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Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact

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Scientific guidelines on Environmental Assessment

André Moura, Teresa Simas
Wave Energy Centre
Robert Batty; Ben Wilson
Scottish Association for Marine Sciences
David Thompson, Mike Lonergan
University of St. Andrews, Sea Mammal Research Unit
Jennifer Norris, Matthew Finn
European Marine Energy Centre
Gérard Veron, Michel Paillard
Institut Français de Recherche pour l'Exploitation de la MER
Cyrille Abonnel
Electricité De France

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Summary

In this report, guidance on the implementation of EIA following best practices is presented for wave and tidal energy projects and the application and integration of other environmental assessment techniques is discussed. This document is the basis of the Equimar protocol document providing information on the conduction of an EIA process for wave and tidal energy projects and on suitable tools, methodologies and techniques that may be applied during it.

CONTENTS

1 INTRODUCTION

Environmental assessments are conducted to understand and evaluate the potential environmental effects of a marine renewable energy project and to promote the sustainable development and implementation of ocean energy projects. The assessments are typically used by stakeholders and consenting or regulatory bodies to inform the consultation and decision making process from concept to decommissioning. An environmental assessment of a marine renewable energy project is used to:

- Inform the project development process and if possible the design phase;
- Identify, predict, evaluate and classify the potential environmental and socio-economic impacts (beneficial and harmful) from construction to decommissioning, and are most useful if initiated from the conceptual stage of the project;
- Recognize and evaluate possible cumulative impacts of the project itself and in combination with other projects – existing or planned – and / or marine activities;
- Contribute to site selection by identifying significant environmental and socio-economic features of the possible deployment areas, by estimating their sensitivity to the project characteristics (baseline survey outcomes);
- Identify appropriate mitigation measures for potentially harmful impacts;
- Establish a monitoring programme for the pre-deployment, operation, decommissioning and post-decommissioning stages;
- Consult with and inform stakeholder groups and the public in general;
- Propose and implement adaptive environmental management actions.

The environmental analysis should be considered a planning instrument and thus it is desirable that it can form an integral part of the project development from the very beginning. It is normally conducted by a formal Environmental Impact Assessment (EIA) and reported in an Environmental Statement[1]. In the European Union, regulation on EIA is established in the EIA Directive (85/337/EEC, amended by Directive 97/11/EC and Directive 2003/35/EC). This Directive refers to two other Directives – the Wild Birds Directive (79/409/EEC), on the Conservation of Wild Birds, and the Habitats Directive (92/43/EEC) – on the nature conservation policy in the European Union. All areas classified under these Directives form an ecological network known as Natura 2000. The Habitats Directive requires that any activities, plans or projects whether inside and outside a "Natura 2000" Site, that are likely to have a significant effect on the conservation status of a site's features shall be subject to assessment. Therefore when a proposed wave or tidal energy project is proposed to be located within, or would be likely to significantly affect, a designated area (Special Area of Conservation – SAC – and/or Special protection Area – SPA), the consenting authorities shall ensure that an Appropriate Assessment be carried out under the Directive. The requirement and scope of such assessment is usually clarified during the scoping stage of the EIA, in which the developer seeks initial feedback from the consenting authority and its advisory bodies.

There are other environmental assessment techniques (SEA[2], ERA[3], LCA[4]) which can be consulted / applied before / during the EIA process. The results of these complementary environmental assessment techniques / instruments can further be integrated in the EIS.

In this report, guidance on the implementation of EIA following best practices is presented for wave and tidal energy projects and the application and integration of other environmental assessment techniques is discussed. This document is the basis of the Equimar protocol document providing information on the conduction of an EIA process for wave and tidal energy projects and on suitable tools, methodologies and techniques that may be applied during it.

2 ENVIRONMENTAL ASSESSMENT APPROACHES

The environmental assessment of wave and tidal projects is a process that should be carried out by project developers to inform stakeholders and regulatory bodies in their assessment and decision making process from concept to decommissioning.

EIA and SEA are the legal tools used for conducting impact assessment at different levels. EIA is the traditional approach that has been widely used to address environmental impacts of a given project. SEA is a more recent mechanism for identifying and assessing the likely significant environmental effects of a plan or programme and its alternatives. SEA and EIA are tools that share a common root - impact assessment, but have different assessment foci: strategies for future development with a high level of uncertainty in SEA; proposals and measures, concrete and objective, for the execution of projects in EIA.

The results of other techniques application such as ERA (section 7.1.1) and LCA (section 7.1.2) can also be applied or consulted during the EIA and/or to inform and support the decision making process of the device concept design and activities planned. The results of these complementary instruments can further be integrated in the EIA report.

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[1] Although most projects in the EU will fall under the remit of the EIA Directive, there may be some exceptions, due to the scale or location of the proposed project. In such cases, a formal EIA may not be required (see Equimar deliverables 6.1.1 and 6.1.2), but there is likely to be a requirement for supporting environmental information to accompany any applications for permissions to deploy. Such exceptions may exist at test sites such as EMEC, for devices of limited generation capacity.

[2] Strategic Environmental Assessment

[3] Environmental Risk Assessment

[4] Life Cycle Assessment

SEA is a recent strategic tool that ensures the incorporation of environmental considerations into policies, plans and programmes at a regional or national scale. It is therefore used by strategic authorities to consider the potential wide-ranging effects of plans and programmes in a structured way and to demonstrate that environmental and other effects have been taken into account during their preparation. In Europe, the SEA Directive (2001/42/EC) entered into force in 2004 and thus few examples of its application are available. In UK, the Scottish government conducted a SEA for marine renewables. This document was concluded in March 2007 [1] and covers the entire west and north coast of Scotland to a distance of 12 nautical miles offshore based on where the main wave and tidal resource areas are located. In the UK a series of SEA reports covering offshore energy (offshore wind, offshore oil and gas and gas storage) have been published with a specific SEA report targeting renewable wind published in 2009 available online [2]. Outside of the European Community, examples of the SEA process application to offshore energy sector are available for Canada, where the Offshore Energy Environmental Research Association (OEER) was commissioned by the Nova Scotia Department of Energy to carry out a SEA focusing on tidal energy development in the Bay of Fundy [3]. SEA recommendations need to be taken into account in all environmental assessment planning for specific projects on marine renewable energy and should provide relevant information for use in site selection.

3 ADAPTIVE MANAGEMENT

The initial lack of information regarding new technologies constrains the accurate assessment of environmental impacts. There is a need to learn from the device's operating experience in order to validate the predicted environmental effects of a project and adapt mitigation and/or monitoring strategies as knowledge progresses. This process of adaptive management centres on an iterative process used by resource managers to improve management decisions over time while environmental impacts are still uncertain.

Adaptive management is not a new concept and the steps for its application to wave and tidal energy projects have been proposed elsewhere and could be used as guidance for developers, regulators or managers (e.g. [4], [5], [6]). It is recommended that it should be employed at the project developers' level rather than mandated by a particular authority since its proper implementation requires ownership and regulatory management. For initial projects, the implementation of adaptive management plans may require a close liaison between developer and regulator.

4 SITE SELECTION AND CONCEPTUAL DESIGN: ENVIRONMENTAL CONCERNS

The environmental assessment of a project should start at site selection and project development design. The identification of environmental risks for a given site (and/or alternatives) and/or device type and the incorporation of environmental criteria in the decision making process of the development design are considered environmental best practices. These practices aim to minimise any negative impacts, maximise positive impacts and reduce development constrains at the early stage of the environmental assessment process. The Scottish guidance for Marine Renewable Energy Developments [10] presents several useful criteria that should be taken into account for site selection and design stages of the project development. Based on this approach examples of criteria that should be taken into account are presented in Table 1.

Table 1 Examples of criteria that should be considered when selecting a potential development site for a given development design (adapted from [10]).

Criteria for site selection	Examples
Marine Spatial planning	Strategic Environmental Assessment
The proximity of the site to nature conservation interests	Special Areas of Conservation; fish spawn areas at certain times of the year
Cumulative or in combination impacts with other nearby developments	Noise disturbance an proximity of cetacean habitats
Regulatory context	Proximity of legal protected areas
Potential impacts on landscape and visual amenity	Beach proximity
Availability of access and necessary infrastructure	Transport routes, number and type of vessels, frequency of transport
Effects on other marine uses	Navigation, tourism and fisheries
Impacts on wildlife	Proximity of migratory routes or movement routes of birds and cetaceans
Criteria for project development plan	**Examples**
Device design	Marine animal physical harm due to sharp edges of the machine
Device installation and decommissioning operations	Disturbance on fisheries in the vicinity
Methods of operation	Collision of marine animals with the device rotor blades
Device maintenance activities	Antifouling methods and vessel traffic

5 ENVIRONMENTAL IMPACT ASSESSMENT STEPS

The current methodology model of EIAs is a stepwise approach, which requires continuous reappraisal and adjustment as is shown by the feedback loops in Figure 1. The EIA process steps are briefly described below taking into account its application to wave and tidal energy projects.

5.1 SCREENING

Screening is the process to identify whether or not an EIA is required for a given project or development and what needs to be done if an EIA is not required. The legal framework which supports the screening process is the EIA Directive (85/337/EEC as amended by 97/11/EC) regarding the decision on whether the project typology falls within Annex I or Annex II. Annex I provides a list of projects for which EIA is mandatory and a statutory EIS is required. The projects listed under Annex II may require an EIA either through a case-by-case analysis or by considering thresholds or criteria set by each Member State. Wave and tidal energy projects are likely to fall within Annex II category and the criteria for the EIA requirement differ within European countries (a legislation review is presented in Equimar deliverable 6.1.1).

The screening process usually requires that the developer contact the regulator entity for comments on the project characteristics. The way this communication with the regulatory bodies starts also varies within countries but key information on the project such as device design and operation, equipment to be installed, size of the project, site(s) under consideration, timescale and duration of the project, identification of significant constrains and any other specific queries is usually requested by the authorities.

At the end of the screening process the developer should be clearly informed on what environmental studies or information he will need to provide to the regulator to support the consent application. If an EIA and a statutory EIS are required, the developer progresses to the EIA Scoping step.

5.2 SCOPING

The Scoping process is an essential step of the EIA, which aims to identify, at an early stage of the project development, the key environmental issues that will need the most attention. Environmental key issues are e.g. environmental receptors significantly affected by the project, effects or potential impacts of the project on the environment, environmental issues that need detailed study (both desk study and or baseline survey), methodologies to use, possible mitigation measures, constraints that may pose problems and whom to consult. During this process, a number of potential environmental and socio-economic potential impacts can be avoided through amendments to the e.g. choice of location, technology and materials. Scoping checklists and matrices are valuable tools to fulfil this exercise, particularly in identifying key impacts and receptors. The selection of appropriate consultants and interest groups can also be addressed using a checklist ([7], [8]). Examples of the application of such tools are given in section 3 below.

The scoping exercise should provide a ground plan for subsequent EIA steps determining what information should be submitted to the regulator within an EIS and what actions need to be taken to compile the required information and its detail (methods and levels of study needed to obtain reliable baseline information). The findings of the scoping exercise are usually reported in a "scoping report". A lack of detailed information at the scoping stage means that scoping estimates and decisions should be reassessed in the light of baseline information gained as the EIA progresses [7].

The initial task of the scoping exercise is a comprehensive description of the device(s) and associated activities. This shall focus on the aspects that are important from an environmental perspective and a non-expert language should be used to simplify its understanding.

An example of the project description details to be considered is presented in the EMEC's EIA guidance for developers [9]. The scoping report should also provide information on the project location (for all offshore and onshore aspects of the project) and the suggested alternatives to the development. Table 2 presents a (non-exhaustive) summary of the key information that can be submitted in the scoping report.

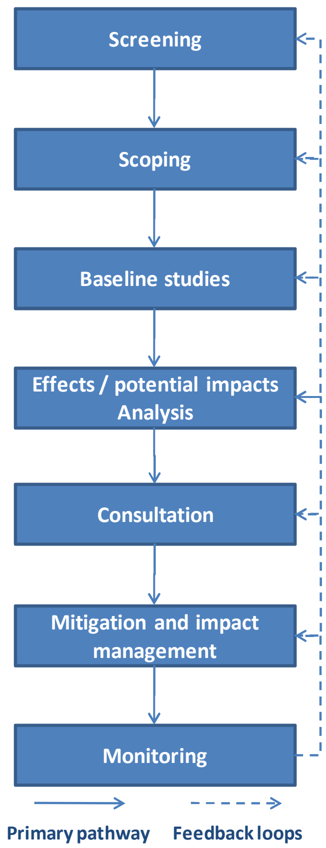

Figure 1 Esquemathic representation of the Environmental Impact Assessment methodology (adapted from [11]).

Table 2 Example list (non-exhaustive) of key information to be submitted in a formal scoping report (adapted from [7] and [10]).

Topics	Contents
Project details	• Device characteristics • Location and suggested alternatives for the development • Summary of the project activities (e.g. installation, maintenance and decommissioning methods and plans)
Potential effects	• List of receptors likely to be affected by project stages and activities • Identification of the potential environmental impacts • Knowledge and data gaps
Mitigation measures	• Possible mitigation measures

	• Guidance on identifying the preferred option from an environmental perspective
Methods and level of studies	• Details / plan for conducting technical studies, methodologies and resources to be used • Methodologies for baseline surveys (field work)
Consultation	• Stakeholder consultation strategies • List of consultants and interest groups
Structure of the EIS	• Suggestion on the contents and length of the EIS

The scoping report is usually submitted by the developer to the regulator, who collates the information from statutory consultees which in turn should define the scope of the EIS to be submitted. Therefore, it is a good practice to update the scoping report in light of the information received.

It is usually during the scoping stage that the requirement for an Appropriate Assessment (AA) is determined. According to the Habitats Directive an AA is required if a project is likely to have a significant effect on a Natura site i.e. a Special Protected Area (SPA) or a Special Area of Conservation (SAC). An EIA cannot substitute the need for an AA and it is the responsibility of the competent authority (with advice from conservation agencies) to determine (and fully justify) whether a proposed project is likely to have a significant effect on a European site. Guidelines on AA application and development regarding offshore projects can be found elsewhere (e.g. [10], [11], [12], [13] and [14]).

5.3 BASELINE STUDIES

Baseline studies are the backbone of the components (or descriptors) assessments. They inform about the reference condition on environmental and socio-economic systems in the impact area and are the basis for valid impact predictions and effective mitigation and monitoring programmes. Sometimes the required information can be compiled by means of a desk study, which is generally less expensive and time-consuming than obtaining new data. Furthermore, it is pointless to undertake new work that duplicates existing information. Strategic Environmental Assessments (SEAs) made for offshore marine renewable energy and Marine Spatial Plans can be very useful at this stage of the process since they provide various offshore biological, ecological and geological data. The assessment of the environmental datasets for a given location should be one of the first tasks (undertaken from the screening procedure) in order to ascertain what data is available and to determine what, if any, further information is required.

In some cases, the existing baseline data can be inadequate or out of date and it is necessary to obtain new data by some form of field survey. It is not possible to prescribe a universal list of data that developers should gather to make an accurate description of the environment conditions within a given site due to the natural variability within sites and constraints of the project itself. However, there will be some similarities in the baseline data required of renewable energy projects they are likely to include bathymetry, benthic ecology, birds and marine mammals ([10], [15]). The types of issues that might need to be considered are listed in Table 3.

Table 3 Type of issues that might be considered under the baseline line survey (adapted from [10]).

Key topics for wave and tidal project EIAs
Designated sites
Coastal sedimentary processes
Geology, hydrology and hydrogeology
Benthic ecology
Fish and shellfish
Commercial fisheries
Marine mammals
Birds
Terrestrial habitats and ecology
Marine uses: navigation, fisheries, cultural heritage, recreation and access
Visual landscape and seascape
Noise and vibration
Cumulative impacts

Another important aspect to be considered in the collection of relevant baseline data is the coverage of the environmental variability timescale, since the conditions may change seasonally or inter-annually. The survey duration for baseline data collection depends, amongst others, on the sensitivity of a site and on the species under study (species associated with the benthos, marine mammals, birds, fish, etc). Criteria for sensitivity evaluation are presented below (Section 3.3.1). If an AA is required (Section 2.2 above) the baseline survey should also include the collection of data needed to support its development.

5.3.1 Sensitivity characterization

In the baseline characterization, an evaluation should be carried out on the sensitivity of the site (or site alternatives) regarding both environmental and socio-economic issues. The site selected for wave or tidal energy projects strongly influences both the potential environmental and socio-economic impacts; each site will have its unique sets of sensitivities. When available, the Strategic Environmental Assessment of wave and tidal energy development provides important information, at the strategic level, on the potential environmental effects of this type of projects in a given area. This information should be taken into account when evaluating the sensitivity of a given site.

The criteria to identify environmentally valuable areas for protection are well-established (a recent review can be found in [16]). The environmental sensitivity of a site is generally associated with the identification of species, habitats and/or areas of marine natural heritage importance. Accurate characterisation of special natural features is an essential initial stage in site selection. Table 4 presents a set of criteria for biological valuation of a site. The assessment approaches for each criterion are described elsewhere [16].

Table 4 Example of a set of marine valuation criteria and their definitions [16]. These criteria were selected from three different sources of literature: articles on peer-review articles, reports on selection criteria for Marine Protected Areas (MPAs) and international legislative documents that include selection criteria (e.g. EC Birds and Habitats Directives, RAMSAR convention, OSPAR guidelines, UNEP Convention on Biological Conservation).

Valuation criteria	Definition
Uniqueness / Rarity	Degree to which an area is characterised by unique, rare or distinct features for which no alternatives exist
Aggregation	Degree to which an area is a site where most individuals of a species are aggregated for some part of the year or a site which most individuals use for some important function in their life history or a site where some structural property or ecological process occurs within an exceptionally high density
Fitness consequences	Degree to which an area is a site where the activity(ies) undertaken make a vital contribution to the fitness (increased survival or reproduction) of the population or species present.
Resilience	The degree to which an ecosystem or a part/component of it is able to recover from disturbance without major persistent change
Naturalness	The degree to which an area is pristine (i.e. absence of perturbation by human activities) and characterized by native species (absence of introduced or cultured species)
Proportional importance	Global importance: proportion of the global extent of a feature (habitat/seascape) or proportion of the global population of a species occurring in a certain subarea within the study area. Regional importance: proportion of the regional (e.g. NE Atlantic region) extent of a feature (habitat/seascape) or proportion of the regional population of a species occurring in a certain subarea within the study area National importance: proportion of the national extent of a feature (habitat/seascape) or proportion of the national population of a species occurring in a certain subarea within territorial waters

The identification of the spatial and temporal distribution of habitats and species (using both field work or existing data) could be made for each site as well as for its adjacent area taking into account the Red List Species[5] can be used as well as the lists of habitats and species provided in the annexes of the Habitats and Birds Directives.
From the socio-economic perspective, sensitive locations are those where conflicts may arise from the number and type of other uses. Sensitive locations from a socio-economic perspective are those with a high variety of interests (uses). Where in place, Strategic Environmental Assessment and / or Marine Spatial Planning can assist in identifying the nature, location and extent of these other uses to aid in the process of selecting a suitable site and in conflict management.

5.4 IMPACT ANALYSIS

Screening and scoping inform the developers of the environmental impacts that the project is likely to have in the environment. The next stage is to deepen this analysis through the assessment of the potential impacts scale both onshore and offshore[6]. Therefore, an understanding of the project and of the baseline environmental conditions (Section 2.3) at the proposed site, are required. The impact analysis is composed of three main levels of detail: identification (which, as referred, already started in the scoping step), valuation and significance. To aid the first two levels of the assessment there are several standard techniques / tools that are listed and briefly described in Table 5.

Section 3 below presents a review of the application of such tools to the environmental impact assessment of wave and tidal energy projects. The criteria used in valuation of the impacts may be qualitative and/or quantitative. Qualitative assessments usually employ ratings such as neutral, slight, moderate or large (applied to both negative and positive impacts), whereas quantitative assessments involve the measurement or calculation of numerical values (Table 6).

The final task in the impact analysis stage consists on the analysis of the significance of the impacts which are the product of the recognized impact characteristics (e.g. magnitude and extent in space and time) and sensitivity value and recoverability of the relevant receptor(s). It therefore requires an evaluation of these receptor attributes, which should have been carried out in the baseline evaluation [7]. A stepwise approach for the evaluation of impact significance of wave and tidal developments is proposed

[5] Red List Species: available at http://www.iucnredlist.org/
[6] In this work only offshore environmental assessment is considered

in the Scottish Marine Renewables Licensing Manual [10] and a criteria grid to evaluate the significance of marine energy impacts is established in the EMEC's guidance for developers [9].

The impact analysis is often the most difficult step in an EIA. Direct impacts are usually easy to identify but indirect and cumulative impacts are, sometimes, much more difficult. It is also important to note that impact analysis is not an exact science having bound by a degree of uncertainty which should be clearly stated in the EIS [7].

Regarding the different levels in which a project can be assessed (identification, valuation and significance) it is recommended to use a specific method for each detailed level and the partial conclusions should be integrated to get the global picture.

Table 5 Commonly used methods for impact identification and prediction (adapted from [7] and [8]).

Method	Features	Examples
Checklists	Useful for identifying key impacts especially in scoping. Can include information such as data requirements, study options, questions to be answered and statutory thresholds – but not generally suitable for detailed analysis.	Lists of specific areas of potential impacts and or environmental attributes
Matrices	Mainly used for impact identification; provides the ability to show cause-effect links between impact sources (plotted along one axis) and impacts (plotted along other axis). They can also indicate features of impacts such as their predicted magnitudes.	Leopold matrix [17] Peterson's matrix [18] Rapid Impact Assessment Matrix [24]
Mathematical / statistical models	Based on mathematical or statistical functions, which are applied to calculate deterministic or probabilistic quantitative values from numerical input data. They range from simple forms that can be employed using a calculator or computer spreadsheet, to sophisticated computer models that incorporate many variables. They need adequate / reliable data. The results usually require validation.	Mathematical models on water quality, noise and behaviour of biological systems
Maps and GIS	Maps can indicate features such as impact areas, as well as locations and extents of receptor sites. Overlay maps can combine and integrate two or three "layers", e.g. for different impacts and/or environmental components or receptors. GIS can analyse a number of layers, and has facilities for the input and manipulation of quantitative data, including modelling.	Priority Habitats map (Natura 2000) Maps on the distribution of commercial of bivalve banks

Table 6 Example of classification criteria used in impact valuation.

Criteria	Qualitative grade	Quantitative grade
Nature of impact	Direct, indirect	-
Signal	Positive, neutral, negative	-
Magnitude (severity)	Maximal, moderate, minimal	Threshold levels (e.g. level of a pollutant; noise levels)
Probability of occurrence	High, medium, low	-
Duration	Temporal, permanent	Duration time of each occurrence
Frequency / Periodicity	Continuous, Discontinuous, periodic (e.g. seasonal), regular occurrence, rare	
Temporal extension	Immediate, short term, medium term, long term	Duration time (e.g. during installation or operation)
Spatial extension	Local, adjacent, regional, national, global	Degrees and extension of impact areas of influence
Recoverability	Irrecoverable, irreversible, reversible, recoverable, fugal	-
Inter-relations between actions and effects	Simple, cumulative, synergetic	-
Need for mitigation measures	Critical, severe, moderate Total, partial, no-mitigation	-
Importance	High significance, significant, low significance, irrelevant	-

The likely significance of impacts can be used to prioritise them. However, impacts prioritization is only possible when device(s) monitoring data is available for the analysis of impacts significance. Therefore, at the current knowledge stage it is essential to determine what environmental monitoring should be prioritised. EMEC carried out a workshop with regulators, their advisors and academia to reach agreement on the relative prioritisation of the development of monitoring methods for environmental issues where information was insufficient for impacts evaluation and consequent best practice methodologies (Table 7). According to this consultation, collision of marine species with the devices and alteration to species behaviour were considered the high priority issues for monitoring, regarding marine wildlife, and navigation and limitation of access of fishers access to actual or potential fishing grounds were the priority issues concerning socio-economic impact monitoring.

5.5 CONSULTATION

During the researching of the EIA, culturally appropriate levels of public consultation shall be undertaken. Mechanisms are needed to ensure that all interested parties or stakeholders are participating in the EIA process and contributing to it with concerns and / or opinions which can further be integrated in the decision making process. The Marine Renewables Licensing Manual developed for the Scottish Government [10] refers that "one of the aims of the streamlining of the consenting / licensing process for marine renewables projects is to ensure that consultation at all levels is with the right party and progressed at the right time". Thus, it is recommended that besides the formal public consultation required under the EIA regulations the developers begin informal consultations at an early stage of the project consenting process involving regulatory bodies, their advisors and other stakeholders including local interest groups and the public in general.

There is still a need to develop the technical aspects of public consultation on marine energy projects in order to make it more effective. It is good practice to develop a consultation strategy document listing the stakeholders to be involved in the process as well as the actions and techniques to be used. The experience from offshore wind projects is valuable and its principles and techniques can be adapted to the wave and tidal energy projects. Reviews on the social, economic and cultural concerns of offshore wind energy are available in the literature (e.g. [19]). The British Wind Energy Association produced a useful report on best practice guidelines on consultation for offshore wind energy developments which addresses the principles, stages and techniques for good consultation [20]. Other useful examples of frameworks are available in the literature (e.g. [21]) as well as case studies of consultation on wave and tidal energy projects (e.g. [22], [23]).

Table 7 Environmental interactions / potential impacts of wave and tidal energy developments and its relative prioritization. The priority column represents the relative prioritisation for the development of new monitoring methods where there are no well established best practices. This does mean that an issue which is considered important for the industry, but for which there are well established monitoring methods available, the priority ranking will be low since no new methods need to be developed [24].

Receptor of interaction	Nature of interaction	Priority
Wildlife, particularly marine mammals and birds, but including a few other species such as basking sharks	Collision with devices, particularly tidal turbines	H
	Alteration to wildlife behaviour. For example, reduction in access to feeding areas (mammals and birds), avoidance arising from "barrier effects" of arrays of devices in restricted waters	H
	Entanglement of wildlife in moorings	L
	Damage to hearing (mammals and fish) primarily from survey (e.g. seismic) activities, and construction work (pile driving)	L
	Underwater noise - construction	L
	Underwater noise - operation	M
Seabed, habitats and species	Physical disturbance of the seabed	M
	Alteration to sediment movements	L
	Alterations to benthic faunal communities through changes in flow or wave exposure.	M
	Vibration	L
Marine productivity	Alteration of primary production in development areas	L
Navigation	Surface vessels, merchant shipping, fishing vessels, naval vessels	H
	Submarine navigation	H
Commercial fisheries	Limitation of access of fishers to actual or potential fishing grounds	H
	Impacts on fish spawning grounds	L
	Direct impacts of devices on fish	L
Aesthetic impact	Visual impact of objects on the sea surface	M
	Impact on marine (underwater) landscape	M
This section covers a very wide range of forms of interaction with the marine environment Almost all are not unique to wave and tidal energy developments and are well managed in other contexts.	Leaching of antifoulants from devices	L
	Chemical and oil spill risks	L
	Redistribution of contaminants, primarily contaminated sediment	L
	Changes in turbidity	L
	Debris loss	L
	Impacts on marine archaeology	L
	Recreational users	L/M

5.6 MITIGATION AND IMPACT MANAGEMENT

Mitigation measures are formulated to avoid, minimise / reduce, remedy or compensate for the predicted adverse impacts of the project. An additional best practice should also investigate to include the enhancement or the improvement of the site beyond the existing baseline [10]. Some of these measures can include: selection of alternative locations; modification of the methods and timing of construction, modification of design features, minimisation of operational impacts (e.g. noise and collision), etc.

Different mitigation measures are needed according to the specific impacts on the environmental components and receptors. The Environmental Impact Statement (EIS) should indicate detailed measures on how to carry them out and propose how they can be modified if unexpected post-project impacts arise. Where impacts of medium and high significance are identified, mitigation should be proposed to reduce frequency, probability or extent of the impact. Residual impacts are those that remain following impact mitigation [7]. Discussion on mitigation measures for wave and tidal energy developments is available in several reports (Section 7).

5.7 MONITORING

After the baseline characterization, an operational monitoring plan should accompany the project installation, operation and decommissioning process taking into account that each site is unique and may benefit from more or less monitoring as regards its baseline characterization. Monitoring is the key to validate and expand the findings of the initial EIA. Its conclusions must flow into future assessments at all levels, from the baseline study to the impact evaluation and mitigation measures. The monitoring needed to understand and minimize environmental impacts has either a site-specific (conducted by the developer) and a general (addressed by collaborative groups) value; collaborative monitoring studies can help the individual developers to refine their designs and operations in order to minimize the environmental impacts. Regarding wave and tidal energy developments the monitoring plan should:

- Quantify the presence and extent of key impacts of the device deployment and supporting activities on the identified environmental sensitive issues;
- Take into account the natural temporal and spatial variability of the site;
- Be performed throughout device installation, operation decommissioning and post-decommissioning periods during prototype sea-trials and commercial operation scales in line with recommendations from regulators and current state of knowledge regarding specific potential impacts;
- Follow an adaptive management process in order to identify and respond to uncertainties regarding the project's effects;
- Provide a rationale for the type, number and duration (e.g. seasonal, inter-annual) of measurements according to the key environmental aspects identified in the baseline survey; where possible, reference protocols or methods/ instrumentation should be used;
- Assess the cumulative interference of multiple devices on the receiving environment to establish appropriate array spacing and assist the design of the final deployment arrangement; in this case monitoring should follow a stepwise approach to allow the evaluation of the environmental effects of scaling up the number of units
- Assess the cumulative interference of the project in combination with other effects / impacts;
- Provide a context for the use of numerical and statistical models in the quantification.

The progress on the understanding of wave and tidal energy environmental impacts would be faster if monitoring results could be made available for stakeholders and other developers. This practice would streamline the licensing / consenting process and contribute to accelerate projects implementation. Table 8 presents examples of monitoring methodologies currently in use for the marine environment components. More information can be found in review reports of environmental key issues of marine energy projects presented below (Section 7).

Table 8 Environmental monitoring methodologies regarding wave and tidal energy project installation, operation and decommissioning.

Environmental issues	Monitoring issues / methodologies	References
Coastal sedimentary processes Geology, hydrology and hydrogeology	Modelling approaches	[11] [4]
Benthic ecology	Monitoring soft and rocky seabeds: - Qualitative sampling (species composition) - Quantitative sampling (species abundance) Methods for data analysis (application of indices) Video transects and photos of underwater device equipment (e.g. mooring system) and adjacent area	[25] [26]
Fish and shellfish	Video transects and photos in the device site location and in the adjacent area Fishery boat trajectories Artificial reef effect analysis	[26][27]
Marine mammals	Monitoring cetaceans from land sites Monitoring cetaceans from boats Monitoring cetaceans from air Acoustic surveys	 [28] [29]
Birds	Ship and aerial sampling methods	[30]
Electromagnetic fields	Electromagnetic fields measurements in situ	[31] [32]
Noise and vibration	Marine mammals noise exposure Pile driving monitoring: Marine Mammal Observer methodologies and requirements and Passive Acoustic Monitoring	[33] [34]

6 IMPACT ANALYSIS TOOLS

In this section a number of tools for the environmental impact assessment are listed and briefly described. Wherever possible, examples of the use of such tools in the environmental assessment of wave and tidal energy projects are given.

6.1 CHECKLISTS

Checklists are widely used tools to address project description and EIA scoping. Checklists also provide a systematized means of identifying impacts. They can be developed for application to particular types of projects and categories of impacts – sectoral checklists – such as ocean energy projects. However, checklists are not as effective in identifying higher order impacts or the inter-relationships between impacts, and therefore, when using them, consider whether impacts other than those listed may be important (NET).

As an example, according to EMEC's guidance to developers [9], a detailed description list of project characteristics should be provided including developers management system/structure, testing schedule, device structure and operation, mooring or foundation system, installation and power requirements, materials that are going to be used, hydraulic systems, corrosion protection, antifouling system, power conversion system, noise and vibration levels, device marking, electrical systems, heating / cooling and communication systems, shore connections and facilities, energy storage and sink, chemical use and management, potential discharges to the sea, maintenance requirements, decommissioning, environmental monitoring and accidental events. The project characteristics are then linked to key impact issues which should be further evaluated as is shown in Table 9.

In a protocol for the environmental assessment of projects to be developed in the marine environment [27] several checklists are proposed for different environmental assessment steps: checklist on the project characteristics; checklist on the surrounding marine environment features; checklist to identify impact importance; checklist to identify mitigation measures.

Table 9 Possible screening checklist for an ocean energy project.

Project characteristics		**Yes**	**No**
	Project area above xx m^2?		√
	Other	...	...
Proposed project activities		**Yes**	**No**
	Dredging		√
Installation	Pilling requirements	√	
	Foundation construction		√
	Navigational diversion		√
	Vessel requirements	√	
	Other	...	...
Deployment	Corrosion protection	√	
	Lighting arrangements	√	
	Other	...	...
Decommissioning	Generation of waste litter	√	
	Vessel requirements	√	
	Other	...	...
Affected physical and chemical components		**Yes**	**No**
	Hydrodynamic changes	√	
	Water quality		√
	Seabed (sediments) quality		√
	Noise	√	
	Waste disposal issues		
	Local air quality		√
	Other	...	...
Affected biological components		**Yes**	**No**
	Fish populations		√
	Marine mammal populations	√	
	Spawning habitat		√
	Bird habitat	√	
	Wildlife habitat changes	√	
	Contamination of wildlife		√
Affected socio-economic components		**Yes**	**No**
	Employment	√	
	Visual (seascape/landscape)	√	
	Noise		√
	Health		√

6.2 MATRICES

A matrix is a grid-like table that is used to identify the interaction between project activities, and help in the identification / judgement / evaluation of the impacts. Generally the project activities / characteristics (if a checklist is used for project description its items can be included here) are displayed along one axis and the environmental characteristics are displayed along the other axis (if a checklist is used for environmental characterization its items can be included here). Using the table, environment-activity interactions can be noted in the appropriate cells or intersecting points in the grid. The impact severity or other features related to the nature of the impact can be highlighted in the cells. There are several well-known types of matrices; two of the most used are briefly described below.

6.2.1 Leopold matrix

Leopold interaction matrix [17] is a comprehensive matrix, which has 88 environmental characteristics along the top axis and 100 project actions on the left hand column. Potential impacts are marked in the appropriate cell and a numerical value can be assigned to indicate their magnitude and importance. Usually the numerical value ranged from 1, for small magnitudes, to 10, for large magnitudes. The assignment of numerical values is based on an evaluation of available facts and data. Similarly, the scale of importance also ranges from 1, for very low interaction, to 10, for very important interaction (Figure 2). Assignment of numerical values for importance is based on the subjective judgement of the interdisciplinary team working on the EIA study.

The matrix approach is reasonably flexible since the number of specified actions and environmental items may increase or decrease depending on the nature and scope of the study. Technically, although this matrix approach is a gross screening technique to identify impacts, it is a valuable tool for explaining /evaluating impacts by presenting a visual display of the impacted items and their causes. Summing the rows and columns that are designated as having interactions can provide deeper insight and aid further interpretation of the impacts. The matrix can also be employed to identify impacts during the various parts of the entire project cycle – construction, operation, and even decommissioning phases.

The application of Leopold matrix method has been suggested to ocean energy projects ([9], [35] and [5]). One of these examples is presented in Figure 3 where, in a general sense, environmental factors were previously identified in a baseline study and further evaluated considering the main phases of an ocean energy project.

Characteristics and conditions→ Project actions↓	a	b	c	d
A	10 / 2	8 / 3	5 / 3	10 / 1
B	2 / 1	5 / 6	7 / 5	2 / 8
C	-3 / 7	5 / 9	5 / 6	10 / 1
D	2 / 2	4 / 1	4 / 9	3 / 6

Magnitude (strong negative impact)

Importance / significance (perhaps locally contained)

Matrix instructions

1. Identify actions across the top that are part of the proposed project;
2. Under each section place a diagonal slash in the cell at the intersection of each component on the side of the matrix where an impact is possible;
3. Indicate the magnitude and importance / significance of the impact with a value from 1 to 10 (1 is low and 10 is high); in some cases and for the magnitude classification a plus (+) for a positive impact and a minus (–) for a negative impact are used.

Figure 2 Leopold matrix instructions (based on [17]).

According to EMEC's guidance for developers, the impacts evaluation is made through the use of two main tables: a impact summary table, where the significance of the potential environmental impact is evaluated without (potential impact) and with (residual impact) management or mitigation measures in place; and a summary impact matrix, where the impacts are ranked against receptors, considering the mechanisms by which impacts may occur. The significance of the potential and residual impacts should be made using established criteria regarding the following categories: major, moderate, minor, negligible, no interaction and positive.

Environmental factors	Actions	Installation				Operation				Decommisioning			
		Ships	Cable	Mooring	Device	Ships	Cable	Mooring	Device	Ships	Cable	Mooring	Device
Abiotic	Geology and factors affecting coastal processes		×	×			×	×	×		×	×	
	Water quality	×	×	×	×	×			×	×	×	×	×
	Air quality	×				×			×	×			
Biotic	Benthos		×	×				×			×	×	
	Fish		×	×	×		×	×	×		×	×	×
	Marine mammals	×		×	×	×		×	×	×		×	×
	Other aquatic fauna		×	×				×			×	×	
	Marine birds								×				×
	Flora		×	×				×			×	×	
	Terrestrial ecology												
Socio-economic	Conflict of uses	×	×	×	×	×	×	×	×	×	×	×	×
	Archaeology & cultural resources		×	×									
	Visual Impact	×			×	×			×	×			×
	Noise								×				

Figure 3 Simple matrix (based on Leopold matrix) for impacts identification of a wave energy converter [35].

6.2.2 Rapid Impact Assessment Matrix

The Rapid Impact Assessment Matrix (RIAM) is a multi-criteria tool to organize, analyse and present the results of a holistic EIA]. This matrix method (Figure 5) was developed to bring subjective judgements in a transparent way into the EIA process and was originally developed for comparison of alternatives within one project.

Since its development (at the end of the 1990's), the method has been widely tested in many situations and case studies including a renewable energy installation [37]. The potential application of the method to the impacts evaluation of ocean energy projects is a possibility, given its flexibility to be adjusted to different assessment situations and environmental contexts [38].

The basic principle of RIAM is that the impact characteristics form the basis for scoring. The impact is divided into four categories which are scored according to five criteria. Then, an environmental score is calculated based on a three basic formulae and a final classification considering range bands is obtained for each impact. The scores for environmental and social impacts can then be graphically analysed.

6.3 GEOGRAPHIC INFORMATION SYSTEMS

A Geographic Information System (GIS) can be defined as the computer hardware, software and technical expertise that inputs, stores, maintains, manipulates, analyzes and outputs geographically referenced data. A GIS combines the power of spatial database management with high resolution graphic display to effectively present information. GIS outputs can include statistical reports, tables, charts, on-screen displays and high quality maps available in digital format that can be quickly and easily distributed ([39] and [40]). GIS has been widely used in the EIA process (Figure 4).

Regarding renewable energy, one of the biggest issues facing its exploitation is the selection of suitable sites [41]. One of the most widely used techniques to help on this task is the Multi-Criteria Decision Analysis (MCDA) within the framework of GIS which allows multi competing site selection objectives to be taken into account at once by renewable energy developers. This technique has grown significantly in recent years and several articles have been published in refereed journals since 1990 [42].

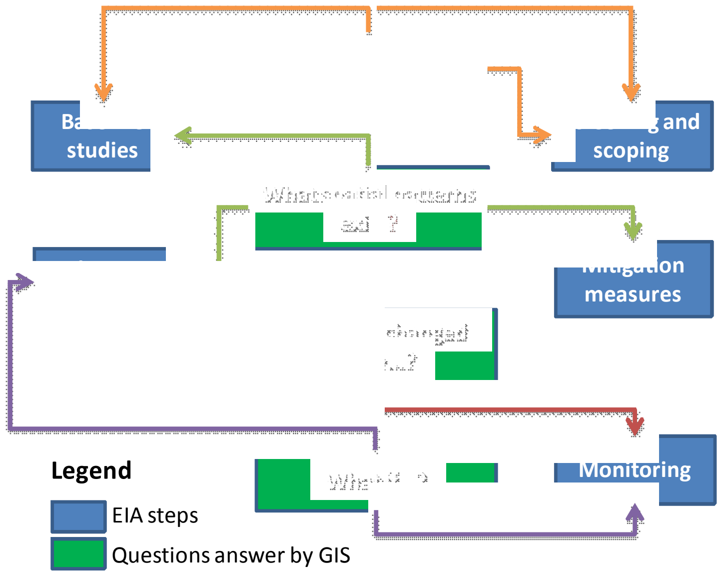

Figure 4 Central questions answered by a GIS during an Environmental Impact Assessment process (adapted from [39]).

As regards ocean energy, this technique has also been used in site selection of wave farms in e.g. UK [43] and Portugal [44]. It considers a wide variety of environmental and administrative factors (water depth, distance to shore, distance to the electric grid in land, geology and environmental impacts) and assign corresponding weights, which returns a numerical result in a given scale – suitability value – to be obtained for each location [44]. The criteria definition has two different supporting factors in the multi-criteria analysis: restrictions and weighted factors. Restrictions (e.g. existing underwater cables, marine protected areas, military exercise areas) are used to define exclusion areas that should be eliminated from the analysis; weighted factors (e.g. ocean depth, bottom type, distance to ports, distance to shoreline and to power grid, wave climate characterized by significant wave height, period and power) are evaluated through the relevance or significance of their impact(s) [44]. A GIS method has also been developed to optimise the cable route between a wave farm and the electricity network, in order to keep the underwater cable infrastructure costs to a minimum [45].

Bibliographic reviews show that the most common GIS applications are by far environmental issues including EIA. Although the use of GIS is limited by the availability of data with a good spatial coverage, its application on EIA process can help answering central questions. Examples of GIS applications on several steps of the EIA process (e.g. for ocean energy schemes) are presented in Table 10. GIS have been applied in several environmental assessments of wave energy projects e.g. WaveRoller in the coastal zone of Peniche - Portugal (AW-Energy Oy) and Wave Dragon in Milford Haven Coast, South West Wales (Wave Dragon Wales Lda).

GIS may be of particular value for identifying submerged sites that may retain archaeological remains, for example around Orkney [46] and in the North Sea. Layers showing submerged sites combined with identification of features likely to have human activity and current tidal and wave energy maps can indicate areas where remains are likely to be preserved. For tidal stream developments, therefore, is not likely that artefacts will remain at such high energy sites but cables to shore may be laid across them.

Components	A - Criteria that are of importance to the condition, that individually can change the score obtained		B - Criteria that are of value to the situation but should not individually be capable of changing the score obtained			A1xA2 = AT	B1+B2+B3 = BT	ATxBT = ES (RB)
	A1 Importance of the impact	A2 Magnitude of change and effect	B1 Permanence	B2 Reversibility	B3 Cumulative			
PC Physical / Chemical	4 National / international interests 3 Regional / National interests 2 Areas immediately outside of local condition 1 Only to the local condition 0 No importance	+3 Major positive benefit +2 Significant improvement +1 Improvement 0 No change -1 Negative change -2 Significant negative disbenefit or change -3 Major disbenefit or change	1 No change/not applicable 2 Temporary 3 Permanent	1 No change/not applicable 2 Reversible 3 Irreversible	1 No change/not applicable 2 Non-cumulative/single 3 Cumulative/synergistic			
BE Biological / Ecological								
SC sociological / cultural								
EO Economic / Operational								

ES: Environmental score	RB: Range bands	Description of range bands
+72 to +108	+E	Major positive change / impacts
+36 to +71	+D	Significant positive change / impacts
+19 to +35	+C	Moderately positive change / impacts
+10 to +18	+B	Positive change / impacts
+1 to +9	+A	Slightly positive change / impacts
0	N	No change / status quo / not applicable
-1 to -9	-A	Slightly negative change / impacts
-10 to -18	-B	Negative change / impacts
-19 to -35	-C	Moderately negative change / impacts
-36 to -71	-D	Significant negative change / impacts
-72 to -108	-E	Major negative change / impacts

RIAM instructions

1. Identify impacts for the components
2. Score impacts according to the main criteria (A and B)
3. Calculate the Environmental Score (ES)
4. Set the Range Band (RB) for each impact
5. Count the number of the same Range Bands per component

Figure 5 Criteria and instructions for RIAM (Rapid Impact Assessment Matrix) application in EIA ([37] and [38]).

Table 10 GIS and Environmental Impact Assessment steps (adapted from [11]).

EIA steps	Objectives of the GIS use	GIS application examples
Screening	Deciding whether a project requires EIA	- Maps of the project area can be generated automatically - Using GIS to overlay a map of the project and a map of the relevant sensitive areas (in which case an Environmental Impact Statement can be required) - In some cases EIA is required if a project is within a certain distance from a certain type of feature (e.g. road, residence area); GIS can be used to create a buffer zone around the project and clip a map containing all the relevant features
Scoping	Identifying impact themes which require further investigation; helping to clarify the spatial scope of the study (In this step GIS can be used in ways not too different from those applicable to screening)	- To inform a scoping decision regarding archaeology, creating a 500 buffer around a proposed project and then combine a map of known archaeological sites; the query can be structured to identify areas of archaeological interest falling within the buffer zone that have been submerged following sea-level rise - Identification of areas or receptor locations which will require detailed consideration in the assessment of a particular impact
Baseline studies	Building on the spatial information generated as part of the scoping process GIS is ideally suited to organizing and storing multi-disciplinary monitoring data sets to be analyzed, queried and displayed interactively;	- GIS can be a powerful tool for displaying and visualizing trends and patterns in spatial data sets: ▪ Point-type data relate to specific sample location ▪ Spatially continuous data (e.g. noise) can be used to produce a contour (isoline) map ▪ Linear data describing features ▪ Area data which relate to discrete spatial units (e.g. census data, designated sites and habitat patches)
Impact prediction	Spatial identification of impact magnitude and dimensions	- GIS is most suited to deal with the spatial dimension of impacts, and at the simplest level of analysis it can be used to make quantitative estimates of aspects such as: ▪ "Land take" caused by the development ▪ Length of zones which passes through designated land or seascape areas ▪ The number / importance of features (e.g. archaeological finds) that would be lost to the development
Impact mitigation	Identification and evaluation of alternative locations for a development project Exploitation of visualizing and displaying impact spatial distribution to identify and target possible mitigation measures (through impact significance)	- The maps produced for the baseline and impact assessment stages in an ecological assessment could be used to investigate: ▪ The potential to minimise impacts on nature conservation sites or habitat patches by project design modifications ▪ The potential for species translocation or habitat creation including e.g. corridor habitats between fragmented habitats ▪ The optimum locations and dimensions of buffer zones to protect sensitive habitats
Monitoring	Integrative tool to store, analyze, and display monitoring data to identify patterns in the data and examine change over time	

6.4 MATHEMATICAL MODELLING

Models, both mathematical and conceptual, may be of value for predicting and assessing the environmental impact of ocean energy devices and schemes. Geospatial models, such as that developed by CEFAS in the UK [47] can be used to quantify the cumulative impact of ocean energy. Ecological modelling is used extensively to predict the wider scale effects of marine protected areas on both commercial species and the ecosystem. These models should also be applied to understanding the impact of ocean energy via the displacement of both key species and of fisheries. Mathematical models are being used in recent, on-going, work [48] to investigate the interaction between fisheries and marine renewable energy. The spatial overlap between fisheries and tidal or wave resources can be modelled to investigate the sensitivity of individual species of both fish and invertebrates. Further spatial fishery models can be used to investigate the potential impact (both positive and negative) of marine energy developments as fishery exclusion zones affecting fishery yield and spawning potential.

The risk of collision between marine animals (mammals, fish and diving birds in particular) is difficult to predict and to monitor. In an effort to understand the processes that lead to a risk of collision between animals and the moving parts of marine energy converters and identify gaps in knowledge that require further investigation, encounter and evasion models are being developed and used. Three-dimensional encounter models (used extensively to understand predator-prey interactions of marine animals (e.g. [49], have been modified and used to assess the encounter rate with tidal turbines as well as the risk for individual species [50].

This model showed that encounter rate increases with body size, indicating greater risk to larger animals such as marine mammals. Collisions will result from failure to avoid encounter or to evade a close encounter; thus highlighting the need for more detailed information on spatial and temporal distribution of the species at risk.

Evasion models are also being developed as tools to predict the probability of evasion by fish and marine mammals in response to visual and acoustic stimuli. These models estimate the probability of collision evasion during what can be described as near-field, close encounters between marine animals and tidal stream turbine blades. Such models are based on the extensive literature on the behaviour and locomotion of fish in predator-prey interactions (see review by [51]). So far, a model has been constructed for fish responding to the visual looming stimulus of an approaching turbine blade [52]. By combining computational fluid dynamic models (verified by tank testing) with behavioural models it will be possible to construct models to predict evasion probability in response to transient sound pressure pulses resulting from the "bow-wave" of an approaching turbine blade. A further challenge will be to extend this approach to cover other marine vertebrates. This may, however, require further behavioural and physiological experiments. Collision evasion models have the potential to assist with the assessment and comparison of relative risks posed by different device types and to inform mitigation measures; for example improving visual and auditory cues to evoke animal evasive responses.

Considering the possibility of reducing collision by behavioural responses at greater distance, an acoustic avoidance model [53] has been developed to predict the range at which marine mammals may detect the sound emitted by tidal turbines over the ambient noise and be able to avoid encounter. This type of model has to be used in conjunction with ambient noise survey data.

Physical models that predict tidal and wave resources (see other Equimar documents) can also be adapted and used to indicate likely areas that will be impacted by reductions in energy input or in some cases increases in tidal energy due to displacement resulting from the drag induced by tidal stream arrays [54].

7 ENVIRONMENTAL KEY ISSUES

There are a number of recent reports on general environmental effects or potential impacts of wave and tidal energy projects (Table 11). These are exhaustive reviews on the state of the art regarding the list of potential affected environmental receptors, environmental effects / potential impacts, environmental assessment (baseline and monitoring studies), mitigation measures and knowledge gaps. The information provided in the reports listed in Table 11 is not much different within documents. In most of these reports the potential impacts are listed and analysed through the identification of stressors and receptors. Another possible approach is to identify impacts through the mechanisms by which they occur. This approach is proposed in the EMEC's guidance for developers [9] and can be used as a checklist to ensure that all potential impacts from the devices and associated operations are being assessed. Whatever the approach selected for impacts identification, the significance of each of them should always be judged against receptors.

Table 12 shows the most widely discussed issues regarding the environmental effects of wave and tidal energy technologies on the environment. It is important to stress that EIA study requirements are site and project specific and should be defined at the EIA scoping stage; therefore, the environmental issues list presented herein should be considered non-exhaustive and non binding.

Despite the considerable amount of information available regarding the identification and analysis of potential environmental impacts, there is still a need to collect and analyse more data to reduce effects uncertainties, prioritize impacts and improve best practices on project development and deployment.

Table 11 Examples of recent reports on reviews of environmental key issues of wave and tidal energy developments.

Title	Year	Country / entity	Description	Reference
Protocol to develop an environmental impact study of wave energy converters	May 2010	Spain, AZTI Tecnalia	Reviews the likely environmental effects of wave energy and presents a risk management framework to predict, prevent and deal with the environmental impacts of wave energy deployment of in Spain	[27]
Marine renewables licensing manual – Part IV Wave and Tidal Annex	April 2010	Scotland, Marine Scotland (MS)	A comprehensive guidance for licence applications of wave and tidal energy projects. This annex provides detailed information on the potential impacts (offshore and onshore) that might need to be considered during the EIA and the methods by which the impacts should or may be assessed	[15]
Report to the congress on the potential environmental effects of marine and hydrokinetic energy technologies	December 2009	USA, U.S. Department of Energy (DOE)	Describes the technologies that are being considered for development, their potential environmental impacts and options to minimize or mitigate the impacts, and the potential role of environmental monitoring and adaptive management in guiding their deployment	[4]
Worldwide synthesis and analysis of existing information regarding environmental effects of alternative energy uses on the outer continental shelf	July 2007	U.S.A., U.S. Department of the Interior, Minerals Management Service (MMS)	Identifies, collects, evaluates and synthesizes existing information on offshore alternative energy activities for public acceptance, potential environmental impacts, mitigation measures, physical and numerical models for environmental impacts prediction and information gaps	[19]
Ecological effects of wave energy development in the Pacific Northwest	October 2007	U.S.A., U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), National marine Fisheries Service	Presents the results of a workshop held in Oregon to develop an initial assessment of potential impacting agents and ecological effects of wave energy development and formulate general conceptual framework of physical and biological relationships that can be applied to wave energy	[5]

Table 12 Key environmental issues to be considered in the environmental assessment.

Receptors	Stressors	Effects and / or ecological issues
Physical environment Pelagic habitat Benthic habitat Fish and fisheries Marine birds Marine mammals Humans (users)	Physical presence of the devices Chemical effects Lighting Acoustics Electromagnetic fields Cumulative effects	• Alteration of currents and waves due to the energy extraction and or physical presence of the devices • Alteration of substrates and sediment transport and deposition which may alter coastline processes and morphology • Benthic habitat disturbance or destruction • Changes to factors such as nutrients, temperature, light levels, turbidity (suspended sediments) • Water contamination due to e.g. effluent or waste discharge, oil leaks • Collision, strike, entrapment and entanglement of marine invertebrates, fish, mammals and birds with the equipment e.g. device, mooring lines • Interference with animal movements and migration • Displacement of marine species • Noise disturbance • Effects of electromagnetic fields in elasmobranchs fish (sharks, rays and skates) orientation and reproduction

8 OTHER SHARED AND INTEGRATIVE METHODS

8.1 ENVIRONMENTAL RISK ASSESSMENT

Risk assessment or analysis is a well established management tool for dealing with uncertainty. It usually helps decision makers or other interested parties in a variety of purposes: determine environmental and health problems associated with several activities and substances (for example, hazardous waste disposal and the use of chemicals); compare new and existing technologies or determine the effectiveness of different control and mitigation techniques designed to reduce risks; select sites for potentially hazardous facilities; set management priorities, such as which of several activities should be considered first for regulatory or corrective action [55].

Risk Assessment has been only recently extended to wider environmental considerations. Environmental Risk Assessment (ERA) is a generic term for a series of tools and techniques concerned with the structured gathering of available information about environmental risks and then the formation of a judgment about them [56]. EIA and ERA are very similar concepts in that they have broadly the same goals and that are to inform decision-makers on the frequency and magnitude of adverse environmental consequences. However a major additional aspect provided by ERA is that it provides the probability of a particular impact occurring. A general framework for an ERA is presented in Figure 6.

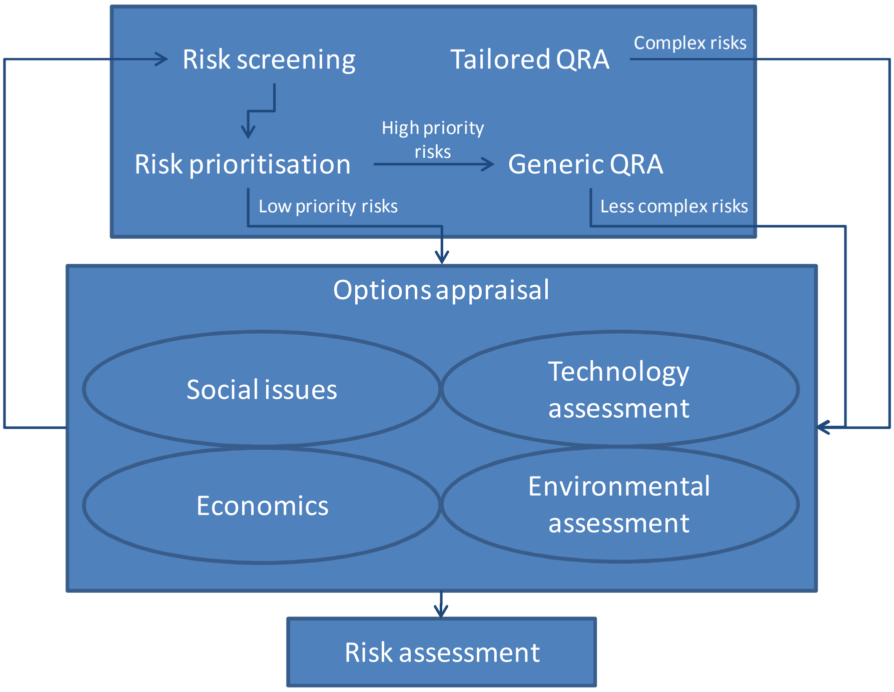

Figure 6. A framework for environmental risk assessment; QRA: Quantitative Risk Assessment (adapted from [56]).

A risk assessment framework has been proposed for large renewable deployments [57]. It is considered especially useful to evaluate such deployments along coastal national areas when political decisions based on scientific evidence, comparison to other energy supply options and stakeholder and public concerns all have to be taken into account. This framework concerns potential risk evaluation of marine renewable energy deployments based on a consistent program of research over time that collects relevant data by each sectoral group (marine mammals and fish, safety within ship lanes, etc). The proposed approach recognizes that every site has a unique set of potential risks and thus information is needed across risks and sites in order to discover where the problem areas or the benefits may be. This integrated framework also addresses what the potential tradeoffs may be in deciding whether to site a renewable technology or some other energy supply option. Although it has only been applied to the renewable energy sector in a draft version, this technique has been already modified specifically for it, including offshore wind and marine (wave and tidal) energy technologies.

Figure 7 presents the framework step application designed for land based and offshore wind but can be used to evaluate sitting of all marine renewable energy options, including wind and wave technologies. The steps of the Environmental Risk Assessment framework are described in [57].

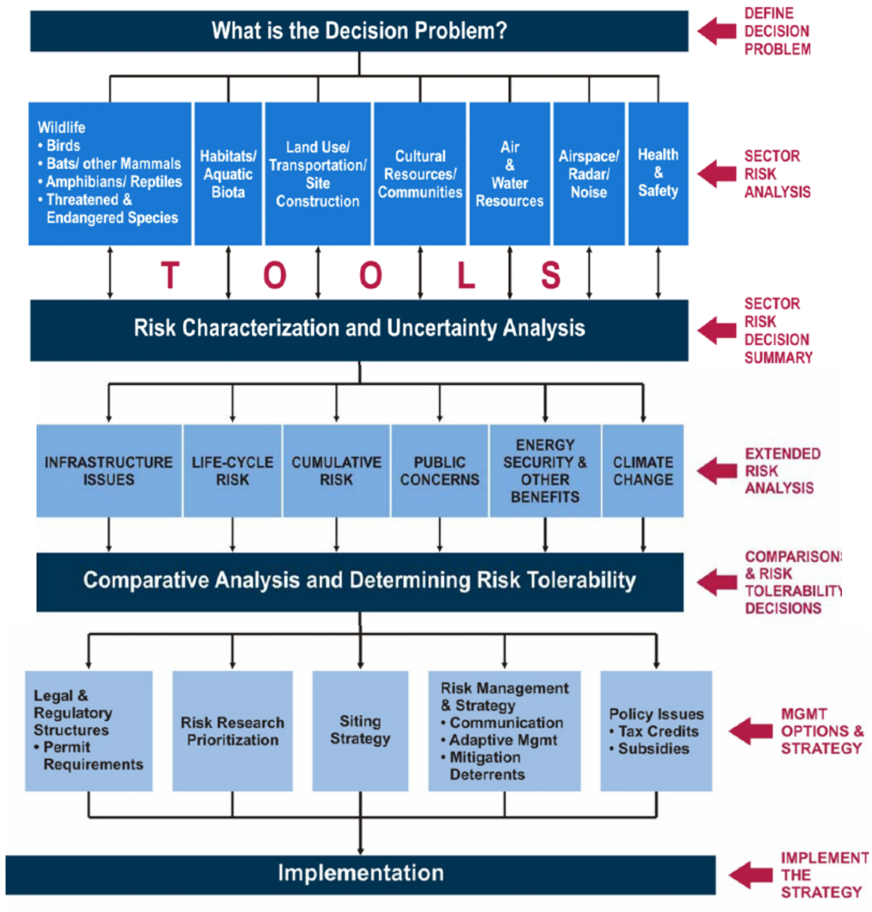

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Figure 7 A framework for integrated risk analysis of renewable energy deployments (from [57]).

8.2 LIFE CYCLE ASSESSMENT

LCA represents a tool to estimate the cumulative environmental impacts resulting from the whole product life cycle, often including impacts ignored in traditional analyses (e.g. raw material extraction, transportation, maintenance process, final disposal, etc). An LCA allows a decision maker to study an entire product system, avoiding the sub-optimization that could result when the focus of the study is on only a single process. The LCA helps to avoid shifting environmental problems from one place to another. Burden shifting can occur from one life-cycle phase to another, from one location to another or from one environmental problem to a different one. By including the impacts throughout the whole product life cycle, LCA enables a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection. It is important to note that LCA is always performed relative to a 'functional unit'.

The LCA process is regulated by the International Standards Organization (ISO) 14000 series:

- ISO 14040: 2006 (Environmental management - Life cycle assessment - Principles and framework) [58]
- ISO 14044: 2006 (Environmental management - Life cycle assessment - Requirements and guidelines) [59]

According to the definition given by the ISO standards, LCA is "a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases
- Evaluating the potential environmental impacts associated with identified inputs and releases
- Interpreting the results to help decision-makers to make a more informed decision" [58]

LCA is a procedure constituted by four different phases (Figure 8) [58]:

1. Goal Definition and Scoping - Define the purpose of the study. It includes a description of the studied product, process or activity. Establish the context in which the assessment may be made, identify the functional unit to be used and establish the system boundaries and limitations. This phase includes a description of the method used for assessing potential environmental impacts and which impact categories will be included in the study.
2. Inventory Analysis – Consists of data collection and analysis. For each process within the studied system boundaries, data including energy, water and materials usage and environmental releases (air emissions, water emissions, solid waste disposal, etc.) are quantified. Other types of exchanges or interventions such as radiation or land use can also be included. Data are then processed to produce an inventory of inputs and outputs per functional unit.

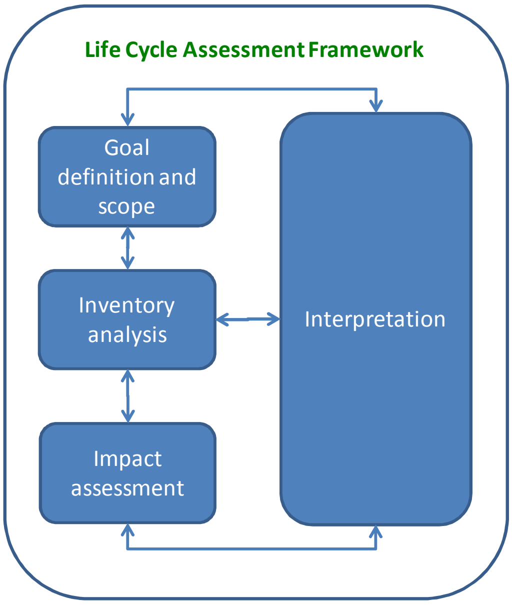

Figure 8 Phases of a LCA (adapted from [58]).

3. Impact Assessment – Assess the potential environmental effects of the inventory items identified in the inventory analysis. Contribution to impact categories such as global warming and acidification are evaluated by calculating impact potentials from the LCI results. Economic and social impacts are typically outside the scope of LCA.
4. Interpretation – Evaluate the results of the LCA study to draft conclusions and make decision, taking into account not only the numerical results, but also the boundaries of the system, the quality of data and the sensitivity of results. The interpretation phase can be used to adjust the goal definition or improve the inventory analysis or the impact assessment investigation, showing as the LCA is an iterative process in which all the phases are interdependent, as illustrated in Figure 8. Interpretation may include normalization to provide a basis for comparing different types of environmental impact categories. Although non-compliant with the ISO standards, an impact weighting process is sometimes undertaken to create a single impact measure based on the users' subjective judgment of the relative importance of particular factors.

Examples of LCA for different renewable energy technologies can be found in [60], [61] and [62]. LCAs for marine energy devices have also been published for the Seagen tidal current turbine [63], the Pelamis [64] and Wave Dragon [65] wave energy converters. A review and guidelines on LCA for marine energy technologies are presented in Equimar Deliverable 6.4.2.

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