# Environmental Impact Assessments for wave energy developments – Learning from existing activities and informing future research priorities

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## ABSTRACT

Plans for Marine Renewable Energy Installations (MREI) are developing worldwide, yet many questions still remain about the impacts such developments may have on marine ecosystems and on coastal and oceanographic processes. This uncertainty, combined with a lengthy and complex Environmental Impact Assessment (EIA) phase prior to consent, has slowed the growth of the marine renewables sector. Information on completed and ongoing EIAs at MREI sites across Europe was summarised and compared amongst sites and with completed, comprehensive EIAs for Horns Rev offshore wind farm and the SeaGen tidal turbine site at Strangford Lough. This allowed for the identification of commonalities and differences in monitoring activities, and of data gaps in the wave energy EIA process. Studies on the socio-economic impacts of MREIs were lacking, as were monitoring of fish, fish habitats, electromagnetic fields and their impacts on marine wildlife. Even amongst sites monitoring similar topics, methodologies varied greatly. Science cannot inform the management of marine renewables whilst there are inconsistencies in baseline and impact monitoring, as this study has documented. A streamlined EIA process and collaborations between researchers and developers are required to move the industry forward.

**KEY WORDS:** Environmental Impact Assessment; wave farms; tidal energy; marine renewable energy; monitoring; wind farms

## 1. INTRODUCTION

Whilst wind power is currently the main form of renewable energy generation in the marine environment, developments in the fields of wave and tidal power in recent years have brought these technologies to the forefront of renewable energy generation. Wave energy holds enormous global potential for meeting future renewable energy goals and this has encouraged the development of wave energy pilot projects, test sites and pre-commercial sites across the world (e.g. Boehlert et al., 2008; Cada et al., 2007; Dal Ferro, 2006; Nelson et al., 2008). The technology could, potentially, provide a significant contribution to renewable energy production in the future, in areas with suitable wave conditions (Carbon Trust, 2006; Kerr, 2007). Renewable UK (2010) estimated that marine renewable energy could provide 15 - 20% of electricity generation in the longer term, based on current demand levels. However, the effects that Wave Energy Converters (WECs) and other Marine Renewable Energy Devices (MREDs) will have on physical and biological processes and their impact on various species and habitats in the marine environment are yet to be fully determined.

In Europe, the majority of marine renewable energy installation (MREI; used here to describe devices for harnessing wave and tidal energy) developments require some level of Environmental Impact Assessment (EIA), the purpose of which is to ascertain the effects of the development on the natural environment, species, biological and physical processes (although test sites and small-scale demonstration projects may not be required to carry out a full-scale EIA). The permitting process can then weigh the scale of such effects on the environment against the value of the installation, in order to determine whether consent to proceed with the development will be granted or not. While some of the effects of introducing MREIs to the marine environment will be the same regardless of the installation involved, other effects will be device-specific (Margheritini et al., 2012). Effects will vary with the stage (construction, operation and decommissioning) and scale of the project and will depend on the location and ecosystem in that area. In particular, removal of energy directly from the water column distinguishes wave and tidal energy generation from the offshore wind experience and presents a suite of new potential issues which have not been confronted in offshore wind EIA. One obvious example of this is the introduction of moving components to the underwater environment. The question of scale is important, as experience to date indicates that some small-scale demonstration projects have not had to go through a full EIA process. EIAs for marine renewables installations have thus far evolved, in most instances, without any specific guidance and have thus been largely based on the design and principle of EIAs for offshore wind farms. The wind energy industry is several decades ahead of wave energy and consequently of all the categories of MREIs, the greatest knowledge base regarding effects on the marine environment comes from offshore wind turbine developments (e.g. Evans, 2008; COWRIE[1]).

The potential effects of WECs on marine organisms have been comprehensively investigated by Inger et al. (2009), Nelson et al. (2008) and Witt et al. (2012), and include effects on nearshore intertidal and benthic habitats, fish, fish habitats, large marine vertebrates (sea birds, marine mammals and large fish), oceanographic and coastal processes. Marine mammals or diving birds, for example, may be at risk of collision or entanglement with underwater elements of WECs (Wilson et al. 2007). Decreases in wave energy and the resulting changes in wave-driven processes are the basis for the majority of anticipated impacts of wave energy conversion technology on the coastal environment and morphological processes. Numerical modelling has predicted that WECs will extract between 3 and 15% of incident wave energy, (Largier et al., 2008) and this energy reduction is likely to affect wave shoaling, sediment transport, beach building and mixing. Coastal erosion patterns may be altered, and the seabed and mid-water habitats could be affected by changes in currents, mixing of the water column and sedimentation

[1] Collaborative Offshore Wind Research into the Environment; associated reports available at: http://www.thecrownestate.co.uk/energy-infrastructure/downloads/cowrie/

patterns. This, in turn, may affect benthic vegetation and fauna and have knock-on effects through the ecosystem.

Whilst many of the impacts considered may be negative, there are also potential positive impacts of marine renewable energy (MRE) developments. The closing of an offshore area to vessel transit and, in particular, to fishing activities, may cause the MREI to act as a *de facto* Marine Protected Area (MPA), by removing fishing pressure and potentially allowing fish to breed and grow (Witt et al., 2012). This in turn could have spillover effects to other areas (e.g. Gell and Roberts, 2003). Likewise, the provision of additional hard substrate and seabed structure, which may be a component of the foundations or anchoring of some (though not all) MREIs, may have artificial reef effects, as the structures are colonized by benthic organisms and then attract other marine life (Linley et al., 2007). The structures themselves may also act as fish aggregating devices (FAD) (Fayram and de Risi, 2007; Wilhelmsson et al., 2006). In this way, MREI may help restore areas of seabed that have been lost through destructive methods of commercial fishing (Thurstan et al., 2010). Most pertinently, it is unknown at this stage in the industry's development whether many of the postulated effects will actually occur. For some impacts, such as the long-term effects of changes to sediment deposition patterns or coastal processes and possible FAD effects, it is also unclear whether such a change would be of overall benefit or not.

The socio-economic impacts of MREIs are less frequently addressed and there is even less structure in place in terms of the guidance on requisite elements to address, or appropriate methods with which to address them. Socio-economic impacts for offshore renewable projects typically include elements like demography, employment and regional income; sea and land use; aesthetics; infrastructure; socio-cultural systems and implications for other maritime activities such as fisheries, tourism and recreation (e.g. Bailey et al. 2011; Haggett 2008; Lilley et al. 2010; WAVEPLAM, 2010). Concerns may be voiced by, for example, surfing groups and surf tourism industries about a reduction in wave strength or quality (e.g. McLachlan, 2009; Bailey et al., 2011); by other recreational sea user groups and local fishing industries regarding closed areas to prevent collisions between vessels and WEC devices; or local residents regarding the visual impact of WECs and the onshore stations to which they are linked (e.g. West et al. 2010). However, diminished erosional potential from reduced wave fields may be perceived by landowners or coastal managers as a beneficial outcome of such a development, as would opportunities associated with construction, deployment, and operations and maintenance, which usually contribute jobs and income to local communities.

Many of these potential environmental impacts of MREIs, at least in terms of the biological and oceanographic elements, have yet to be confirmed or refuted. In order for the marine renewables industry to move forward, it is now necessary to identify the knowledge gaps in the Environmental Impact Assessment process, determine how best to address those gaps and then create partnerships between industry, researchers and government that will facilitate the investigative process. This study collected data on the monitoring activities that were underway or complete at wave energy sites throughout Europe in 2011. Differences and commonalities between these monitoring programmes and EIAs completed for the now well-developed offshore wind industry were identified, and gaps in the wave energy EIA process have been highlighted. Recommendations are made for the efficient use of research activities to address potential concerns, inform a calculated risk-based approach and encourage the growth of the wave energy industry. The findings are relevant to MRE developments worldwide.

## 2. METHODS

### 2.1 Gathering data on existing wave energy EIAs in Europe

In order to identify both the necessary elements of EIAs for wave energy and the data gaps or areas where more understanding is required, data were collected on ongoing and planned EIA activities at wave energy sites in Europe. This work was carried out as part of the SOWFIA Project (Streamlining of Offshore Wave Farm Impact Assessment; www.sowfia.eu). The SOWFIA Project drew together ten partners, across eight European countries, who were actively involved with existing or planned wave farm test centres. Anticipated tidal stream test sites were also included, as not only are they required to address many of the same monitoring issues as wave energy sites, but consideration of them significantly increased the sample size. A questionnaire (Appendix I) was developed and emailed to wave energy project developers, device developers, renewable energy consortia and researchers, to collect information on the completed, ongoing and planned monitoring activities at wave and tidal energy developments and test sites. In addition, publicly-available EIA documents on the internet were scrutinised in order to gather more information on the baseline data collection and baseline or impact monitoring that had been carried out at various sites. Data were collected between April and August 2011.

The SOWFIA project identified 18 European wave energy test sites[2] (hereafter referred to as the 'test sites'), as well as two tidal energy sites and five sites where scoping for future MRE developments was taking place. Data on monitoring activities were provided via questionnaires from the various institutions conducting monitoring at these sites, and were in some cases supplemented with

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[2] In this study, a test site is defined as a site where a single type of device, either singly or in small numbers, is tested whereas a test centre is defined as a location where multiple devices may be tested.

information from Environmental Scoping reports, EIA reports and related correspondence. This information is listed in Table 1.

### 2.2 Data analysis

Only established test sites, where at least some monitoring (other than wave and meteorological monitoring) was already underway, were included in the data analysis. Data on wave- and tidal-related research being conducted at numerous scoping sites were also supplied, but these were not included in analyses as they did not take place at designated MRE sites. 15 sites were included in the final analysis, comprising 14 wave energy sites and one tidal site. Monitoring activities were classified into nine broad categories: benthos, seabirds, fish and fish habitats, marine mammals, other marine megavertebrates (sharks and turtles), physical oceanographic environment, acoustics, terrestrial habitats and socio-economic considerations, plus an additional category for other activities which did not fall within the aforementioned classes. Commonalities amongst and differences between monitoring suites at MRE sites across Europe were examined and monitoring gaps were identified.

**Table 1:** List of test centres/ proposed test sites and the organisations which provided information on Environmental Impact Assessment activities. 'W' indicates wave energy site, 'T' indicates tidal energy site. 'Q' indicates information provided via questionnaire; 'R' indicates data sourced from publicly-available reports.

| Site name | Location | Organisation Facilitating Measurements |
|---|---|---|
| Atlantic Marine Energy Test Site (AMETS) (W; Q) | Ireland | Sustainable Energy Authority of Ireland / Irish Marine Institute |
| BIMEP (W; Q) | Spain | Ente Vasco de la Energía (EVE) – AZTI Tecnalia |
| Coaña and Cudillero, Asturias (W; Q)* | Spain | Fundación Asturiana de la Energía (FAEN) |
| EMEC Test Site – Billia Croo Oyster array (W; Q) | Scotland | European Marine Energy Centre (EMEC)<br>Scottish Power Renewables<br>Aquamarine Power Ltd. |
| European OWC Wave Power Plant (Pico) (W; Q) | Azores, Portugal | WavEC |
| Farr Point (W; R) [a] | Scotland | Pelamis Wave Power (Aquatera, 2011) |
| Galway Bay Test Site (W; Q) | Ireland | Sustainable Energy Authority of Ireland / Irish Marine Institute |
| Isle of Lewis (W; R) | Scotland | Aquamarine Power Ltd. (Lewis Wave Power Ltd., 2011) |
| Pilot Zone (W; Q) | Portugal | Wave Energy Centre (WavEC) |
| Réunion (W; Q) | Réunion Island | SAS SEAWATT |
| Runde (W; Q) | Norway | Runde Environmental Centre (REC) |
| SEM-REV (W; Q) | France | Ecole Centrale de Nantes |
| Sotenas (W; Q)[a] | Sweden | Seabased Industry AB |
| Various (3 in consideration) (W; Q) [a] | Ireland | ESB International |
| Lysekil (W; Q) | Sweden | Uppsala University |
| Wave Dragon (W; R) | Wales | PMSS (consultants) / Wave Dragon Ltd. (2007) |
| Wave Hub (W; Q) | England | University of Exeter<br>University of Plymouth<br>WaveHub |
| Waveroller (W; Q) | Portugal | Wave Energy Centre (WavEC) |
| Islay (T; Q) | Scotland | Scottish Association of Marine Science (SAMS) |
| Kyle Rhea (T; Q) [b] | Scotland | Scottish Association of Marine Science (SAMS) |
| Pentland Firth and Orkney (scoping only) (R) [b] | Scotland | The Scottish Government / Marine Scotland (2010) |

(a) No monitoring in place at time of study. Excludes monitoring of wave and weather variables, which were in place at some sites in order to determine whether they were suitable sites for wave energy installations.

(b) 'Site of interest' for development, but no applications for devices had been submitted at the time of the study.

## 3. RESULTS

A diverse array of monitoring topics and methodologies were documented from the 15 European MRE sites (Table 2). The monitoring suites established provided some insight into what were the potential impacts considered to be most likely or of primary concern.

All nine general monitoring categories (excluding the 'other' category) defined by this study are relevant elements to consider for any MREI impact assessment and most of the MRE test sites incorporated at least several of these elements into their monitoring programmes. However, there was considerable disparity in terms of the categories within which monitoring was conducted (Table 2). Only a single site, the Wave Hub (UK), incorporated monitoring elements from all nine monitoring categories, and AMETS (Ireland) was conducting monitoring in eight of those categories. Several sites were only conducting monitoring in a single category.

Despite the early stage of many of the monitoring programmes at European MRE sites, research on the hydrodynamics within the study area, with a focus mainly on monitoring the wave climate and associated factors (e.g. tide), was widespread. Within the broad category of physical oceanographic environment, which included diverse topics such as wave and current characteristics, beach morphology and weather, at least one element was monitored at 11 sites. This is hardly surprising since, from a developer's perspective, a key priority at such sites is to assess the (wave or tidal) resource prior to planning an installation. Benthos was clearly considered to be an important element of impact monitoring, and 13 of the 15 sites examined were conducting some sort of study on benthic fauna (Fig. 1). Studies of the acoustic environment and of marine mammals (cetaceans and/ or seals) were conducted at 10 sites.

**Table 2:** Comparison of monitoring topics at wave energy development sites for which monitoring was ongoing or completed at the time of data collection (2011). AM: AMETS, Ireland; BI: BIMEP, Spain; EM: EMEC (Billia Croo Oyster array), Scotland; PI: Pico, Portugal; GB: Galway Bay, Ireland; IL: Isle of Lewis, Scotland; PZ: Pilot Zone, Portugal; RE: Réunion, France; RU: Runde, Norway; SR: Sem-Rev, France; LY: Lysekil, Sweden; WD: Wave Dragon, Wales; WH: Wave Hub, England; WR: Wave Roller, Portugal.

| **Monitoring topic** | **AM** | **BI** | **EM** | **PI** | **GB** | **IL** | **PZ** | **RE** | **RU** | **SR** | **LY** | **WD** | **WH** | **WR** | **IS** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. BENTHOS | | | | | | | | | | | | | | | |
| Seabed species | x | x | x | | x | x | x | x | x | x | x | x | x | x | |
| Biofouling of devices | | | | | | | | | | | x | | | x | |
| 2. SEA BIRDS | | | | | | | | | | | | | | | |
| Sea bird diversity, abundance, habitat use | x | | x | | x | x | x | | x | | | | x | | |
| Diving bird behaviour around devices | | | | | | | | | | | | | | | |
| 3. FISH & FISH HABITATS | | | | | | | | | | | | | | | |
| Fish diversity/ abundance | | x | | | | | x | | | | | | x | | |
| Fish behaviour | | | | | | | | | | | x | | | | |
| FAD/ artificial reef effects | | | | | | | | | | | x | | | | |
| 4. MARINE MAMMALS | | | | | | | | | | | | | | | |
| Cetacean abundance/ distribution | x | x | x | | x | x | x | x | x | | | | x | | x |
| Cetacean behaviour | | | | | | | | | | | | | | | |
| Seal abundance/ distribution | | | | | | | | | x | | | | x | | x |
| Seal behaviour | | | | | | | | | | | | | | | |
| 5. OTHER MARINE MEGAVERTEBRATES | | | | | | | | | | | | | | | |
| Sharks | | | | | | | | x | x | | | | x | | |
| Turtles | | | | | x | | | | | | | | | | |
| 6. PHYSICAL OCEANOGR. ENVIRONMENT | | | | | | | | | | | | | | | |
| Wave characteristics | x | x | x | | x | | x | x | x | x | | | x | | |
| Current monitoring | x | | x | | | | x | x | x | x | | x | x | | |
| Beach morphology/coastal processes | | | | | | | | | x | | | | x | x | |
| Water variables (turbidity/ temp/salinity) | | | | | | | | | | x | | | x | | |
| Plankton | | | | | | | | | | | | | x | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bathymetry | x | | | | | | | | | x | | x | | | |
| Seabed habitats/sediment | x | | | | x | | x | | | x | | x | x | | |
| Weather/ meteorological variables | x | | x | | x | | | | | x | | | | | |
| 7. ACOUSTICS | | | | | | | | | | | | | | | |
| Noise underwater/in air/ anthropogenic | x | x | x | x | | x | | | x | | x | x | x | x | |
| 8. TERRESTRIAL HABITATS | | | | | | | | | | | | | | | |
| Littoral/intertidal fauna & flora | x | | | | | | | | | | | x | x | | |
| 9. SOCIO-ECONOMIC | | | | | | | | | | | | | | | |
| Fisheries | | x | | | | | x | | | | | x | x | | |
| Visual impacts | x | | | | | x | | | | | | x | x | | |
| Tourism/recreational | | | | | | | | | | | | | | | |
| Road traffic | | | | | | | | | | | | | x | | |
| 10. OTHER | | | | | | | | | | | | | | | |
| Archaeological | x | | | | | x | | | | | | x | x | | |
| Navigation risk | x | | | | | | | | | | | | x | | |
| Vessel activity | | | | | | x | | | | | | | | | |

Sources of data other than questionnaires: AQUAFACT International Services, 2010; D'Olier and Daruvala, 2009; SWRDA, 2006; Wavedragon Ltd., 2007; Willsteed, 2008.

Monitoring of seabirds occurred at less than half of the 15 sites; socio-economic considerations (including impacts on road traffic, fisheries and visual impacts), were examined at six sites; fish and fish habitats at only a third of all sites and studies on the impacts of nearby terrestrial environments were conducted for only three sites (Fig. 1).

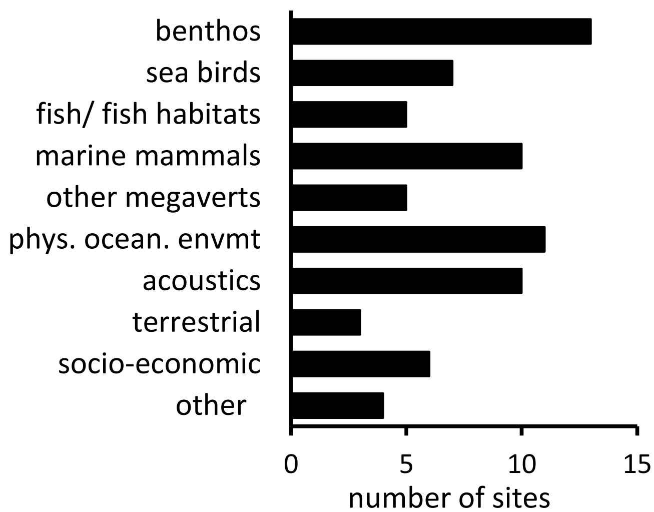


**Fig. 1:** Number of wave and tidal energy sites monitoring in each of ten categories.

Particularly surprising was the paucity of studies on fish and fish habitats, and likewise on potential impacts on fisheries (within the 'socio-economic' category). Whilst visual impacts may be less of a concern for many MREIs with underwater devices, research on other socio-economic considerations such as community perceptions of costs and benefits were few. Even within these broad categories, not all topics were equally addressed. Only a single site was examining fish behaviour and artificial reef effects, and only two sites were monitoring biofouling on underwater devices.

Methods also varied greatly, such that even when several sites were essentially addressing the same ecological question, they were often using markedly different methods to do so. An example of this may be seen in the diversity of methods used to monitor marine mammals. Table 3 compares the methods used to monitor cetaceans and seals at several wave energy sites, Horns Rev offshore wind farm, Strangford Lough tidal turbine site and at sites in the Pentland Firth/ Orkney area (as part of preliminary assessments carried out by Scottish Natural Heritage with a view to the development of renewable energy schemes). A number of the listed methodologies, including boat-based and aerial surveys, static acoustic monitoring devices (C-PODs), towed hydrophone surveys, land-based surveys and the use of existing data, are generally (although not exclusively) used to assess marine mammal abundance and distribution, which is an important part of EIA baseline data for most marine habitats. What is notable is the disparity amongst sites in the methods selected for monitoring marine mammals, as a means of indicating impacts at a local population level. This disparity is particularly remarkable given that all but one of the sites were located in either the UK or Ireland, and all sites were thus essentially monitoring for the same group of species.

Finally, several monitoring gaps were apparent. None of the sites included in this study were examining the effect of the Electromagnetic fields (EMF) associated with submarine electrical cables required to transfer power from sub-sea devices to transformers and the mainland. Likewise, although monitoring of the abundance and distribution of large marine vertebrates was ongoing or planned at many of the sites examined here, none were conducting studies on the behaviour of marine mammals, basking sharks or diving birds around marine renewables devices, despite the risk of collision being a key concern for MREIs (Wilson et al., 2007).

**Table 3:** Example of the diverse monitoring methods used at various MREI sites to collect information on one component of EIA monitoring – distribution, abundance and habitat use of marine mammals (cetaceans and pinnipeds). WH: WaveHub, BC: Billia Croo, EMEC; AM: AMETS, Ireland; PF: Pentland Firth and Orkney area, Scotland (scoping by Scottish Natural Heritage); HR: Horns Rev, Denmark (offshore wind site); SL: Strangford Lough, UK (tidal turbine site). Sources: Bedford & Fortune (2010a, b); Carl Bro Group Ltd. (2002); Fortune et al. (2008) ; Hastie (2012); Keenan et al. (2012); MERC Consultants Ltd. (2009); Tougaard et al. (2003, 2004, 2006, 2009); and questionnaire responses.

| Method | WH | BC | AM | PF | HR | SL |
|---|---|---|---|---|---|---|
| T-POD / C-POD | x | | x | | x | x |
| Other static hydrophone | x | | | | | |
| Towed hydrophone | | | x | | | |
| Boat-based sightings surveys | x | | x | | x | x |
| Aerial sightings surveys | | | | x | | x |
| Aerial videography surveys | | | | | | |
| Land-based / fixed point sightings surveys | | x | x | x | | x |
| Satellite tagging (seals only) | | | | x | x | x |
| Sonar imaging | | | | | | x |
| Surveillance for beach-cast carcasses | | | | | | x |
| Baseline data from existing databases | x | x | | | x | x |

## 4. DISCUSSION

The disparity in monitoring activities amongst wave energy sites described by this study is somewhat concerning and likely reflects the lack of guidance available for MREI developers, and the considerable expense involved in carrying out a comprehensive EIA. The diversity of monitoring topics and methods documented even over a small number of test sites highlights the need for a more unified approach to the EIA process. The findings of the long-term studies at Horns Rev and similar sites are invaluable in this respect, as they provide some indication of the likely impacts, the time scales required to detect these and thus at least some of the necessary elements of a monitoring scheme for wave and tidal sites.

Horns Rev, the world's largest offshore wind farm, was constructed off the Danish west coast in 2002 and a comprehensive EIA was carried out at this site over several years[3]. Addressing firstly how wave energy EIAs compare to the well-established practices associated with offshore wind developments, it is evident that there are some commonalities but also a number of issues unique to one industry or the other. This might be expected given the very different physical constructions and placements of the various technologies. Commonalities between wave and tidal sites and Horns Rev included a focus on benthic fauna (Leonhard and Pedersen, 2006) and oceanographic processes such as currents. Marine mammal monitoring was also clearly a priority for many of the test site developers, as it was for both the Horns Rev EIA. This is likely due to the fact that such species are protected by European legislation (EU Habitats Directive) as well as by national legislation in most countries, and as such, any development which is likely to cause disturbance to a local population must monitor for potential impacts. In addition, marine mammal species are often considered 'flagship species' or charismatic species which attract public attention and thus any perceived negative effect on such species would bring with it a negative association to a given MREI. Developers are likely to wish to minimise any such perception and thus will likely continue to focus monitoring efforts on charismatic megafauna known or thought to be present in the area of the development. Efforts to understand the underwater acoustic environment around offshore wind farms (e.g. Betke, 2006) were replicated at many of the sites examined for this study, possibly because of a growing awareness of the impacts acoustic disturbance may have on marine mammals and other marine fauna (e.g. Brandt et al., 2011; Tougaard et al., 2009).

Some disparities between wave energy sites and the Horns Rev monitoring programme were to be expected. For example, the effect of new hard substrate and bio-fouling communities on the existing fish and benthic communities was investigated at Horns Rev, whereas, at least for offshore wave energy

[3] Horns Rev data summarised from: Betke, 2006; Diederichs et al., 2008; ENERGI E2, 2005; Hvidt et al., 2006; Leonhard and Pedersen, 2006; Petersen, 2005; Tougaard et al., 2003; 2004; 2006; 2009.

sites, little hard substrate will be introduced to the environment. Visual impacts of wind turbines are considered to be greater than those for MREIs (Devine-Wright, 2008; Haggett, 2008; West et al., 2010), and thus the lack of studies on perceptions of visual impacts at MRE sites is perhaps not surprising. Similarly, few seabird studies were being conducted at SOWFIA test sites, whilst seabirds are a key concern for offshore wind farms. At both terrestrial and offshore wind farm sites including Horns Rev, birds have been a key monitoring focus due to concerns that wind turbines can potentially act as obstacles to migration routes for some species, and due to evidence that collision between turbines and birds does occur (Garthe and Huppop, 2004; Langston and Pullan, 2003; Pearce-Higgins et al., 2008; Petersen, 2005). Less effort on surveys for birds flying through the area would likely be required for a wave energy site (as was also the case for the SeaGen site, which focused instead on birds observed at the water surface; Bedford & Fortune 2010a, b), since no WECs to date have involved aerial components. The data collected from SOWFIA test sites show that seabird studies were indeed less numerous than cetacean studies. Baseline noise assessments are currently more important for wave energy development, as wind is not thought to have as much effect on the underwater acoustic environment (e.g. Tougaard et al., 2009).

Generating an overview of monitoring activities at MRE sites across Europe highlighted several areas where knowledge was lacking and where no ongoing monitoring or research was occurring. The effect of marine renewable devices on fish is poorly understood, yet few of the sites assessed here were carrying out studies on fish and fish habitats. There is little known about the risk of collision between fish and underwater devices (ABP MER, 2010; Wilson et al., 2007) and in addition to the possibility of collision, devices may exclude fish from an area simply by their presence, or they may artificially aggregate certain species. This will be important to quantify in order to ascertain whether MREIs can in fact act as artificial reefs or FADs, and what the effects of large-scale MREIs will be on the marine biodiversity of a region.

Similarly, WECs involve moving parts at the sea surface or below it (depending on the device type) and behavioural studies to investigate the effects of wave and tidal devices on species inhabiting the water column and the air-water interface (cetaceans, pinnipeds, sharks and other fish species, as well as diving seabirds), are thus needed for the MRE industry in order to address concerns relating to interactions between these species and MREDs, both underwater and at the air-water interface (Wilson et al., 2007). The EIA conducted for the tidal turbine in Strangford Lough set an example for this by using active sonar to detect animals in the vicinity of the turbines, since this was a key concern for operation of the underwater turbine, and by facilitating pile-based observations around the turbine itself (Hastie, 2012). This area is one which will require methodological innovation and most likely, the use of new technologies in order to collect meaningful data on underwater behaviour linked to moving device parts. Indeed, the wave and tidal industries have a number of overlapping areas of potential impact, particularly with regard to the presence of moving underwater structures, tethers, entanglement or collision risk and changes in animal behaviour. This suggests that collaborative efforts between the wave and tidal industries, as well as the floating offshore wind industry, might more efficiently address these concerns.

Surprisingly few sites were carrying out studies to assess the impacts of their device(s) on fisheries. All MREIs will require a closed area around devices, which will exclude fishing activity, and whilst it is often assumed that this will benefit the marine ecosystem, developers must also consider the socio-economic impacts of placing limitations on an industry which may be important to coastal communities. Consideration of socio-economic impacts will be a key issue for MREIs and this element should be integrated into future monitoring programmes for MREIs, to quantify the impacts on livelihoods and examine how best to manage issues such as fisheries displacement and effects on recreational activities (Inger et al., 2009).

EMF have been suggested as a potential impact on many marine organisms including electrosensitive fish (Gill, 2005; Gill and Kimber 2005; Gill et al., 2012), elasmobranchs, marine mammals and turtles (Gould, 2008; Inger et al., 2009; Luschi et al., 2007; Wilhelmsson et al., 2010; Wiltschko and Wiltschko, 2005); however, such effects are difficult to study. None of the sites included in this study have any research programme in place to examine this effect, and no monitoring of EMF appears to have occurred in past EIAs for offshore energy. The existence of undersea cables long pre-dates the marine energy industry and continued inattention to this issue by regulators in all offshore energy sectors suggests a perception that any effects are of low impact, but it is not clear that this has been conclusively demonstrated.

Many studies of marine protected areas and no-take zones have found that commercial species of fish and shellfish have increased in density and size inside areas where fishing is prohibited (e.g. Abesamis and Russ, 2005; Beukers-Stewart et al., 2005; Goñi et al., 2006; Hoskin et al., 2011), and that the effect of this increase in size and density of organisms has a 'spillover' effect, whereby larvae, additional or larger individuals benefitting from the protected area might populate adjacent areas (e.g. Abesamis and Russ, 2005; Gell and Roberts, 2003; Hoskin et al., 2011). Artificial reef, FAD and *de facto* marine protected area effects are often mentioned as a possible benefit of MREIs, yet only one wave energy test site, Lysekil, was investigating potential artificial reef effects. Given that these positive effects are often promoted by MREI developers in order to offset the necessary closing of the development area to fisheries, it will be important to assess whether they do indeed occur and whether the benefits extend beyond the boundary of the MREI, as well as to ensure that fishing activity can validly be displaced without major impacts to local fishing industries and coastal communities.

Many of the reports referred to for this study provided outlines of the studies carried out, but not always details on the methodology or study design. It will be essential that monitoring studies specify their study design and methodologies, and that such designs and methods be comparable across multiple EIAs, if data are to be pooled to provide a wider understanding of impacts and the necessary monitoring activities. The design of an impact assessment study is important if the resulting data are to actually inform the hypotheses regarding potential impacts and how to mitigate for these. The first requirement for effective monitoring is an *a priori* decision as to what outcome would constitute (and demonstrate) success – in this case, usually (but not always) minimal or no negative impact on a particular biotic or abiotic feature. Once this goal has been determined, it must be translated into a precise, testable hypothesis which in turn informs the design of sampling and statistical analyses that will reliably test that hypothesis (Hoskin et al., 2011; Underwood, 1994, 1995). The importance of multiple control sites and of appropriate monitoring time and spatial scales should not be underestimated.

The offshore wind industry is considerably more developed, having been in existence for several decades, and thus has had the opportunity to refine its impact assessment processes, whereas the wave (and tidal) energy industry is only beginning to understand which elements of impact assessment are necessary. The majority of the monitoring activities described in this study mirror, to some extent, impact assessment activities previously implemented for offshore wind energy sites. This suggests that the designs of current EIAs are not necessarily based on known data gaps but rather, often follow previous templates for EIA in the marine environment. This may result in the incorporation of monitoring elements which are unnecessary, either because the impact being addressed is known not to be a concern at that site or because previous studies can provide adequate relevant information. It may also result in necessary monitoring elements being omitted. Certainly, the conflict between cost-efficiency and appropriate monitoring - collecting sufficient baseline data prior to the commencement of any impact, and carrying out a comprehensive monitoring programme at spatial and temporal scales appropriate to detect biologically significant changes – is a key issue for the EIA process (e.g. Macleod et al., 2010). Nonetheless, this factor should not determine the scope of monitoring programmes at MRE sites.

A goal of the SOWFIA project was the streamlining of EIA requirements and methods, since an efficient EIA process ensures that the marine environment is protected whilst at the same time should not unduly inhibit the development of MREIs. The diversity of devices and of offshore environments in which these devices may be deployed means that it is difficult, at present, to provide generalised guidance which applies to all situations. Margheritini (2012) suggested that a classification scheme for technology based on relevant environmental and device parameters would prove a useful tool to assess the potential impacts of wave energy developments, and thus to target monitoring activities. This system requires that the project, including the intended WEC or tidal device, is described with sufficient precision – a key issue for the EIA process. However, this system would be problematic for any test centre in which multiple devices and devices of varying types, likely to affect different environmental receptors, are proposed over the life time of the project. In addition, Margheritini's system does not account for the hypothesised positive impacts of MREIs such as artificial reef effects, reduction in $CO_2$ emissions and socio-economic benefits.

In establishing the role of ocean renewables within the larger energy policy, a key step will be the prioritisation of research that will prove the ‘green credentials’ of wave energy (Salcido, 2009). This study has highlighted some of the gaps in the knowledge required to build these credentials. Research must take a collaborative approach which results in an evidence-based, ecosystem-level picture of the interactions between MREIs and the marine environment. It will be essential to combine lessons learned from EIA at various sites and using various technologies. The extensive and well-established offshore wind industry has learned numerous lessons regarding monitoring methodologies and key receptors (Wilhelmsson et al., 2010), which should also be integrated. With MREI developers as key partners, research consortia should now address data gaps and facilitate the sharing of knowledge and experience across ocean energy sectors, in order to inform EIA and project consenting processes.

**Conclusions**

The MRE sector can likely benefit from the results of impact assessments conducted by the offshore wind industry, but also faces a number of new monitoring challenges for issues specific to wave and tidal devices. Wave energy developments, whether demonstrator sites, test sites or full-scale commercial developments, require long-term, inter-disciplinary work to describe in detail, at this nascent stage of the industry, the actual impacts of different devices in varying marine environments. Collaborations between researchers and MREI developers will be essential in order to achieve this. Where possible, impact assessment methods should be standardised or at least analogous, to facilitate comparison of datasets, and ideally, these datasets would be publically available to ensure best use of the data collected.  The SOWFIA project brought together industry partners with researchers, stakeholders and management bodies to initiate data sharing and streamlining of the processes involved in Impact Assessment. The resulting knowledge will ensure that the development and growth of commercial wave farms is encouraged, whilst simultaneously ensuring that the marine environment and the communities that depend upon it are safeguarded.


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Appendix C: http://www.wavehub.co.uk/wp-content/uploads/2011/06/Appendix-C-Habitat-Survey.pdf

Appendix D: http://www.wavehub.co.uk/wp-content/uploads/2011/06/Appendix-D-Intertidal-Bird-Surveys.pdf

Appendix E : http://www.wavehub.co.uk/wp-content/uploads/2011/06/Appendix-E-Offshore-Bird-Surveys.pdf

Appendix F: http://www.wavehub.co.uk/wp-content/uploads/2011/06/Appendix-F-Intertidal-Study.pdf

Appendix I: http://www.wavehub.co.uk/wp-content/uploads/2011/06/Appendix-I-Subtidal-Benthic-Survey.pdf

Appendix K: http://www.wavehub.co.uk/wp-content/uploads/2011/06/Appendix-K-Baseline-Fisheries-Survey.pdf

Appendix M: http://www.wavehub.co.uk/wp-content/uploads/2011/06/Appendix-M-Landscape-and-Visual-Assessment-Part-A.pdf

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**Appendix I:** Questionnaire on environmental monitoring data being collected at marine renewable energy sites.

| |
|---|
| **Name of organisation/ institution**: |
| **Contact person name**: |
| **Contact person email**: |
| **Name of site**: |
| **Location of site (area, country)**: |
| **Project resource type (wave, tidal, offshore wind)**: |
| **Technology type:** |
| **Project developer:** |
| **Project scale (test site, prototype, array, commercial):** |
| **Current status of project implementation:** |
| **Expected operation date (for projects in development):** |
| **Installed capacity:** |
| **Project website:** |
| **Today's date:** |

| We would like to know about the environmental monitoring activities, past, present and future, at your site | |
|---|---|
| **Is there, has there been or will there be environmental monitoring activities at your site?** | |

**If yes, please list each activity separately and provide any associated information for each activity (the first entry in the table is provided as an example).** Please complete this table for all biological, acoustic, coastal processes, hydrographic and socio-economic monitoring, and any other relevant activities.

| Monitoring activity | Time period | Methods | Will it be available to SOWFIA & in what form?* | Expected size of dataset to be provided | Why is it being monitored? |
|---|---|---|---|---|---|
| *e.g. Surveys for marine mammals* | *Jan 2008 - present OR scheduled to begin in Jun2011* | *Boat-based transect surveys* | *Yes – raw data (effort & sightings data).* | *20 MB per year OR 150 MB total* | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

*Forms in which data can be provided include: metadata only; raw data; refined data products (modified data); reports/papers. If these data will be provided only at a cost, please indicate.