile driving of offshore windfarms and may cause behavioural changes in seals, dolphins and porpoises more than 20 kilometres away (Madsen *et al.*, 2006; Tougaard *et al.*, 2009; Kyhn *et al.*, 2014; Thompson *et al.*, 2015a). According to Wilhelmsson *et al*. (2010) these changes seem to be short-term, unless the wind farm is very large and requires several years of construction. Madsen *et al*. (2006) estimated that the known noise levels and spectral properties of wind turbines in operation are likely to have small or minimal impacts on shallow water marine mammals. Similar results are reported by Tougaard *et al*. (2003; 2009), Dong Energy (Dong-Energy and Vattenfall-a/S, 2006) and Thompson *et al*. (2015a). According to Wilhelmsson *et al*. (2010), there is no evidence of marine mammals avoiding wind farms during operation due to noise, and any long-term avoidance behaviour of porpoises and seals should be very local.

A review of the state of knowledge done by Copping *et al*. (2016), underline that studies to date suggest organisms are unlikely to experience severe injury or mortality during construction and operation activities of wave and tidal devices, but more information is needed to determine whether physical injury and behavioral changes caused by installation noise will be harmful. To date no studies have indicated that the level of operational noise from MRE devices is likely to be harmful to marine animals.

Little work has been done to examine the potential effects of underwater sound on sea turtles and diving birds (Copping *et al.*, 2016).

Thus the key impact pathways of underwater sound over marine mammals could be the following:

- IP24: disturbance and avoidance behaviour during construction stage due to underwater noise generated.

## 4.6 Electromagnetic fields

The main objective of ORE devices is to produce electric power, hence all ORE devices have a variety of Electromagnetic fields (EMF) emitting sources. The dominant sources are the electric cables, usually buried or on the seabed. According to current industry specifications, the cables used inside tidal, wave, and wind energy arrays can be either Alternate Current (AC) or Direct Current (DC) power. An AC generates a time-varying magnetic (measured in µT) and electric field (B-field and iE-field), measured in volts per meter (V/m), in the surrounding environment (Cmacs, 2003), while a DC only generates a static magnetic field . The primary electrical field rapidly diminishes in the marine environment; however, a magnetic field can persist for longer distances as does the induced secondary electrical field. The screen/armouring efficiently confines the primary electric field to the inside of the cable but not the magnetic field and associated EMF. The most recent evidence of EMFs in the environment emitted by subsea cables comes from the European MaRVEN study, which clearly demonstrated that electric and magnetic fields are emitted by electricity being transported through cables associated with an MRE device (a wind farm) and the separate EMF components (E- and B-fields) can be measured both at the seabed and at tens of meters distance from a cable (Copping *et al.*, 2016).

EMF generated by AC or DC can produce negative impacts on aquatic species sensitive to electric and/or magnetic fields. Many marine animals can detect these fields and utilize them in important life processes such as movement, orientation and foraging (Gill *et al.*, 2014). Among them, are elasmobranchs (sharks, skates and rays), agnatha (lampreys), crustacea (lobsters and prawns), mollusca (snails, bivalves, cephalopods), cetacea (whales and dolphins), bony fish (teleosts and chondrosteans), and marine turtles (Kirschvink, 1997; Luschi *et al.*, 2007; Lohmann *et al.*, 2008; U.S. Department of Energy, 2009; Wilhelmsson *et al.*, 2010; Witt *et al.*, 2012). The majority of these animal groups are considered magnetoreceptive, principally in relation to local-scale orientation or large-scale navigation within the marine environment. Animals that are sensitive to electric fields (electrosensitive) are considered able to detect E-fields whether directly emitted or induced via magnetic fields (Gill *et al.*, 2014).

### 4.6.1 Icthyofauna

The most sensitive **fish** species are elasmobranches (sharks and rays), common eels and electric fish, which use weak electrical currents for orientation (induced electric field in relation to the geomagnetic field) and/or prey location (Meyer *et al.*, 2005; Peters *et al.*, 2007; Gill *et al.*, 2009). According to Wilhemsson *et al*. (2010), eventual effects on fish should be local, and overall impacts on resident fish assemblages should be small. However, the consequences or long-term ecological effects of the disruption of EMF on these populations (chronic effects), at different life stages are not yet clearly identified (Ohman *et al.*, 2007; Gill *et al.*, 2012). While available research suggests that many fish species are able to detect electric and/or magnetic fields and behavioural responses have been demonstrated, it is not possible to extrapolate these studies to situations where there are networks of multiple cables, such as those associated with MRE devices (Gill *et al.*, 2014) and data on the effects of underwater cables on fish are inconclusive (Isaacman and Daborn, 2011).

According to Isaacman and Daborn (2011) the key impact pathways of EMF over icthyofauna could be the following:

- IP25: Change in movement patterns, effect on navigation/operation, avoidance or attraction behaviour, effect on predation-prey detection, physiological effects, change in health, survival and/or reproductive success.

### 4.6.2 Benthic communities

Among benthic **invertebrates**, there are also considerable uncertainties due to the limited number of studies addressing invertebrate tolerance to EMF (Ugolini and Pezzani, 1995; Boles and Lohmann, 2003; Bochert and Zettler, 2004; Leeney *et al.*, 2014; Lindeboom *et al.*, 2015). Based on the evidence to date there is no demonstrable impact (whether negative or positive) of EMF related to MRE devices on any electromagnetic sensitive species (Gill *et al.*, 2014). It appears that continued exposure to EMFs can in some cases potentially alter early life history development attributes (Woodruff *et al.*, 2012) but according to Wilhemsson *et al*. (2010), the potential long-term impacts on sessile organisms are likely to be very localised and small.

According to Isaacman and Daborn (2011) the key impact pathways of EMF over benthic communities could be the following:

- IP26: Change in movement patterns, effect on navigation/operation, avoidance or attraction behaviour, effect on predation-prey detection, physiological effects, change in health, survival and/or reproductive success.

### 4.6.3 Marine mammals and turtles

Little consideration has been given to whether magneto-receptive marine mammals and turtles might be able to detect and respond to EMFs from MRE devices and/or subsea cables (Gill *et al.*, 2014). The likely explanation is that the MRE device/cable EMFs are less intense than the geomagnetic field, so it is assumed that the animals are less likely to respond, but this still remains an open question. If they did respond to cables then mammals and turtles would more likely detect EMFs from DC cables than from AC cables, because the former characteristically have static B-fields (similar to the geomagnetic field) and they are of higher intensity than the latter. The likeli-hood of exposure will also be a function of the depth of the water above the cable and the depth of swimming because field strength dissipates with distance (Copping *et al.*, 2016).

# 5. SCALE OF THE PROJECT

## 5.1 Initial SDM policy risk assessment of the scale of the project

The initial scheme of SDM policy described in Deliverable 3.1 (Bald *et al.*, 2015) identified the scale of development as one or the three factors enabling assessment of the overall project risk. It has initially been assessed on the proposed total installed generating capacity in megawatts (MW) of the development, on a 3 points scale as shown in Table 3.

**Table 3.** Initial risk assessment related to the scale of a project (according to SDM policy)

| Scale | Criteria | Assessment |
|---|---|---|
| Small Scale | Up to 10 MW | Low |
| Medium Scale | More than 10 MW, to 50 MW | Medium |
| Large Scale | More than 50 MW | High |

## 5.2 Risk assessment of the scale of the project

During the Expert Workshop 3 held in November 2015, experts suggested that this classification could be improved in 2 ways:

- Refine or improve the parameters used to describe the **physical scale** of the project, and to apply metrics of scale that reflect the relevant impact pathways. For example, introducing the notion of **area** covered by the project, either as a complement or to replace the generating capacity scale where the impact pathway is displacement. For instance, Troldborg *et al*. (2014) expressed the area requirement as $m^2$/kW. Where the impact pathway is collision, consider using the number of devices as the most relevant metric of scale.

- Introduce **project duration** in addition to physical size, in order to perform the overall development scale risk assessment of the project.

### 5.2.1 Physical scale of the development

There are several parameters that can describe the physical scale of the project: generation capacity, number of devices, size of the devices, area of the project, etc. The proposal here is to assess the physical scale of the project on the basis of: (i) generation capacity in MW and (ii) area occupied by the project in $km^2$.

#### c) Generation capacity

For the generation capacity the proposal is based upon maintaining the assessment criteria included in the SDM Policy (see Bald *et al*., 2015) (Table 3).

Generation capacity is proposed to be kept as a secondary criteria. Using generation capacity rather than more detailed characteristics (number of device, size, etc) enables risk assessment of a project location at stages where the number of devices and the unitary generation capacity are not determined, or if these factors change during project development while preserving total generation capacity. This regularly occurs, a good example being the early development stages of the offshore wind park of Saint Brieux, France in 2014.

#### d) Area occupied by the project

Taking into account the $m^2$/kW values reviewed by Troldborg *et al*. (2014) for wind, wave and tidal projects and the generation capacity values shown in Table 3, the thresholds showed in Table 4 are proposed for risk assessment.

**Table 4.** Example of risk assessment related to area of the project for wind, wave and tidal projects.

| Scale | Wind | Wave | Tidal | Assessment |
|---|---|---|---|---|
| Small Scale | < 2 $km^2$ | < 1,5 $km^2$ | < 1 $km^2$ | Low |
| Medium Scale | 2 - 10 $km^2$ | 1,5 – 7,5 $km^2$ | 1 - 5 $km^2$ | Medium |
| Large Scale | > 10 $km^2$ | > 7,5 $km^2$ | > 5 $km^2$ | High |

### 5.2.2 Duration of the project

Project duration of the operational phase has been stressed by experts attending workshops as a very important criterion. It has already been used in existing risk assessments (Sparling *et al*. (2015)) of wave and tidal projects on marine mammal populations in Wales. According to the criteria established by these authors, the risk of the project according to the duration can be assessed as shown in the Table 5. Consideration of differing life history traits between organisms may lead to alternative classification time scales on a case by case basis.

**Table 5.** Example of risk assessment related to the duration of the operational phase of a project, taken from Sparling *et al*. (2015).

| Time Scale | Criteria | Assessment |
|---|---|---|
| Short | 1-3 Years | Low |
| Medium | 3-10 Years | Medium |
| Long | >10 Years | High |

It´s worth noting that duration of the installation and decommissioning phases of the project could be also be included in the assessment of the "duration of the project". This is a most difficult issue due to the wide range of projects that could be proposed and the specific conditions of each site, thus remaining an open question to be further developed and incorporated into the risk assessment approach.

# 6. RISK ASSESSMENT

Following the methodology suggested by the SDM Policy (see Deliverable 3.1), the assessment of the risk of a MRE development is based on assessments of environmental sensitivity, project scale, and technology risk (Figure 4). These are each categorised as High, Medium or Low and then summarised into a single project risk assessment (Figure 4).

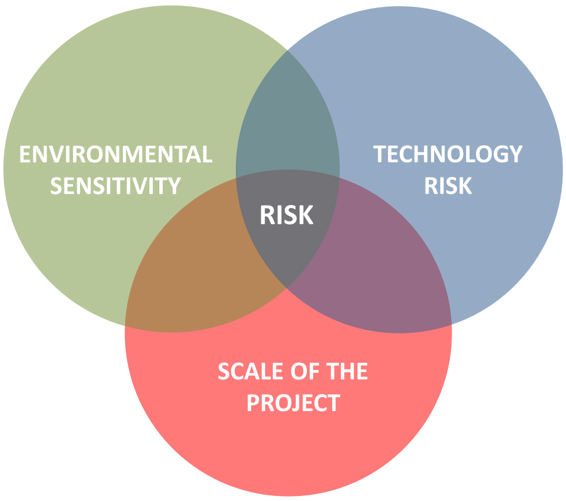


**Figure 4.** Risk assessment approach.

Similar to Sparling *et al*., (2015), the assessment of the risk of a MRE development is based on the combined outcomes of the overall sensitivity of the receptors, taking into account the sensitivity of the location, and the risk posed by the project, taking into account the scale and the technology.

## 6.1 Environmental sensitivity

As previously stated, in developing SDM, Marine Scotland chose to take a qualitative approach to classifying the overall environmental sensitivity of the project location using expert judgment based upon the mapping exercise of all environmental sensitivities combined. An alternative and potentially more transparent approach to scoring the overall environmental sensitivity of a potential development location is given in Table 6.

**Table 6.** Calculating overall environmental risk of the proposed location for MRE development: score (1, 2 or 3 for Low, Medium or High respectively); GM = Geometric Mean.

| **Location of project** | **ENVIRONMENTAL SENSITIVITY LAYERS (RECEPTORS)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **PHYSICAL ENVIRONMENT** | | | | **BIOTIC ENVIRONMENT** | | | |
| | Marine Dynamics | Seafloor integrity | Water quality | Landscape | Benthos | Fish | Marine mammals | Birds |
| **Low, medium or high sensitivity at the location** | | | | | | | | |
| **Overall RISK** | GM | | | | | | | |

For each environmental sensitivity of concern at the location a value of 1, 2 or 3 is assigned for Low, Medium and High risk assessments respectively, depending on the perceived importance of the location. For example locations that are protected areas for habitats or species would score more highly than other areas, and areas of the wider marine environment with relatively higher densities of a particular species would score relatively more highly than other areas. This exercise would be informed by the environmental sensitivity mapping at a national scale, that was of sufficient robustness to allow quantification at local scales to be undertaken with confidence. As such it would appear to be more appropriate for Member States who have access to comprehensive and reliable data sets on environmental sensitivity. Having obtained a risk value for each receptor of interest at the project location the overall environmental sensitivity of the location can be calculated using the geometric mean.

In principle, scoring environmental sensitivity in this manner should make it more transparent which factors at a particular location are of particular importance for the subsequent assessment of environmental impacts from the project. This may be particularly useful where a scoping exercise is undertaken as part of an Environmental Impact Assessment.

## 6.2 Technology risk (TR)

Table 9 summarizes the IP of MRE developments over the marine environment identified in Section 4. For each IP a value of 1, 2 or 3 is assigned for Low, Medium and High risk assessments respectively. In this way, a risk value can be obtained for each stressor and receptor by means of the calculation of the geometric mean (GM) of the assigned scores for each IP (Geometric Mean = $((IP_1)(IP_2)(IP_3).....(IP_n)^{1/n})$. This analysis need to be done for each of the project stages, that is, construction, operation and decommissioning. For each of these project stages we will obtain a Low, Medium or High risk assessment. Thus, it is recommended that the overall risk assessment of the technology consists of the calculation of the Geometric Mean of the three scores (stressors, physical receptors and biotic receptors) as shown in Table 7.

**Table 7.** Technology Risk (TR) assessment.

| Technology Risk | GM score | Overall risk |
|---|---|---|
| $TR_{Construction} = ((IP_1)(IP_2)(IP_3).....(IP_n))^{1/n}$ | 1 – 1.60 | Low |
| $TR_{Operation} = ((IP_1)(IP_2)(IP_3).....(IP_n))^{1/n}$<br>$TR_{Decommissioning} = ((IP_1)(IP_2)(IP_3).....(IP_n))^{1/n}$ | 1.61 – 2.20 | Medium |
| $TR = ((TR_{Construction})*(TR_{Operation})*(TR_{Decommissioning}).....(IP_n))^{1/n}$ | 2.21 – 3.0 | High |

## 6.3 Scale of the project

For each of the three scale factors (generation capacity, area occupied by the project and duration), a value of 1, 2 or 3 is assigned for Low, Medium and High risk assessments respectively. An overall project scale risk value can be obtained by means of the calculation of the geometric mean (GM) of the assigned scores for each scale factors as shown in Table 8.

**Table 8.** Scale of the Project Risk (SPR) assessment.

| Scale of the project Risk | GM score | Overall risk |
|---|---|---|
| | 1 – 1.60 | Low |
| $SPR = ((\text{Generation Capacity})*(\text{Area of the project})*(\text{Project Duration}))^{1/3}$ | 1.61 – 2.20 | Medium |
| | 2.21 – 3.0 | High |

**Table 9.** Impact pathways of the MRE developments over the marine environment. Key: Sc = score (1, 2 or 3 for Low, Medium or High respectively); GM = Geometric Mean.

<table>
<tr><th colspan="2" rowspan="3">Installation<br>Operation<br>Decommissioning</th><th colspan="16">ENVIRONMENTAL FACTORS (RECEPTORS)</th><th></th></tr>
<tr><th colspan="8">PHYSICAL ENVIRONMENT</th><th colspan="8">BIOTIC ENVIRONMENT</th><th rowspan="2">RISK</th></tr>
<tr><th colspan="2">Marine Dynamics</th><th colspan="2">Seafloor integrity</th><th colspan="2">Water quality</th><th colspan="2">Landscape</th><th colspan="2">Benthos</th><th colspan="2">Fish</th><th colspan="2">Marine mammals</th><th colspan="2">Birds</th></tr>
<tr><td rowspan="11">ACTIONS OF THE PROJECT (STRESORS)</td><td rowspan="2">Physical presence of devices</td><td colspan="2" rowspan="2"></td><td colspan="2" rowspan="2"></td><td colspan="2" rowspan="2"></td><td>IP7</td><td>Sc</td><td colspan="2" rowspan="2"></td><td>IP1</td><td>Sc</td><td>IP3</td><td>Sc</td><td>IP5</td><td>Sc</td><td rowspan="2">GM</td></tr>
<tr><td colspan="2"></td><td>IP2</td><td>Sc</td><td>IP4</td><td>Sc</td><td>IP6</td><td>Sc</td></tr>
<tr><td rowspan="2">Physical presence of supporting structures</td><td colspan="2" rowspan="2"></td><td>IP12</td><td>Sc</td><td colspan="2" rowspan="2"></td><td colspan="2" rowspan="2"></td><td>IP8</td><td>Sc</td><td>IP10</td><td>Sc</td><td>IP11</td><td>Sc</td><td colspan="2" rowspan="2"></td><td rowspan="2">GM</td></tr>
<tr><td>IP13</td><td>Sc</td><td>IP9</td><td>Sc</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="4">Dynamic effects of devices</td><td>IP18</td><td>Sc</td><td colspan="2" rowspan="4"></td><td colspan="2" rowspan="4"></td><td colspan="2" rowspan="4"></td><td colspan="2" rowspan="4"></td><td>IP14</td><td>Sc</td><td>IP15</td><td>Sc</td><td>IP16</td><td>Sc</td><td rowspan="4">GM</td></tr>
<tr><td>IP19</td><td>Sc</td><td colspan="2" rowspan="3"></td><td colspan="2" rowspan="3"></td><td>IP17</td><td>Sc</td></tr>
<tr><td>IP20</td><td>Sc</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>IP21</td><td>Sc</td></tr>
<tr><td>Chemical effects</td><td colspan="2"></td><td colspan="2"></td><td>IP22</td><td>Sc</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td>GM</td></tr>
<tr><td>Acoustic effects</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td>IP23</td><td>Sc</td><td>IP24</td><td>Sc</td><td colspan="2"></td><td>GM</td></tr>
<tr><td>EMF</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td>IP26</td><td>Sc</td><td>IP25</td><td>Sc</td><td colspan="2"></td><td colspan="2"></td><td>GM</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">**RISK**</td><td colspan="2">GM</td><td colspan="2">GM</td><td colspan="2">GM</td><td colspan="2">GM</td><td colspan="2">GM</td><td colspan="2">GM</td><td colspan="2">GM</td><td colspan="2">GM</td><td rowspan="2">GM</td></tr>
<tr><td colspan="8">GM</td><td colspan="8">GM</td></tr>
</table>

Key to IP:

- IP1: Changes in fish behaviour; may act as fish aggregation devices.

- IP2: Barrier to movement (a real or perceived obstacle to normal movement of sea life during migration or day to day activities).
- IP3: Changes in marine mammal behaviour; may act as aggregation devices.
- IP4: Barrier to movement (a real or perceived obstacle to normal movement of sea life during migration or day to day activities), and displacement of activities such as feeding, mating, rearing, or resting habitats.
- IP5: Displacement of marine birds.
- IP6: Collision risk with turbine blades.
- IP7: Landscape alteration due to the presence of devices
- IP8: Increases of sea bottom habitat heterogeneity and biodiversity of sessile and mobile benthic organisms due to the addition of hard substrata coming from moorings, foundations and cables.
- IP9: Changes in biogeographic distribution of hard substrata species and introduction pathway of alien species.
- IP10: Reefing effect.
- IP11: Entanglement and collision with cables and mooring lines.
- IP12: Dragging or rubbing of materials such as chains, wires, ropes or cables across the seabed and changes in sediment transport regime and the morphology of sandy areas.
- IP13: Artificialisation and change in proportion of hard/soft substratum in the installation area.
- IP14: Collision with structures and moving parts.
- IP15: Collision with structures and moving parts.
- IP16: Collision with wind turbines.
- IP17: Collision with tidal turbines.
- IP18: Scour processes due to the movement of previously stable sediment due to accelerated flows and turbulence induced by structures on or near seabed. Sedimentation processes due to accumulation of previously mobile or suspended sediments due to reduced flows or turbulence arising downstream or in the shadow of structures.

- IP19: Dissipation of wave energy due to the presence of marine energy devices leading to calmer waters or less exposed coastlines.
- IP20: Change in tidal flows and fluxes (changes in the velocity , direction, quantity and or duration of flows).
- IP21: Reducing or more likely increasing turbidity in the water column through the release or mobilisation of fine particles.
- IP22: Releases of contaminants from oils and other operating fluids and anti-biofouling coatings deriving in toxicity due to the exposure to contaminants; potential bioaccumulation of metals and other compounds and effects on behavior.
- IP23: Disturbance and avoiding behaviour during commissioning stage due to underwater noise generated.
- IP42: Disturbance and avoiding behaviour during commissioning stage due to underwater noise generated.
- IP25: Change in movement patterns, effect on navigation/operation, avoidance or attraction behaviour, effect on predation-prey detection, physiological effects, change in health, survival and/or reproductive success.
- IP26: Change in movement patterns, effect on navigation/operation, avoidance or attraction behaviour, effect on predation-prey detection, physiological effects, change in health, survival and/or reproductive success.

## 6.4 Overall assessment

Following the methodology suggested by the SDM Policy (see Deliverable 3.1), the assessment of the risk of a MRE development is based on assessments of environmental sensitivity (see section 3), technology risk (see section 4) and project scale (see section 5), based on the geometric mean of the three scores as shown in the following table:

| OR | GM score | Overall risk |
|---|---|---|
| Overall Risk = $((ESR)*(TR)*(SPR))^{1/3}$ | 1 – 1.60 | Low |
| | 1.61 – 2.20 | Medium |
| | 2.21 – 3.0 | High |

The project did not identify any alternative methods considered more suitable, and the current recommendation is that this method is applied by Member States.

# 7. DISCUSSION

As stated before, the objective of this deliverable is to provide guidance on the further development of the criteria on which the experts in charge of the risk analysis of a specific project will base their analysis in Member States. As it has been pointed out in the Expert Workshop 3 held in November 2015, ultimately, any risk-based approach should rely on expert opinion and at the discretion of Member States whether or not to undertake a more prescriptive approach at national or regional levels. This means that the suggested approaches to applying methodologies and criteria are open questions and consequently it is the responsibility of the experts to argue each of the assessments made under the suggested methodology.

This is especially clear taking into account the uncertainty that still remains associated with interactions between MRE devices and marine animals and/or habitats which are directly related with the risk analysis of the technology (Section 4), and with respect to the variation in the baseline data that can be used to define environmental sensitivity (Section 3). In order to reduce this uncertainty and better understand those interactions a continuing monitoring effort need to be implemented. Even if some data are available in relation to single devices, it is difficult to extrapolate the obtained results to larger deployments over longer time scales. Also, the question of cumulative impacts become a bigger issue as MRE development reaches commercialisation – particularly for tidal stream as the areas of resource interest tend to be in clusters around islands/entrances to lochs. Although cumulative impacts became an increasingly important component of environmental impact assessment, practice remains contested (Duinker *et al.*, 2012) with few EIAs even considering cumulative impacts (Masden *et al.*, 2010).

The dynamic nature of the marine environment, combined with continuous improvements in our understanding of the abundance and distributions of the species that are associated with the individual factors within the environmental sensitivities layer mean that periodic updating should be considered best practice. The recommendation of the RiCORE Project is that timing of updates should reflect significant changes in the baseline understanding, or in response to further phases of planned deployment of novel technologies.

Regarding the project scale criteria, further development could be expected as MRE develops to commercial scale and other questions such as layout of an array are addressed under the present approach.

The flexible approach adopted by SDM policy towards characterisation of the environmental risk profile is generally considered to be consistent with the underlying principle that the policy driver is in response to scientific uncertainty associated with novel activities whose impacts are necessarily poorly understood. More prescriptive approaches are more likely to be associated with more established, larger-scale human activities whose impacts are understood with greater scientific certainty.

# 8. CONCLUSIONS

The conclusions are provided in the form of a checklist of take home messages for the further development of risk profiling at a Member State level:

- Data gaps associated with environmental risk mapping should be addressed with reference to the best available information in preference to no attempt to characterize environmental risk being made.

- The specific environmental sensitivity layers considered by Member States will vary depending on information available and local concerns.

- Individual environmental sensitivity layers should be weighted and scored based on Member State priorities.

- Weighting of environmental sensitivity layers by refering to established assessments that relate the sensitivity of receptors to pressures can provide consistent treatment of marine renewable energy with other human activities.

- Overall environmental sensitivity can be risk profiled by calculation using the geometric mean method. This may provide a more comprehensive and transparent alternative to qualitative ranking of environmental sensitivity as either 1, 2 or 3 for each project location.  Undertaking this exercise could also inform scoping for projects that subsequently undertake Environmental Impact Assessment. Balanced against this are the benefits associated with more qualitative approaches that place more weight upon expert opinion which may be preferred; particularly where there are reasonable grounds to be concerned about the robustness of the data layers informing environmental sensitivity scores.

- Overall technology risk should be informed by identification and scoring of impact pathways between stressors and receptors. This can be used to arrive at an overall technology risk score using the geometric mean approach.

- Best available information on impact pathways should be used. This report reviews current state of knowledge, recognizing that the evidence base may change rapidly.
- Technology risk assessment should address construction, operation and decommissioning risks.
- The geometric mean scoring system should be applied to impact pathways in order to calculate overall technology risk.
- For scale of project risk the recommendation is to incorporate additional factors to consider the timescale of the different project phases and physical scale of the project in addition to the electrical output (megawatts). Physical scale may be sub-divided into spatial area for displacement impact pathways and number of devices for collision risk impact pathways.
- The geometric mean scoring system should be used to calculate overall scale of project risk.
- The overall project risk should also use the geometric mean scoring system.
- The suggested approach for a risk analysis of a specific project developed in the present deliverable remain an open question and consequently it´s the responsibility of the experts to argue each of the assessments made under the suggested methodology. Further developments are expected an encouraged as new research reduce uncertainties about environmental interactions between MRE devices and marine animals and/or habitats,

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