Environmental Assessment for Ocean Energy Schemes: Useful Tools and Case Studies

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ABSTRACT

This work concerns a review of the state of the art of current and practical experience on environmental assessment (including monitoring) in order to set the path to be followed for future ocean energy schemes. It includes a revision of the work done so far in some test sites and deployment sites and discusses the use of several tools considering project phases (installation, deployment and decommissioning) and environmental impact assessment steps (screening, scoping, baseline studies for reference condition characterization, impact identification and evaluation, mitigation measures and monitoring). Within the list of such tools the applicability of checklists, matrices, mathematical modelling, Geographic Information Systems are considered as well as other shared and integrative methods: Environmental Risk Assessment and Life Cycle Analysis.

KEY WORDS: EIA tools; ocean energy; monitoring plan; baseline studies.

INTRODUCTION

The Environmental Impact Assessment of wave energy projects cannot only be a legislative requirement but also a sustainability proof of the project, a promoter of public acceptance and a benefit for industry, making the project more attractive to investors and governments who traditionally have seen environmental concerns as a barrier. The EIA carried out for ocean energy projects should has the following objectives:

1. Characterize the reference environmental condition through baseline environmental studies. If a project starts without measuring the reference condition it will be difficult to prove if there are relevant environmental impacts or not;
2. Describe the potential environmental impacts during the installation and operation phases of the project. This analysis should be conducted taking into account the technical specifications of the project;
3. Propose mitigation measures for the identified negative environmental impacts. To reduce significantly the negative effects until an acceptable level is the main goal at this stage of the process;
4. Establish monitoring plans for the project installation and deployment considering the relevant environmental parameters or indicators.

The environmental and socio-economic effects of operating ocean energy devices are strongly dependant on the technology and location of the project. However, since wave and tidal energy technologies are still in development, the uncertainties regarding the most part of the potential impacts are still assumptions or predictions which need to be evaluated through monitoring. A lack in methodological approaches for environmental and socio-economic impacts evaluation of marine projects is also recognized because these projects have unique characteristics, different from other types of marine projects. A new approach for environmental analysis is needed for offshore energy projects particularly, wave and tidal energy projects and this can include a revision of methods and tools used for environmental impact analysis of land projects.

In this article a review is made to analyze the state o the art of current and practical experience of environmental assessment (including monitoring) of marine systems in order to help setting the path to be followed for future ocean energy schemes. The applicability of several tools is described considering the main phases of a general Environmental Impact Assessment process.

This paper contains results of the EU funded project EquiMar (Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact https://www.wiki.ed.ac.uk/display/EquiMarwiki/EquiMar) on the Environmental Impact Assessment work package and aims to be one of the products of its dissemination.

ENVIRONMENTAL IMPACT ASSESSMENT FOR OCEAN ENERGY SCHEMES

Environmental Impact Assessment steps

Several types of general methodological approaches have been proposed in the literature for the framework of impact assessment. However, there are major phases or methodological framework elements that characterize the most part of EIAs. After the analysis of several EIA framework designs and apart from the description of the project characteristics (which has to be known previously), an indicative outline for an EIA on marine energy projects can be composed of the following sections: 1) Scoping, 2) Baseline studies, 3) Impact analysis, 4) Public consultation, 5) Mitigation measures, 6) Monitoring plan (Morgan, 1999; Morris and Therrivel, 2005).

Review of EIA for ocean energy projects

Although few wave and tidal devices have actually been deployed at sea, the experience and know-how acquired by those who have, is very valuable and useful to assess what should be recommended as a protocol of good practices. A comparison of different environmental surveying methodologies used at different device deployment sites / test zones of ocean energy projects is presented in Table 1. This comparison provides an insight into how the impacts of marine renewable energy devices have been assessed.

USEFUL METHODOLOGIES AND TOOLS FOR ENVIRONMENTAL ASSESSMENT OF OCEAN ENERGY SCHEMES

In this section a number of tools and methodologies are listed and briefly described to conduct the environmental assessment. Several of them (e.g. checklists and Geographical Information Systems), can be used in several EIA steps. Other methods or techniques, which results can be integrated or added to the environmental assessment, are also identified (Environmental Risk Assessment and Life Cycle Assessment). Wherever possible, examples of the application of such methods or tools on ocean energy projects are given. The list of tools and methodologies concern the most sensitive components to the potential impacts of ocean energy projects. Preliminary results of the application of some of the methodologies are presented as case studies.

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 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. According to EMEC's guidance to developers (EMEC, 2008), a detailed description list of project characteristics should be provided which are then linked to key impact issues. In a protocol for the environmental assessment of projects to be developed in the marine environment (Solaun et al., 2008), several checklists are proposed for different environmental assessment steps: checklist on the project characteristics; checklist on the surrounding marine environment features; checklist to identify impacts importance; checklist to identify mitigation measures.

Matrices

A matrix can be 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.

Leopold matrix

Leopold interaction matrix (Leopold et al., 1971) is a comprehensive matrix, which has originally 88 environmental characteristics, along the top axis, and 100 project actions in the left hand columns. 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. Assignment of numerical values for importance is based on the subjective judgment of the interdisciplinary team working on the EIA study. The application of Leopold matrix method has been suggested to ocean energy projects (EMEC, 2008; Huertas-Olivares, 2007). One of these examples is presented in Fig. 1 where, in a general sense, environmental factors were previously identified and further evaluated considering the main phases of an ocean energy project.

According to EMEC (2008), the impacts evaluation is made through the use of two main tables: 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 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 presented criteria.

Rapid Impact Assessment Matrix for EIA

The Rapid Impact Assessment Matrix (RIAM) is a multi-criteria tool to organize, analyse and present the results of a holistic EIA (Pastakia and Jensen, 1998). This matrix method was developed to bring subjective judgments 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 (Haie, 2006).

Table 1. Sampling techniques used for biological components in several wave energy project's EIAs.

Component: Marine mammals					
Project	Method	Species	Duration	Spatial and temporal resolution	Main Results
Wave Hub	Bibliographic review	All	-	-	List of mammal sightings and likelihood of occurrence
	T-POD deployment on site		3 four month deployment periods	Only on deployment site	T-POD data revealed the species present and how frequently they visited the area
Wave Dragon Wales	Bibliographic review	All	-	-	The project occurred with a SAC and had undergone constant monitoring (a great deal of information available); specific monitoring was not considered necessary.
Beatrice (offshore windfarm)	Boat based visual transects	All but particularly the bottlenose dolphin and the harbour porpoise	27 surveys over two summers	Deployment site vicinity (covering a total 1930 km)	Species present and their distribution in the deployment area and surroundings.
	Passive acoustic methods (T-Pods)		One on device location and two reference areas	Deployment site vicinity and reference areas	Animal number and distributions in the area
Seagen (tidal energy project)	Bilbiographic review of sightings	All	-	-	List of mammal sightings and likelihood of occurrence
	Telemetry	Grey and common seals	One tag before deployment and one during operation	-	The movements of 12 individuals of the populations within Straghford Lough
	Passive acoustic methods (T-Pods)	Harbour porpoises	Several survey periods during baseline, commissioning and operation	4 T-Pods used to cover important sites	Animal number and distributions in the area
	Active sonar tracking	Seals and cetacean	-	80 m upstream from the device	Animal interactions and behaviour in the imediate vicinity of the device
	Aerial sightings	All	-	Vicinity and adjacent coast	Animal number and distributions throughout the area
	Boat sightings	All	-	Vicinity of the deployment area	
	Marine Mammal carcass survey	Seals and cetaceans	First year of commissioning and during operation	Area of deployment and adjacent coast	Assessment of a possible interaction between the device and species that results in mortality
Component: Benthos					
Project	Method	Species	Duration	Spatial and temporal resolution	Main Results
Wave Hub	Sub-tidal survey- 30 seabed samples of 0.1 m^2 using a Hamon grab	Infauna from the surface	-	-	Species diversity, number, and distribution in the area
	Subtidal survey: epibenthic samples collected using a 2 m beam trawl with a 20 mm mesh net and a 4 mm mesh code and liner	Epibenthic species	-	-	Species diversity, number, and distribution in the area
	Biotope study included: sediment sampling, beam trawl and underwater photography	-	-	Over the proposed deployment area	Identification of 2 broad habitats, 4 man habitats, 6 biotope complexes and 15 biotopes and sub-biotopes
Wave Dragon Wales	Bibliographic review	All	-	-	As the area was within a SAC there was a great deal of information available
	Standard Day grab with additional weight	All	One day	14 sites selected after viweing geophysical survey, although only 3 yielded results	Species diversity, number, and distribution in the area, although limited due to the rocky substrate
	Image work planned. Divers, remotely operated cameras and video were considered	All, but particularly relevant due to the rocky substrate	-	-	Important to note that images are particularly relevant in rocky benthic environments
Beatrice (offshore wind)	Day Grab surface samples with camera attached	Infauna and epifauna	-	12 sites with 3 repetitions in total	Species diversity, number, and distribution in the area. It's important to note that this method combines physical samples with images

	Actions / Environmental factors	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								×				

Fig. 1 – Simple matrix (based on Leopold matrix) for impacts identification of a wave energy converter (Huertas-Olivares, 2007).

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 (Ijäs et al., 2009). The basic principle of RIAM is that characteristics of impact 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.

Maps and 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 (ESRI, 1995; Heimiller and Haymes, 2001).

As regards renewable energy, one of the biggest issues facing its exploitation is the selection of suitable sites (Baban and Parry, 2001). 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 (Malczewski, 2006). This technique has been also used in siting of wave farms in e.g. UK (Graham et al., 2003) and Portugal (Nobre et al., 2009). 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. 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) (Nobre et al., 2009).

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 (Prest et al., 2007).

Bibliographic reviews show that the most common GIS applications are by far on 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. 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).

Methodologies for baseline and monitoring studies

Marine Mammals

The following section presents a detailed description of methodologies for marine mammal monitoring, both in terms of species density and distribution and behaviour.

Monitoring techniques of marine mammals include land, boat and aerial surveys. Monitoring cetaceans from land has obvious limitations but can provide data in certain areas where whales and/or small cetaceans consistently utilize inshore (0.5-5 km) habitat around testing sites. Survey staff must be trained to identify species at the operating ranges, e.g. from the shape of the blow, profiles of head and back and specific behaviours, etc. Essential equipment should include effective optics e.g. two pairs of tripod-mounted weather-proof binoculars of excellent optical quality, appropriate direction and range finding equipment. Mounted range finders or units coupled with the binoculars can be used, but are often difficult to calibrate on objects that are only fleetingly visible for a few seconds. In some regions channel buoys etc, will provide location reference, but in their absence, some form of reference system should be established. Effective data logging systems, preferably direct to a laptop with an appropriate software package can also be used. Whale or small cetacean sightings can be recorded effectively over 1-2 h periods allocated and spaced to take into account time of day, and more importantly, the time and state of tide.

Care must be taken to ameliorate inevitable observer fatigue during extended periods of viewing. Data requirements will vary but will usually include at least species, numbers of sightings, distances from shore, locations relative to observation posts and other markers, estimates of the numbers of individual whales involved (difficult), blow rates for large whales, direction of movement, dive periodicity if individuals can be recognized and behaviour state. Conversion of records of estimated numbers and species ratios into indices of biodiversity, density and distribution should be made with caution and in close consultation with scientists experienced with the statistical analysis of particular species in cetacean field studies.

Cetaceans can also be monitored from boat. The size and configuration of survey vessels should be determined by the particular circumstances of local weather conditions. Three survey methodologies are commonly used in this type of field work, depending on the objective: 1) Focal observation, where the subject can be a particular area or "hot spot" of whale activity, a particular group of animals, or recognizable individuals; 2) Line transect technique (LTT) and 3) Strip census methodology (SCM). All these methodologies have advantages and disadvantages and their proponents. LTT is universally regarded as more rigorously scientific (Hammond, 1984a,b; Hayes and Buckland 1983), partly because of the difficulty of measuring the distances of animals from a vessel in strip censuses compared to the angular readings taken during line transects. The latter method presents some statistical problems when a large proportion of sightings are encountered on or close to the track line.

LTT is well documented in the scientific literature. Standardized observation procedures for whale and small cetacean surveys, regardless of the size of vessel, call for maintaining a constant speed throughout the survey. A minimum of two observers are placed forward, at a recorded height above sea level, one to port and one to starboard, scanning ahead 90° to each side of the line of movement (Palka and Smith, 1991; Polacheck, 1991; Palka, 1992). A third observer scans astern for missed animals that surfaced after the vessel passed. Ideally, each observer coordinates with a recorder with a stopwatch.

A modified protractor is used to measure the angle of the sighting from the bow, and the recorder notes the time of the sighting and the time at which the target passes the 90° mark. A mix of naked eye and binocular-assisted search is essential for visual surveys. Because of the irregular movements of the boat, 7 times magnification is sufficient. In good conditions, the blows of large whales can be detected at 3-6 km. For small cetaceans such as the harbour porpoise, which normally occur only in ones and twos, a survey width of about 0.5 km on each side is optimal, although animals will be detected further away (Palka 1992, Polacheck 1991).

Surveys of large whale species or dolphins that aggregate in large schools can be based on a greater search width (Kasamatsu, 1991), 5 km each side of the bow in good conditions. A significant literature has grown up to deal with the effect on sightings of, for example, observer altitude above sea level, differential success of trained vs. untrained observers, the scanning rate of the human eye, sea state, visibility, length of observation periods and observer fatigue, differential attraction or avoidance by cetaceans of vessels of various characteristics etc (Hammond, 1984a,b; Hammond, 1986; Smith, 1981; Palka and Smith, 1991).

To monitor cetaceans from air, the chief advantage of aircraft, is to give opportunity to survey more territory in much less time, often without significant change in visibility and sea conditions, hence minimizing the need for correction factors. There are disadvantages however, primarily the narrowness of the strip searched, sometimes less than 0.5 km, depending on the configuration of plane windows. Additionally, the speed of transit results in more animals being missed because they were under the surface, than in equivalent ship-based surveys, when several dive sequences of one animal might be recorded during the same transect length. Kingsley and Hammil (1991) (DFO Mont-Joli) experimented with a system of external paired cameras below the aircraft, in which photographs are taken at a controlled rate along each transect. These can be developed and scanned for marine mammals after the survey, and the results correlated with visual counts which use methods equivalent to those described for seaborne surveys (St. Lawrence Beluga Recovery Team, 1995). Fixed-wing aircraft and helicopters can be used quite efficiently to survey seal populations on long stretches of coastline; photographic surveys carried out this way are likely to yield more accurate counts than those made from boats, the approach of which tends to scare seals into the water if close to the beaches or ledges. Conversely, observers on a boat at a distance are likely to miss many animals in shadow or in depressions behind outcrops.

Many marine mammals produce sounds underwater, thus acoustic surveys are also important for its monitoring. Some can be identified to species and to activity type e.g. echolocation output, communication, individual acoustic 'signatures' or 'codas'. While this field is relatively new it may offer easier and cheaper ways to conduct assessments of populations of marine mammals in the future and is already useful for augmenting current survey methods.

Passive Acoustic Monitoring (PAM) is another monitoring methodology which consists of a system of hydrophones either towed or stationary in the water column that feed into a signal processing system using purpose written software. Specialist PAM operatives are needed operate equipment and interpret the received signals. A PAM operative could also be a trained MMO, and this would allow them to switch roles, if required, between acoustic and visual monitoring. Current PAM systems are particularly effective in detecting harbour porpoises, although the systems have their limitations and can only be used to detect vocalising species or individuals. PAM can provide a useful supplement to visual observations undertaken by MMOs, but localization may not be as precise as visual observation for determining range. Any mitigation zone must reflect the range accuracy of the system. Localisation PAM systems require deployment of 3 or more marine hydrophones in an array around the survey vessel, or fixed station. Such an array can provide location of individual animals in a group and sonograms can be simultaneously logged for reference and comparisons.

Seabirds

Seabirds are widely recognized as useful indicators of changes in marine environments and as such are likely to be sensitive to certain forms of disturbance. Monitoring the effects of marine renewable developments on bird populations, bird foraging and bird movement patterns are important aspects of testing of effects of marine renewables. Fortunately and importantly they are mostly fairly large, diurnal, easily observable and identifiable to species and often to sex and age class. As a result, techniques for estimating population size and distributions are well established, both for breeding birds at colonies and for non-breeding populations at sea. The protocols for estimating seabird density and distribution at sea as well as monitoring breeding populations are generally accepted by the international scientific community. At breeding sites it is feasible to estimate total numbers because the population is concentrated, during the breeding season, within a relatively small geographic area. At sea, populations are mobile and dispersed over large areas, so can only be sampled; here, total population estimates are rarely feasible, but estimates of relative abundance can be achieved.

Since wave or tidal farms are supposed be located far from seabird breeding sites the present discussion will focus on monitoring at sea. The method in which all birds seen per 10 minutes within a 300m transect either side of the vessel are counted, is probably best suited method to an offshore site monitoring program (Tasker et al.,1984). Another standard for seabird surveys is the Canadian technique which assumes the following rules:

1. Count all birds identified in a 180° field forward from the observation point of the ship, normally about 15 m above the surface, on the bridge (Tasker et al. (1984)'s method);
2. The ship's speed should be at least 5 knots (9.25 km h^{-1});
3. Observations are confined to daylight hours, and are suspended in heavy rain, fog or rough seas;
4. Latitude and longitude are recorded at the beginning and end of each 10-minute count;
5. Individuals following the ship (large gulls, albatrosses) are counted only once;
6. The presence of fishing boats within the survey area is recorded, as it may affect the behaviour of the birds;
7. Data are accumulated in blocks of 10 minute periods, and are available in that form, but can be aggregated into degree or other spatial cells as required (Brown 1986).

Benthic Fauna

In assessing the effects of particular devices, the objective of benthic faunal monitoring is to detect any spatial or temporal change in the fauna, compare it with natural variability, and if possible attribute the change to its cause. The community/site to be investigated will generally be matched with similar pristine reference site, if possible free of manmade influence to evaluate natural diversity and variability. Where possible other impacted sites can be used to compare effects of other anthropogenic input. Two important environmental variables affecting species composition of the benthic macrofauna are depth and sediment grain size.

For marine benthic studies methods that use quadrats (simple square method) or transects are feasible for estuarine, intertidal and hard bottom areas. For soft bottom substrates a site may be defined as an area with relatively homogeneous habitat from which adequate replicates may be taken. The size of the sampling area will depend on the size of natural limits of the area with a particular habitat and on the size and number of samples being taken.

Marine sampling operations invariably require the use of a boat which will influence survey procedures and choice of gear to a large extent. The choice of gear also depends on the questions and resulting sampling strategies that drive a particular investigation. However, for benthos monitoring programs, obtaining a simple species diversity index only requires qualitative sampling (e.g. dredges) from different types of habitat. This will be of limited use in assessing effects. Usually indices of relative abundance of species over time are required. Estimating the number or biomass per unit area, requires quantitative sampling using devices such as grabs and corers and rigorous planning of a sampling program. To design a sampling program for a given area all available bathymetric, geomorphological, sedimentological, oceanographic and biological data should be gathered as well as preliminary observations from any pilot study to map out the extent of various types of habitat within the area.

Typically, benthic sampling stations are selected by means of stratified random sampling (e.g. Elmgren et al. 1984) taking into account factors such as sediment type. For hard-bottom benthos the same principles apply and species-area curves are most useful in determining the minimum effective sample size. However, there are more constraints on sample size than with soft bottom communities. Sampling frequency depends on the objectives. In the absence of background knowledge a study incorporates sufficient sampling effort to encompass temporal variability in species assemblages.

If seasonal changes are known, predictable sampling can be reduced / targeted on specific times. There is growing evidence of large temporal changes on a non-seasonal basis in hard bottom benthos. If natural long term changes are suspected, then long time series will be required to establish normal diversity patterns.

The major abiotic factors useful for benthic sampling are salinity, temperature, depth, current speed and direction, as well as sediment grain size. Sampling of soft bottoms in the subtidal zone requires ships larger than 10 m length equipped with cranes and winches capable of hauling wire ropes for dredges, grabs and corers.

The ship must be fitted with relevant navigational facilities and a suitable echosounder for bottom determination. Winching operations are crucial to sample integrity and depend on the type and size of sampling gear. The objective is to obtain representative samples. The type of data to be recorded should include the date, time, position, crew, temperature and salinity (surface and bottom).

Sampling with dredges and trawls provides qualitative and sometimes semi-quantitative material by standardizing the condition and duration of towing. Grab and corer samplers have long been used for quantitative study of benthic infauna. The grab takes a constant volume bite of sediment. Corers penetrate the sediment and remove a plug of sediment. Small corers can exhibit edge or boundary effects, which are disturbances of the sample caused by the edge of the sampler. There are numerous types of grabs being used for benthic sampling (14 types have been identified by Eleftheriou and Holme, 1984). The vessel type and size for subtidal hard-bottom sampling varies greatly with the method to be employed, from large vessels operating manned/unmanned submersibles, to small vessels operating diver surveys. The surveys cannot only include sampling gear but also cameras, remote still cameras and video cameras.

The methods used to analyse results can be univariate and multivariate. Univariate methods includes species richness, basic diversity measurements, based on the total number of species at a site; the term species richness is often preferred since the exact number of species in a community is rarely known. Shannon-Wiener's index is an example etc. Multivariate methods: Methods that reliably compare the degree of similarity or dissimilarity in species composition between stations, or at the same station over time. These can be combined with correlative evidence of cause and effect, such as from pollutants. Requires measured environmental and pollution/disturbance gradients or some indirect measure of intensity, such as distance from source or duration of disturbance. The use of indicator species to conclude about community disturbance type can also be used here.

Other shared and integrative methods

***Environmental Risk* Assessment**

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 (Brookes, 2009). ERA is also a well established management tool for dealing with uncertainty e.g. 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, etc (Cohrssen & Covello, 1989).
Risk Assessment has been only recently extended to wider environmental considerations. EIA and ERA are very similar concepts in that they have broadly the same goals and are that inform decision-makers on the frequency and magnitude of adverse environmental consequences. However a major additional aspect provided by ERA is the probability that it gives for a particular impact to occur.
A risk assessment framework has been proposed for large renewable deployments (Ram, 2009). 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 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 been only applied to the renewable energy area in a draft version, this technique has been already modified specifically for the marine renewable area, which includes offshore wind and hydrokinetic technologies.

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 the 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 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.
The LCA process is standardized by the International Organization for Standardization. A first standardization led to the development of International Standards Organization (ISO) 14000 series which has been recently revised by ISO 14040, 2006, principles and framework and ISO 14044, 2006, requirements and guidelines.
According to the referred standards LCA is a procedure consisting in four different phases:

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.
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.
3. Impact assessment – Assess the potential human and ecological effects of the inventory items identified in the inventory analysis. Contribution to impact categories such as global warming and acidification are evaluated. The Impact Assessment phase consists of three steps: a) Calculation of impact potentials; b) Normalization, which provides a basis for comparing different types of environmental impact categories; c) Weighting, which implies assigning a weighting factor to each impact category depending on the relative importance assigned.
4. Interpretation – Evaluate the results of the LCA study to draft conclusions and make decision, taking in 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.

Examples of LCA of renewable energy technologies can be found in Banjeree (2006), Weinzettel (2008) and VWS (2006). LCAs for wave energy devices have also been published for Wave Dragon (Soerensen and Russell, 2006), Seagen (Douglas et al, 2008) and Pelamis (Parker et al, 2008).

CONCLUSIONS

Although there are a number of uncertainties associated with the environmental impacts of the wave and tidal device's deployment, this should be expected given the testing phase of these new technologies. The present and future tests to these technologies will be used not only to analyze the technical performance of the devices, but will also advance understanding on environmental issues. The current work shows a number of EIA tools that have already been applied to ocean energy projects. These tools need to be revised / adapted in order to fulfil the specificity of the environmental assessment.

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