A REVIEW OF DEVELOPING MARINE RENEWABLE TECHNOLOGIES

Deborah Wright, Vicki C. Brown and Mark P. Simmonds[1]

Whale and Dolphin Conservation Society
Brookfield House, 38 St Paul Street, Chippenham, Wiltshire SN15 1LJ, UK.

ABSTRACT

This paper provides an overview of the latest information regarding the development of marine renewable energy generating devices, including current-driven mechanisms. It highlights the potential impacts of these devices on cetaceans and recommends that this matter deserves further attention by the IWC Scientific Committee.

KEYWORDS: Marine renewable energy, UK, Europe, cetaceans, dolphins, whales, windfarms

INTRODUCTION

Marine renewable energy is typically regarded as an abundant, inexhaustible and non-polluting resource. Spurred on by the growing global energy crisis, and to meet requirements to reduce greenhouse gases, governments around the world are investing in new renewable energy technologies. Much of the development is going on out at sea (Brown and Simmonds, 2009).

Many European countries are particularly well placed to generate energy from the sea, especially the more westerly nations such as Portugal and the UK, with their extensive coastlines and exposure to high winds, strong currents and powerful waves. Various wave and tidal pilot projects have been established or are being planned, to test devices in real conditions in European waters (Brown and Simmonds, 2009). For example, in 2007, the first commercial tidal stream converter, the SeaGen, became operational in Strangford Lough, in Northern Ireland.

Windfarms are being progressed particularly swiftly. Europe now has 67 marine windfarms in various stages of development, forming of 70.5% of all Marine Renewable Energy Developments (MREDs) (Brown and Simmonds 2009). There was a 257.7% increase in the number of marine windfarms in Europe during 2005-2009.

There are currently 15 tidal power sites and 13 wave power sites at various stages of development in European waters (Brown and Simmonds 2009). These are relatively new developments and it is probably true to say that, apart from some tidal barrages (such as those at La Rance in Brittany and Annapolis in Nova Scotia), energy production from the sea and its commercial application has yet to be fully realised. However, as wave and tidal devices are still relatively new, little is known about their potential impact on wildlife.

Simmonds and Dolman (2008) identified a range of potential impacts on cetaceans from wind farms (which may also relate to other MREDs) including:

- Intense noise during pile-driving, drilling and dredging operations;
- Increased vessel activities during exploration and construction;
- Increased turbidity and re-suspension of polluted sediments due to construction;
- Physical decommissioning of wind farms which might involve the use of explosives;

[1] Corresponding author: mark.simmonds@wdcs.org

- The presence of structures (including artificial reef effects causing habitat alterations) and, potentially, changes to prey and food webs;
- The continual operational noise and vibrations emanating from the wind turbines;
- Electromagnetic impacts due to cabling that may impact navigation (which may be of particular concern for elasmobranchs);
- Increased vessel traffic from maintenance operations; and
- Effects on prey, such as changes to fish behaviour.

Arguably the pile driving process during construction of wind farms offers the greatest threat to cetaceans. Other concerns relating to MREDs could include collisions between cetaceans and structures on the surface or in the water column, contamination of water (for example by leaks of lubricants), entanglement (for example in cables) and habitat degradation and displacement.

Effects on marine mammals can be expected to differ according to the type of MRED in question, how it works and how, and where, it is positioned. Some of the information relating to the impacts of other marine industries, such as offshore oil and gas production, will be relevant to wind, wave and tidal projects, such as the effects of pile driving into the sea bed. Jefferson *et al*. (2009) provide a useful review of marine industrial activities, their relationship to cetaceans and attempts to mitigate them focused on busy Hong Kong waters. They note that most of the developments there have been very noisy and that this "has the potential to cause disturbance of the cetaceans' normal activities, largely through underwater noise. While such noise can occasionally be intense and loud enough to injure or kill dolphins or porpoises (such as in blasting or percussive piling operations), the impacts are usually sublethal".

This is a brief overview of the present state of the wave, tidal and wind energy industries with some further speculation about how they may affect cetaceans. However, the authors note that with their rapid development and expansion, these industries are in a state of flux making impact predictions especially difficult.

METHODS

This preliminary review of MRED devices has been conducted using web-based information, other literature and through discussions with various developers. We have focused on European developments in wave, wind and tidal energy, as this is where the majority of methods are seemingly being developed and tested.

Marine windfarms have been in use since 1991 when Vindeby, off the coast of Denmark, was built. By contrast wave and tidal energy devices are mainly in the early stages of development and this means that they are still changing. Different developers also have different names for very similar or identical types of converters, making it difficult to know the exact numbers and types that that are currently being developed, tested or deployed.

Because of the changing nature of wave and tidal converters only the primary types have been included in this report. We regard the information provided here on wave and tidal converters as preliminary and would be pleased to be provided with additions or corrections.

DISCUSSION

Much of the information presented here comes from a variety of web-based sources – please see the list at the end of the paper and figures 1 and 2 for details.

Wave power

Waves are formed by winds blowing over the sea's surface. The power of the waves depends on the speed of the wind, its duration and the distance it travels over the water (its 'fetch'). Other determining factors are the sea depth and interacting tides. The most powerful waves are created by strong winds over a long fetch, such as those along the western coasts of Europe, South America and Australia. There are wave energy projects emerging in several countries around the world, notably in the UK, Portugal, Australia, Spain, Norway and the US.

The main disadvantage is the variability and poor predictability of waves, making them a less reliable source of energy than tidal power. There may also be significant construction and maintenance problems, with devices having to withstand very severe conditions in the water.

Waves have two types of exploitable energy; kinetic from their horizontal motion, and potential, from the vertical difference between the wave's crest and its valley. It is not easy to harness the energy of waves, hence the development of a wide range of possible devices to attempt to do so. The converters are floating, moored or fixed, and they can be sited on shore, near to shore or offshore. There are up to 35 different wave energy devices currently proposed.

Wave energy converters are generally categorised by the nature of the method used to harness energy. However there are variations in their categorisation. For example, according to the UK Department of Trade & Industry, there are 3 types of converter; the 'buoyant moored device', 'hinged contour device', and 'oscillating water column'. Whereas according to The European Marine Energy Centre (EMEC), there are at least 6 types of converter; the 'attenuator', 'point absorber', 'oscillating wave surge converter', 'oscillating water column', 'overtopping device', and 'submerged pressure differential'.

Further confusion is caused by the inconsistency of terminology used, including giving the same converter different names. For example, an 'attenuator' can also be called a 'hinged contour device', or a 'surface following device'.

Figure 1 provides a summary of how each type of wave converter works.

Tidal power

Tidal power can be subdivided into two categories:

- *Tidal stream power* (also called marine current energy) is produced from the horizontal movement of water in a current (kinetic energy). Useful energy can be extracted from marine currents using completely submerged turbines and hydrofoil devices called Tidal Energy Converters. They are a relatively new technology, converting energy from sea currents. Water is 832 times denser than air, which means that a single generator can provide a significant amount of energy. The location of tidal stream systems is important and to maximise efficiency they need to be in fast currents where sea flows are compressed, such as at the entrance of a bay, around headlands, or between islands.

- *Tidal range* power is produced from the vertical movement of water in the rise and fall of the tide. Tidal barrages make use of the potential energy in the difference in height between high and low tides. Barrages, such as that at La Rance, are a type of dam spanning an estuary, providing a predictable and reliable source of energy.

Barrages suffer from very high infrastructure costs, negative environmental impacts, (such as damage to estuarine ecosystems, feeding and breeding areas for wildlife) and a worldwide shortage of sites that would be expected to produce viable amounts of electricity. For a site to be viable, the difference between high and low tides needs to be at least 5m, and there are only about 40 such sites around the world. Tidal barrages are also seemingly becoming outdated and may be superseded by recent, more efficient technologies, such as tidal fences and tidal lagoons. A tidal fence is a continuous fence of underwater turbines stretching across an estuary or strait, with some spaces to allow the passage of ships and migrating species such as salmon.

A tidal lagoon is an adaptation of the barrage, exploiting the height between high and low tides to generate energy. It is an area of coastline enclosed by a structure typically of aggregate, rubble or rock. Turbines are set into the walls of the lagoon under the water's surface, and are driven as the sea flows in and out with the rise and fall of the tide. From a distance the lagoon resembles a breakwater or low rocky island.

As there are two tides each day one advantage of both tidal stream and tidal range energy is that their energy production capacities are predictable, frequent and regular. Several trial projects are planned in Europe, mostly around the British Isles, including, for example, one in the narrow Pentland Firth in Scotland (Brown and Simmonds 2009).

There are 3 types of tidal power converter and figure 2 shows the summary of how each type works. The devices can be floating, or mounted on the seabed, on a pile, in a barrage (like a dam), and located in a tidal fence or a tidal lagoon.

Wind power

Windfarms have been experiencing the swiftest development of MREDs; the number in Europe has increased from 13 sites pre-2000 to 67 sites in 2009. This rapid expansion is continuing and spreading further across Europe and worldwide (Brown and Simmonds 2009) supported by government targets to reduce carbon emissions.

The turbines used in offshore windfarms are horizontal axis turbines (HAWT), typically having three rotor blades facing into the wind 20-40m long, mounted on a tubular tower, bedded into the sea floor and some 60-90m tall.

Potential Impacts

Further to the indicative list provided by Simmonds and Dolman (2008), there are a number of potential negative impacts on marine life from MREDs:

- *Underwater and surface noise:* noise will be generated during construction, installation, maintenance operations and decommissioning. Installation is a particular concern as pile driving may be used and this has the potential to cause physical harm. Explosive decommissioning of sites is another major concern (Prior and McMath 2007). Noise and other disturbance from MRED-associated drilling, dredging, cable laying and vessel activity could also have a negative impact. The noise transmission from an operational array of windfarms or other converters may combine synergistically to have a biological effect.

- *Contamination of the local environment:* this could occur via leaks or spills of hydraulic fluid, the use of biocides to control growth of fouling organisms on submerged structures and also the dumping of wastes from structures.

- *Entrapment, entanglement or collision:* the devices themselves and certain features in particular (such as rotating blades) may present risks of entrapment, entanglement and harmful, perhaps even lethal collisions. The greatest hazards for some animals may be cables. Types and amounts of cable vary according to the device type, but include mooring cables, guy-lines and power cables. They may be slack, taut, vibrating, horizontal, diagonal, vertical, crossed, current-carrying and so forth, and with the potential to be hazards for cetaceans and other wildlife. Floating devices could present a collision hazard along with their supporting structures.

- *Electrical and electromagnetic disturbance*: the extensive underwater electrical cables associated with MREDs may affect wildlife. This has been highlighted as a threat to elasmobranchs but other wildlife, including cetaceans, might also be affected.

- *Siting of devices*: devices may be placed in sensitive areas, such as those used for breeding, feeding or migration. Tidal barrages have a significant negative impact on estuarine ecology such as wading birds and migrating fish.

- *Other habitat degradation:* this might include damage to the sea bed, changes in vertical mixing and increased turbidity (particularly during installation and construction). Local benthic flora and fauna may be disturbed, though the effects may be short-term. Disturbance of pelagic or demersal organisms, including fish, may have negative implications for their predators.

- *Displacement*: It is possible that a combination of disturbing/habitat-degrading activities, potentially including increased vessel movements for maintenance purposes, could cause displacement of cetaceans from the area where converters are deployed. (Boat disturbance has been shown to effect behaviour and displace dolphins (see for example, Lusseau, 2005)).

The severity of these impacts will differ at each site based on a number of variables, the type of converter, location (devices can be sited at the shoreline, near-shore, offshore, deep water channels, in rivers, estuaries, on the sea bed, surface etc.), scale (single devices will have a different impact to that of an array) and so forth.

Other factors potentially affecting impacts could include:
- The type of seabed support used. For example, wind turbines with concrete foundations emit higher noise levels below 50Hz and lower levels between 50Hz and 500Hz, than those with monopole foundations; and
- The topography of the seabed and the nature of the seabed substrate.

Many potential impacts would be site-specific. Baseline data is required to understand the abundance and distribution of species and local habitat use, so that wave and tidal converters or windfarms are not located in sensitive areas such as breeding and feeding grounds, or on migratory routes. For example, many shallow waters in northern Europe are important calving and nursing areas for harbour porpoises (*Phocoena phocoena*). Planning should consider the entire life of the farm from exploration, construction, operation to maintenance and decommissioning, during all seasons of the year.

The acute and chronic effects of noise pollution and disturbance on cetaceans are considered further in Simmonds *et al*., (2004), Jasny (2005) and Weilgart (2007). As noted above, Jefferson *et al*. (2009) provide valuable insights into the implications for cetaceans of a range of industrial developments at sea, and how such matters might be addressed. Issues relating to marine windfarms are discussed more fully in Evans (2008) and the authors note that there are concerns that relate to the potential impacts of marine wind farms on seabirds, mainly relating to collisions with moving turbine blades.

There are also possible positive impacts for wildlife that may result from deployment of MREDs, although evidence for this seems negligible at this time and we can therefore only theorise. For example, the area around an array of devices may become in some respects a protected zone where certain activities, such as fishing or shipping are excluded or limited.

Conclusions
A wide range of concerns is raised by this preliminary review of MRED technologies and by extrapolation from other more fully developed offshore industries. The authors believe that this issue deserves further careful consideration by experts. Given the increasingly widespread nature of such developments, the authors recommend that the Scientific Committee of the IWC make MREDs and their interactions with cetaceans a focus for one of its meetings in the near future, and that it invites suitable experts to facilitate this.

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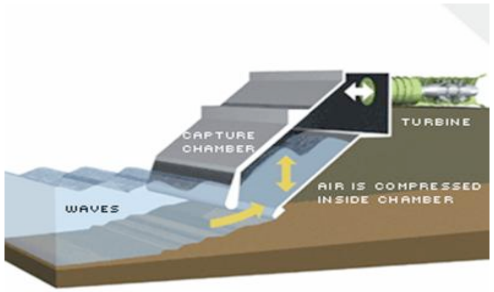
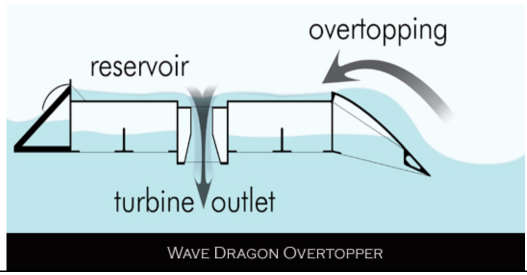
Figure 1. Summary of how each type of wave converter works.

Type of Converter	Example	Manufacturer	Placement in ocean
Attenuator: A segmented floating device that follows the motion of the waves and collects energy by the movement of the joints driving hydraulic motors.	Pelamis 	Pelamis Wave Power Ltd. http://www.pelamiswave.com/index.php	Offshore, floating on deep water. Moored with cables and chains. Each device c.120m long, 3.5m diameter.
Oscillating Water Column: A hollow structure moored to the seabed or installed on shore, which allows the rising wave in, forcing compressed air above to drive a turbine, something like a large piston.	Limpet  	Wavegen http://www.wavegen.co.uk/	Onshore
Overtopping Device: This holds 'captured' water in a reservoir above sea level before being released through low-head turbines.	Wave Dragon  	Wave Dragon http://www.wavedragon.co.uk/	Offshore

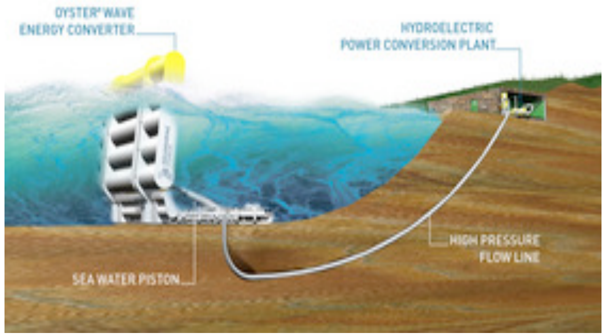
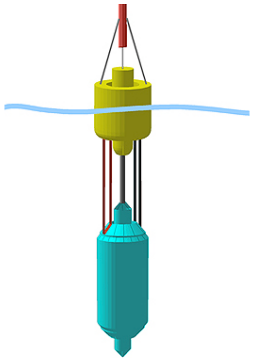
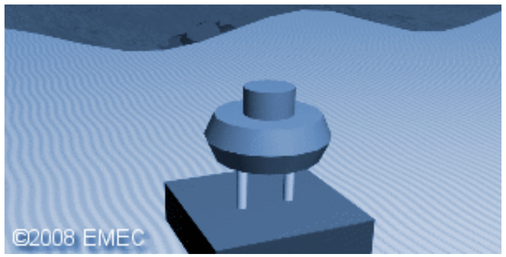
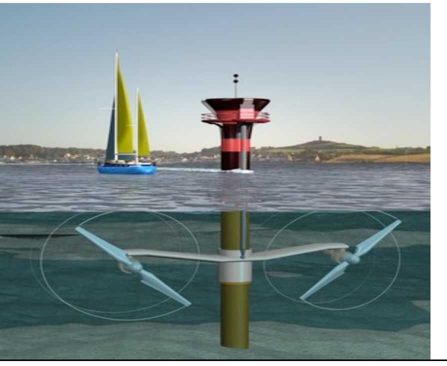
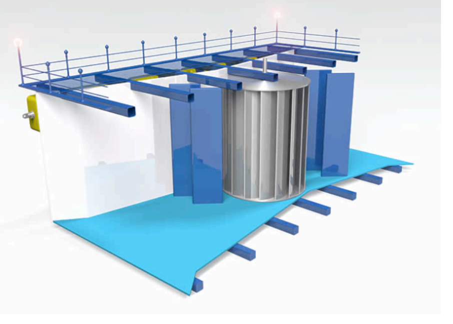
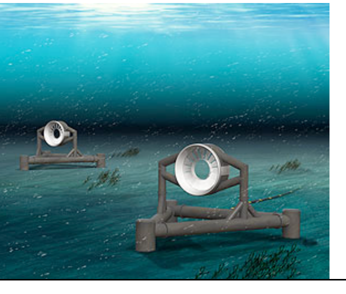
Oscillating Wave Surge Converter: An OWS converter has an oscillating pendulum, mounted on a pivoted joint, attached to the seabed.	Oyster 	Aquamarine Power http://www.aquamarinepower.com/technologies/	Nearshore
Buoyant Moored Device/ Point Absorber: Part of which floats on the surface, rising and falling with the wave, and part is moored to the seabed. Electricity is generated by turbines driven by a variety of mechanisms, such as hydraulic pumps.	Wavebob 	Wavebob http://www.wavebob.com/	Offshore
Submerged Pressure Differential: Mounted on the seabed, the rise and fall of the sea level above causes pressure changes in the converter which drives fluid through a generating system.		Information from: European Marine Energy Centre http://www.emec.org.uk/wave_energy_devices.asp	Nearshore

Figure 2. Summary of how each type of tidal converter works

Type of Converter	Example	Manufacturer	Placement in ocean
Horizontal or Vertical Axis Turbine - these devices vary greatly, but the principle of how they generate power is the same; the kinetic energy of flowing water turns the turbine or rotor which drives a generator.	SeaGen 	Marine Current Turbines http://www.marineturbines.com/	Estuaries, headlands, between islands, or where there are powerful, fast currents.
Duct Turbine (Venturi Effect) housing a turbine in a duct, (or shroud), concentrates the flow of water and creates pressure, maximising the generating potential of the turbine.	Neptune Proteus III 	Neptune Renewable Energy http://www.neptunerenewableenergy.com/tidal_technology.php	Estuaries with powerful currents. The pontoon is moored in the estuary stream and the turbine generates power in both the ebb and flow currents
Oscillating Hydrofoil – a hydrofoil attaching to an arm oscillates in the current, resulting in lift**,** the motion of which drives fluid through a generating system.	Open-Centre turbine 	Open Hydro http://www.openhydro.com/home.html	In fast currents on the seabed Several turbines (an array), are mounted on the seabed, (gravity based).

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