# WORKING GROUP ON MARINE BENTHAL RENEWABLE DEVELOPMENTS (WGMBRED)

VOLUME 1 | ISSUE 6

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk



ISSN number: 2618-1371 I © 2019 International Council for the Exploration of the Sea

# ICES Scientific Reports

Volume 1 | Issue 6

## WORKING GROUP ON MARINE BENTHAL RENEWABLE DEVELOPMENTS (WGMBRED)

### Recommended format for purpose of citation:

ICES. 2019. Working Group on Marine Benthal Renewable Developments (WGMBRED).
ICES Scientific Reports. 1:6. 95 pp. http://doi.org/10.17895/ices.pub.4914

### Editors

Jan Vanaverbeke • Joop W.P. Coolen

### Authors

Jan Vanaverbeke • Joop W.P. Coolen • Marion Harrald • Ross Culloch • Adrian Tait • Bob Rumes • Carol Spar-ling • Kirsty Wright • Rory O'Hara Murray • Tom Evans • William Hunt • Andrew B. Gill • Zoe Hutchison • Jolien Buyse • Robin Brabant • Juan Bald • Daniel Wood • Marijke Warnas • Lara Salvany

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

# Contents

# i Executive summary

This report provides an overview of the state of affairs (1) with regards to the deployment of wet renewables and (2) marine energy storage systems; (3) how they affect abiotic and biotic components of the marine ecosystem and (4) developments and concepts on cumulative impact assessments related to marine renewable energy devices and (5) future perspectives.

This report provides the scientific basis to address the OSPAR request for advice on the current state and knowledge of studies into the deployment and environmental impacts of the following wet renewable energies and marine energy storage (floating, coastal infrastructure), tidal stream (screws, kites), tidal flow (barrage, lagoon) and others. Advice should cover the status of wet renewable developments in the OSPAR region, future prospects, potential environmental problems (sea bed habitat loss/disturbance, fish, marine mammals, birds, seascape/ public perception, and cumulative impacts), potential benefits, next steps and conclusions". The request was directed towards the Working Group on Marine Benthal Energy Developments (WGMBRED) and the Working Group on Marine Renewable Energy (WGMRE).

A pre-meeting chaired by Jan Vanaverbeke, Belgium (WKWET, 15–16 January 2019) at ICES Headquarters, was attended by 11 participants from 4 countries, including members of WGMBRED and WGMRE and additional experts. The group analysed the OSPAR request, agreed on a structure for the report, and certain experts volunteered to conduct a literature review and provide the necessary knowledge base for the report.

WGMBRED met from 12–15 February 2019 in Brussels, Belgium. The input from WKWET participants was compiled, quality checked and adapted where needed; when relevant expertise was represented in the group. WKWET experts, not present at WGMBRED, reviewed text, where needed, and a first version of this report was delivered to WGMRE.

WGMRE met in Oostende (Belgium) from 26–28 February 2019. Participants reviewed the WKWET report following input from WGMBRED, quality checked, and adapted where necessary. Relevant experts contributed additional text and data to tables on MRE developments in ICES areas, and provided text on public perceptions and future prospects of MRE.

This report presents an overview of the currently known "wet renewables" (all marine renewable energy devices, excluding offshore wind devices) and how their deployment will likely change in the future. It further provides an overview of the concepts and techniques of related to marine energy storage devices. Given the conceptual and experimental stage of marine energy storage devices, and the absence of data on how these devices affect the marine environment, the report is limited to a description of these marine energy storage devices.

This report provides a receptor-based summary of how the wet renewables can affect the marine environment. Receptors are either abiotic (hydrodynamics, physical seabed and sediment transport) or biotic (benthos, fish, marine mammals, birds, sea turtles, otters and polar bears). To avoid repetition, effects on these receptors were grouped according to pressure-inducing components (static component of the device, dynamic component of the device, cables) of wet renewables or consequences of their presence.

The report further discusses the developments on cumulative impacts assessments associated with wet renewables deployment in addition to many other human activities, and the need to move away from "data rich – information poor" monitoring of structural aspects of the marine ecosystem to hypothesis-driven functional research at the relevant spatial and temporal scales. This will require cross-border coordination in data collection, data storage and exchange and the development of a joint research agenda.

# 1 Introduction

It is now generally accepted that the Earth's climate is changing, resulting in increased temperatures, ocean acidification and sea level rise, among others. This global warming is related to the increased emissions of $CO_2$ to the atmosphere due to the burning of fossil fuels, deforestation and cement production use (Sabine, Feely, Gruber, Key, Lee, Bullister, Wanninkhof, Wong, Wallace, Tilbrook, Millero, Peng, Kozyr, Ono & Rios 2004). This triggered an increased need to reduce the $CO_2$ emissions to the atmosphere, a goal that partly can be achieved by increasing the share of renewable energy in the global energy demand. In 2014, the European Council adopted 'The 2030 climate and energy framework', thereby committing to reduce greenhouse gas emissions by 40% compared to the 1990 levels and to set a renewable energy target of at least 27% of the European energy consumption (Com 2014, 15 final/2). Increasing the share of renewable energy will not only decrease $CO_2$ emissions, it will reduce national dependencies on imported energy, increase energy security and help replacing diminishing domestic supplies of fossil fuels (Frid, Andonegi, Depestele, Judd, Rihan, Rogers, Kenchington, Rogers, Kenchington, Rogers & Kenchington 2012).

To increase the use of renewable energy, there has been a proliferation of renewable energy devices in the marine realm (Marine Renewable Energy Devices, MREDs). A lot of effort was dedicated to the installation of offshore wind farms: there are currently 4149 offshore wind turbines installed and grid connect in 92 wind farms in 11 European countries, making a cumulative total of 15 780 MW (Offshore Wind in Europe - Key trends and statistics 2017 2018). On top of these offshore wind farms, so called 'wet renewables' are installed as well. For this report, we use the 'wet renewables' to refer to various types of tidal barrages, tidal stream and wave energy schemes. These type of marine renewable energy devices make use of more predictable sources of marine renewable energy such as tidal energy related to change in water level, tidal currents or waves (Frid *et al*. 2012) and are increasingly installed in the marine environment. However, there is a lack of clear understanding of how these devices affect the marine ecosystem (both abiotic and biotic) as the available information is scattered and fragmented. Frid *et al*. (2012) provided an overview of the environmental impact of tidal barrages and fences, tidal stream farms and wave energy devices, largely based on best available scientific knowledge from analogous activities. Copping *et al*. (2016) provided a valuable update, based on a limited number of case studies and found that the bulk of information concerned possible collision risk of fish and marine mammals with the wet renewables.

In order to advance the understanding of the possible effects of wet renewables on the marine environment, this report summarizes the knowledge on the effects of wet renewables on a set of abiotic and biotic receptors. Abiotic receptors include hydrodynamic regimes, underwater sound, marine dynamics, landscape, the physical sea bed and sediment transport. Biotic receptors include benthos, fish, marine mammals, birds and turtles. For reasons of completeness, possible effects on otters and polar bears are summarized as well. In order to structure the possible reasons for change in any of these receptors, possible stress originating from the wet renewables was allocated to several categories: the physical presence of the device, the dynamic component of the device, physical presence of moorings, mooring lines, cables and supporting structures, acoustic effects, electromagnetic fields generated and contaminants. The text summarizes the available knowledge, the extracted key messages are included in a summarizing table.

This report further deals with marine energy storage devices and cumulative impact assessments. Marine energy storage devices are currently highly conceptual and/or experimental and not regularly deployed. As such, information on how these marine energy storage devices affect the abiotic and biotic parts of the marine environments is not available. Therefore, the section on marine renewable energy devices is limited to a description of the current state of affairs of available technology. We further provide a summary of the current insights on cumulative impact assessment with focus on MREDs. Given the fact that MRED (wet renewables and offshore wind) are emerging technologies, there is still considerable debate on how to assess the effects of multiple MREDS in combination with existing human activities. This report therefore summarizes the main issues related to cumulative impact assessment involving MREDs. When specific information is available on cumulative effects on certain receptors, the information is provided in the relevant section of the report.

# 2 Overview of wet renewable devices and Marine Energy Storage Systems

## 2.1 Tidal Energy

### 2.1.1 Energy resource and location

A major study by the European Commission evaluating the tidal current resource for 106 locations around Europe, with predefined characteristics making them suitable for tidal stream energy exploitation, estimated an exploitable resource from those sites of 48 TWh a year (European Commission, 1996) (RICORE project).The aggregate capacity of this selection of sites amounted to an installed capacity of marine current turbines of more than 12 000 MW. A more recent study by Black & Veatch (Black & Veatch for Carbon Trust, 2005) suggests an estimated UK extractable resource of 22 TWh for tidal stream, using a modified and more accurate methodology. Other countries with an exceptionally high resource include Ireland, Italy, the Philippines and Japan. Figure 1 shows the mean tidal amplitude for 237 locations along the European coastline. These locations are situated 50 to 100 km away from the shoreline, and the distance from one location to another is approximately 100 km.

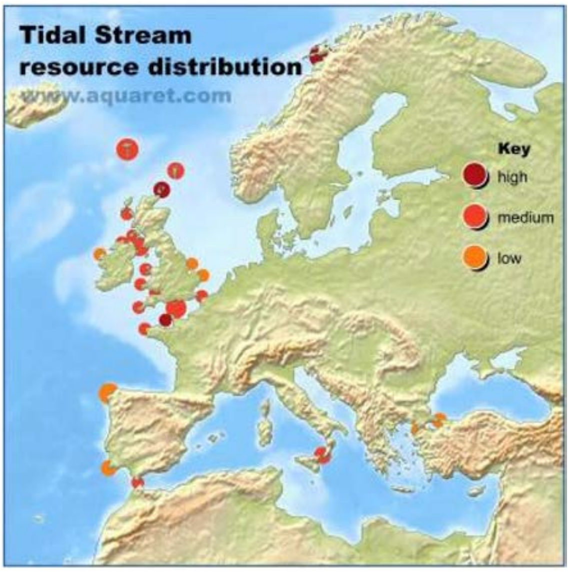


**Figure 1. Tidal stream resource distribution. Source: www.aquaret.com.**

### 2.1.2 Tidal devices

Tidal energy is driven by the gravitational pull of the moon and sun, exploiting the natural ebb and flow of coastal tidal waters. Tidal forces are periodic occurrences which makes them predictable and reliable. Tidal energy which is a form of hydropower can be extracted from areas where there are fast sea currents and these are often magnified by topographical features, such as headlands, inlets and straits, or by the shape of the seabed when water is forced through narrow channels. The tidal stream devices, which utilize these currents, are broadly similar to submerged wind turbines where they exploit the kinetic energy in tidal currents and turn into useful forms of power, mainly electrical. Due to the higher density of water, this means that the blades can be smaller and turn more slowly, but they still deliver a significant amount of power. To increase the flow and power output from the turbine, concentrators (or shrouds) may be used around the blades to streamline and concentrate the flow towards the rotors.

### Horizontal Axis Turbine

Horizontal axis turbines extract energy from moving water in much the same way as wind turbines extract energy from moving air. The tidal stream causes the dynamic rotors to rotate around the horizontal axis and generate power as seen in Figure 2. This type of Tidal Energy Converter (TEC) is pile mounted where rotors are mounted on a vertical static pole or shaft which penetrates the seabed.

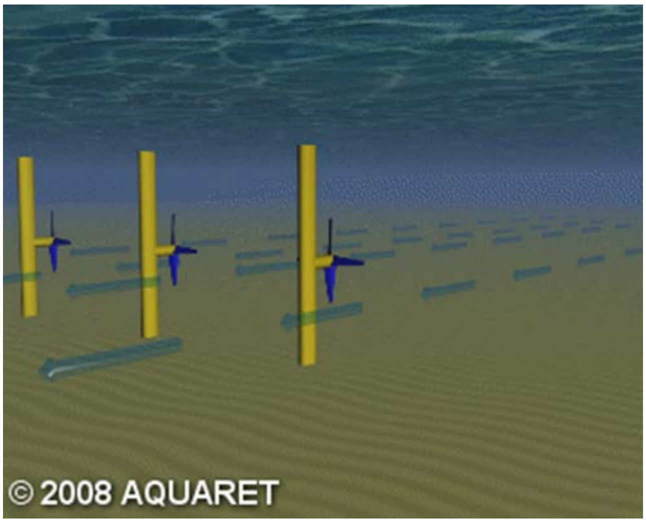


**Figure 2. Horizontal Axis Turbine TEC. Source: [http://www.aquaret.com/](http://www.aquaret.com/)**

### Vertical axis turbine

Vertical axis turbines extract energy from the tides in a similar manner to the Horizontal Axis Turbine, however the turbine is mounted on a vertical axis. The tidal stream causes the dynamic rotors to rotate around the vertical axis and generate power. The device floats on the water surface with the rotor hanging downwards and therefore there is no bottom contact with the seabed, as shown in Figure 3.

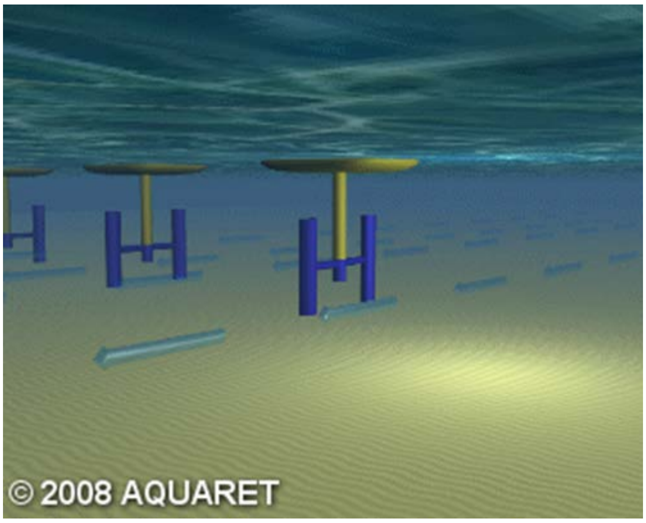


**Figure 3. Vertical axis TEC. Source: http://www.aquaret.com/**

## Oscillating hydrofoil

A hydrofoil is attached to an oscillating arm (Figure 4). The tidal current flowing either side of a wing results in lift, causing a dynamic upwards and downwards movement. This motion then drives fluid in a hydraulic system to be converted into electricity. The device is situated on the seabed by means of a fixed static base. An extension from the hydrofoil principle has been developed by the Eel Energy company who created a biomimetic undulating membrane (Drevet, 2015); the device was tested in the bay of Brest in spring 2018 with promising results (Figure 5).

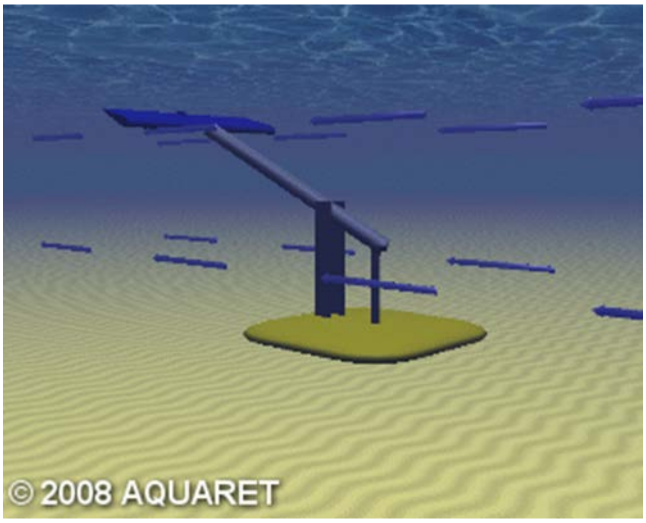


**Figure 4. Oscillating hydrofoil TEC. Source: http://www.aquaret.com/**

**Figure 5. The Eel Energy prototype of biomimetic undulating membrane for tidal energy production (scale 1/6 for a device of 2,5 by 3 m) (source: IFREMER, Eel Energy)**

### Enclosed tips (Venturi)

Venturi Effect devices are essentially a large funnel-like structure which sits submerged in the tidal current, see Figure 6. The funnel houses the device in a duct which concentrates the tidal flow passing through the turbine. The flow of water can drive a turbine directly or the induced pressure differential in the system can drive an air-turbine. The device is situated on a fixed static base with dynamic moving parts being within the duct.

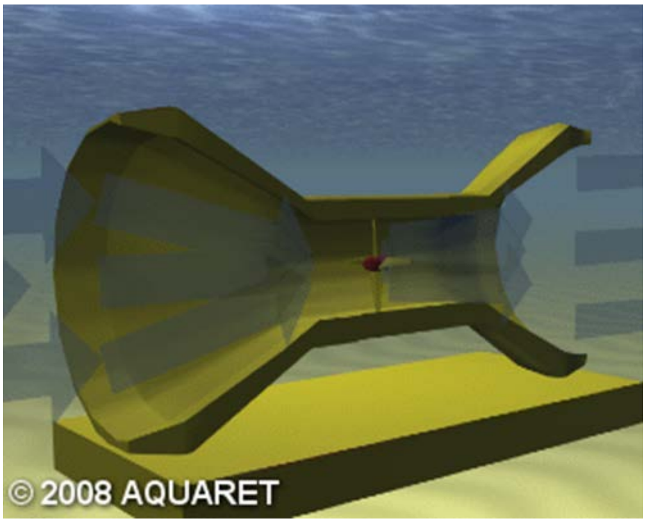


**Figure 6. Enclosed tips (Venturi) TEC. Source: [http://www.aquaret.com/](http://www.aquaret.com/)**

### Archimedes screw

The Archimedes Screw is a helical corkscrew-shaped device (a helical surface surrounding a central cylindrical shaft) (Figure 7). The device draws power from the tidal stream as the water moves up/through the spiral turning the turbines. The device is fixed to the seabed by a static base.

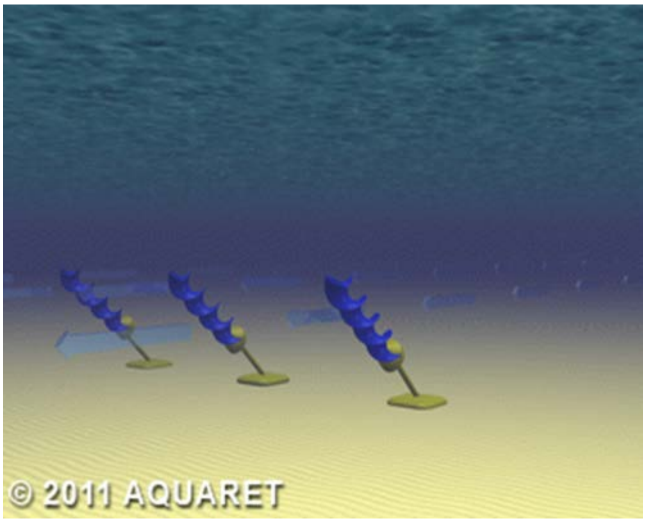


**Figure 7. Archimedes screw. Source: [http://www.aquaret.com/](http://www.aquaret.com/)**

## Tidal Kite

A tidal kite is tethered to the sea bed and carries a turbine below the wing (Figure 8). The kite 'flies' in the tidal stream, swooping in a figure-of-eight shape to increase the speed of the water flowing through the turbine.

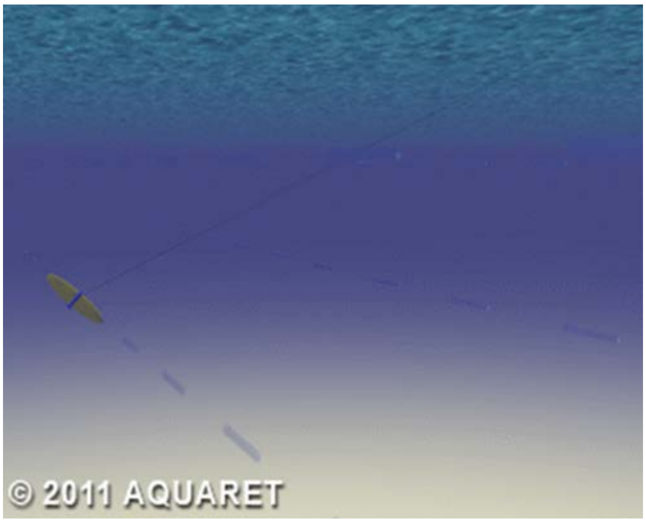


**Figure 8. Tidal kite. Source: [http://www.aquaret.com/](http://www.aquaret.com/)**

The dynamic flying motion and the length of the tether means that all parts will be constantly moving and covering a large area range. A recent example of where this technology is being tested is the concept of Deep Green, Minesto's tidal kite shown in Figure 9. Deep Green has been undergoing testing as a scale model for a number of years and the project to manufacture and commission the first commercial scale device is underway[1].

[1] [https://minesto.com/our-technology](https://minesto.com/our-technology) (Accessed February 2019)

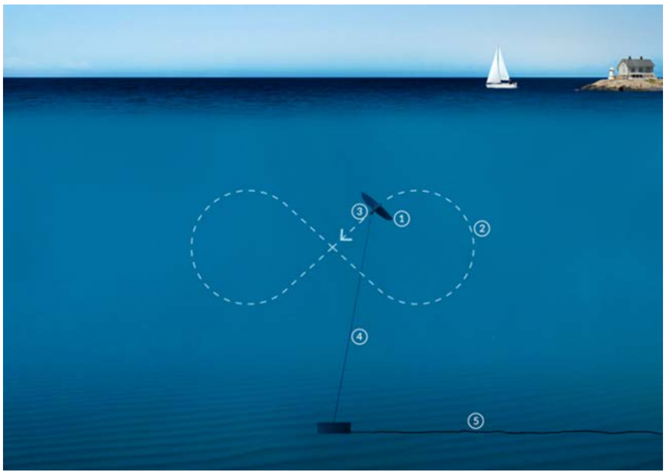


**Figure 9. Diagram showing the eight-shape trajectory flown by Minesto's Deep Green tidal kite (Minesto, 2019).**

There are several methods to fix the TEC to the seabed including:

i) Seabed mounted/gravity base

This is physically attached to the seabed or is fixed by virtue of its massive weight. In some cases, there may be additional fixing to the seabed.

ii) Pile mounted

This principle is analogous to that used to mount most large wind turbines, whereby the device is attached to a pole penetrating the ocean floor. Horizontal axis devices will often be able to yaw about this structure. This may also allow the turbine to be raised above the water level for maintenance.

iii) Floating (with three sub-divisions)

- Flexible mooring: The device is tethered via a cable/chain to the seabed allowing considerable freedom of movement. This allows a device to swing as the tidal current direction changes with the tide.
- Rigid mooring: The device is secured into position using a fixed mooring system, allowing minimal leeway.
- Floating structure: This allows several turbines to be mounted to a single platform, which can move in relation to changes in sea level.

iv) Hydrofoil inducing downforce

This device uses a number of hydrofoils mounted on a frame to induce a downforce from the tidal current flow. Provided that the ratio of surface areas is such that the downforce generated exceeds the overturning moment, then the device will remain in position.

Table 1 and 2 summarize the status of tidal devices (stream and flow) in the OSPAR countries.

Based on the knowledge available to the members of the ICES working groups WGMBRED and WGMRE, OSPAR contracting parties not present in the table have no developments of tidal devices at this time

**Table 1. Status of tidal devices-stream in the OSPAR countries**

| | | turbines | | | | hydrofoils | | | | screws | | | | kites | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Parameter | operational | Under con-struction | Licensed | Planned | operational | Under con-struction | Licensed | Planned | operational | Under con-struction | Licensed | Planned | operational | Under con-struction | Licensed | Planned |
| **Spain** | No. of devices | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Areal extent (km²) | 0.0002 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Capacity (MW) | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Belgium** | No. of devices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Areal extent (km²) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | > 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.2-1.4 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Norway** | No. of devices | 0 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | ? |
| | Areal extent (km²) | 0 | 2 | 10 | ? | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 0 |
| | Capacity (MW) | 0 | 4 | 1 | 12 | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 |
| **Netherlands** | No. of devices | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Areal extent (km²) | <0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | turbines | | | | hydrofoils | | | | screws | | | | kites | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Parameter | operational | Under con-struction | Licensed | Planned | operational | Under con-struction | Licensed | Planned | operational | Under con-struction | Licensed | Planned | operational | Under con-struction | Licensed | Planned |
| | Capacity (MW) | ~0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **UK** | No. of devices | 7 | 0 | 85 | 200+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 20 |
| | Areal extent ($km^2$) | 3.35 | 0 | 24.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.075 | 0 | 0 | 0 |
| | Capacity (MW) | 6.3 | 0 | 160.28 | 300+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 10 |
| **Ireland** | No. of devices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **France** | No. of devices | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Areal extent ($km^2$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Capacity (MW) | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 2. Status of tidal devices-flow in the OSPAR countries**

| | | barrage | | | | lagoon | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Parameter | operational | Under construction | licensed | Planned* | operational | Under construction | licensed | Planned* |
| **The Netherlands** | No. of devices | 8 | 0 | 0 | 18 | 0 | 0 | 0 | 0 |
| | Areal extent ($km^2$) | > 0.1 | 0 | 0 | > 0.1 | 0 | 0 | 0 | 0 |
| | Capacity (MW) | 1.55 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| **UK** | No. of devices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| | Areal extent ($km^2$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11.5 |
| | Capacity (MW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 320 |
| **France** | No. of devices | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Areal extent ($km^2$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Capacity | 240 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

***planned is assumed to mean that the project has formally entered the planning process and submitted documentation to the relevant regulatory authority**
**Swansea Tidal Lagoon – currently seeking funding.**

## 2.2 Wave energy

### 2.2.1 Energy resource and location

According to WEC (World Energy Council, 2010), the economically exploitable resource ranges from 140–750 TWh·yr[1] for current designs of devices when fully mature and could rise as high as 2000 TWh· yr[1], if all the potential improvements to existing devices are realized, if all the potential improvements to existing devices are realized.

Depending on the coastline's orientation towards the open ocean and the latitude, certain countries are well suited for ocean wave energy conversion, while others almost have no potential in the initial phase (Figure 9). Countries best suited for ocean wave energy conversion are the UK, Ireland, Norway, New Zealand, Southern Australia and Chile, followed by Northern Spain, France, Portugal, North American and South American coasts and South Africa.

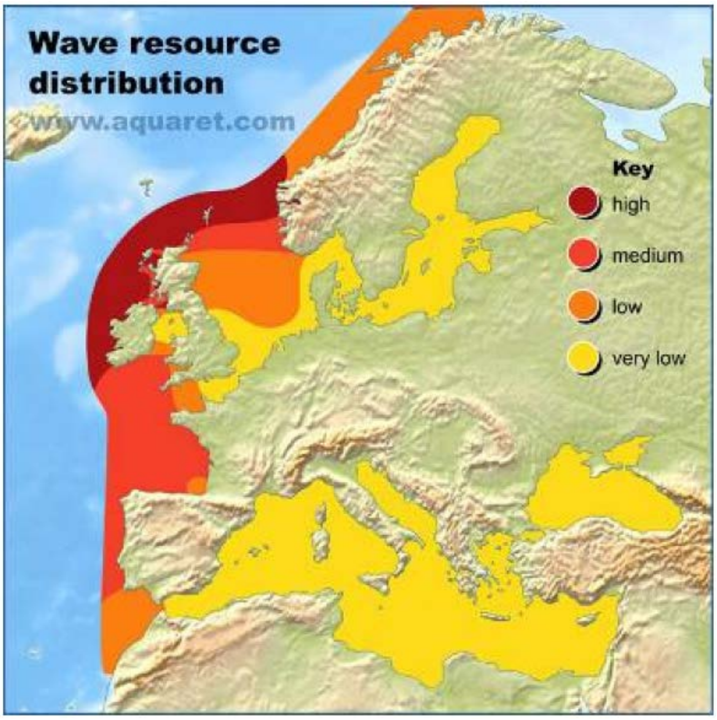


**Figure 10. Wave resource distribution in Europe. Source: www.aquaret.com.**

### 2.2.2 Wave Devices

Wave power is the capture of energy from wind and waves, giving the potential to provide a completely sustainable source of energy. This energy can be captured and converted into electricity by wave energy converter (WEC) machines. These WECs have been developed to extract energy from shoreline out to the deeper waters offshore. There were 8 main types of WEC identified:

#### Attenuator

An attenuator is a floating device which operates parallel to the wave direction and effectively rides the waves (**Error! Reference source not found.**). The device is composed of segments and the joints separating the segments generate energy by compressing hydraulic oil by means of two pistons driving a hydraulic motor and eventually an electric generator. An example of an attenuating device is Pelamis which was manufactured by Pelamis Wave Power[2]. The wave device was tested at EMEC's wave test site at Billia Croo off Orkney (see Figure 11) but the company has since gone into administration.

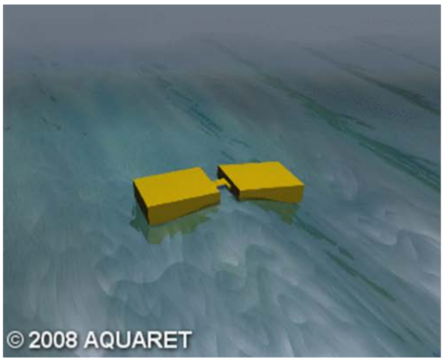



**Figure 11.Right Panel: schematic of wave attenuator. Right Panel: the Pelamis wave device at EMEC, Orkney (EMEC 2014).**

## Point absorber

A point absorber is a floating structure which absorbs energy from all directions through its movements at/near the water surface (Figure 12). It converts the motion of the buoyant top relative to the base into electrical power. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors. The device can either be mounted on a static base on the seabed and the dynamic part moves up and down on the water surface or connected to a number of subsurface components.

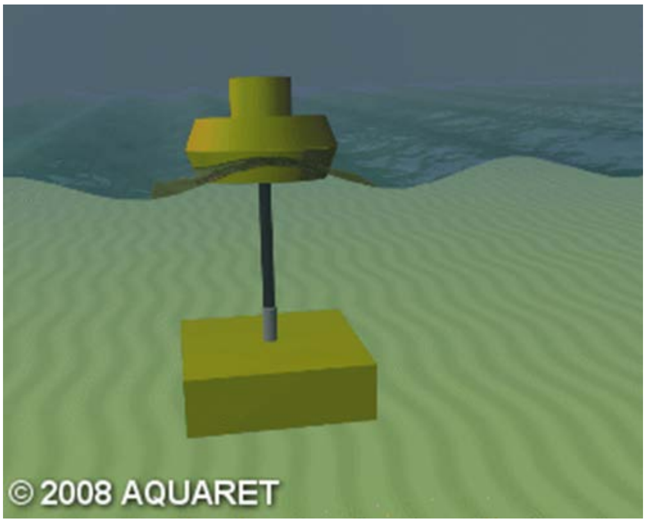


**Figure 12. Point absorber. Source: [http://www.aquaret.com/](http://www.aquaret.com/)**

---

[2] [http://www.emec.org.uk/about-us/wave-clients/pelamis-wave-power/](http://www.emec.org.uk/about-us/wave-clients/pelamis-wave-power/) (Accessed February 2019)

## Oscillating Wave Surge Converter

An oscillating wave surge converter is essentially a paddle, which rotates around a fixed static seabed mount (Figure 13). The paddle oscillates as a pendulum mounted on a pivoted joint in response to the movement of water in the waves. Energy is extracted from wave surges and the movement of water particles within them. The most commercially available Oscillating Wave Surge Converter is the Oyster device, which is manufactured by Aquamarine Power (Talpur, 2016).

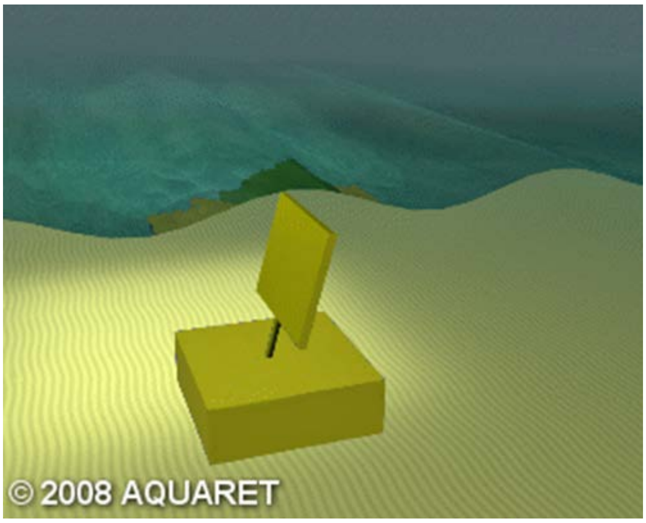


**Figure 13. Oscillating wave surge convertor. Source: http://www.aquaret.com/**

## Oscillating water column (OWC)

An oscillating water column is a partially submerged, hollow structure (Figure 14). It is open to the sea below the water line, enclosing a column of air on top of a column of water. Waves cause the water column to rise and fall, which in turn compresses and decompresses the air column. This trapped air is forced through a bi-directional turbine which rotates to generate electricity. The device is fixed to a static base on the seabed and the dynamic parts are enclosed within the device structure. The world's first OWC, called LIMPET, was installed by Voith Hydro on Islay in Scotland.

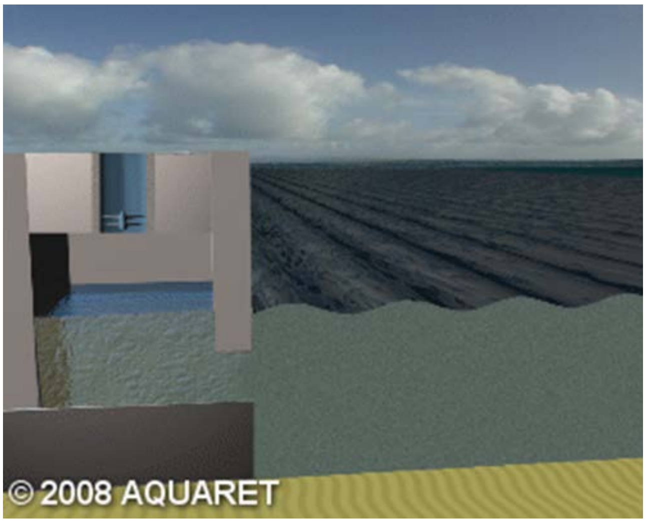


**Figure 14. Oscillating Water Column. Source: [http://www.aquaret.com/](http://www.aquaret.com/)**

## Overtopping/terminator device

Overtopping devices capture water as waves break into a storage reservoir (Figure 15). The water is then returned to the sea passing through a conventional low-head turbine which generates power. An overtopping device may use 'collectors' to concentrate the wave energy. An example of an overtopping device is the Wave Dragon by Wave Dragon.

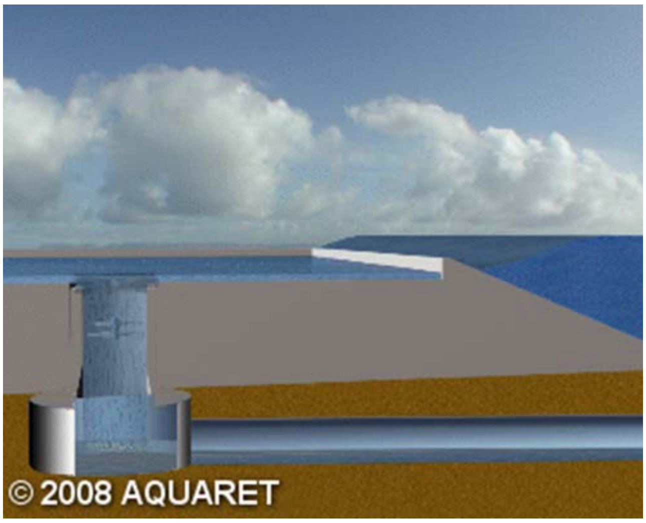


**Figure 15. Overtopping/terminator device. Source: [http://www.aquaret.com/](http://www.aquaret.com/)**

## Submerged pressure differential

Submerged pressure differential devices are typically located near shore and attached to the seabed via a static base (Figure 16). The motion of the waves causes the sea level to rise and fall above the device, inducing a pressure differential in the device. The dynamic motion is therefore the device moving upwards and downwards just below the water surface. The alternating pressure pumps fluid through a system to generate electricity. Archimedes Wave Swing, developed by AWS Ocean Energy is an example of this type of device.

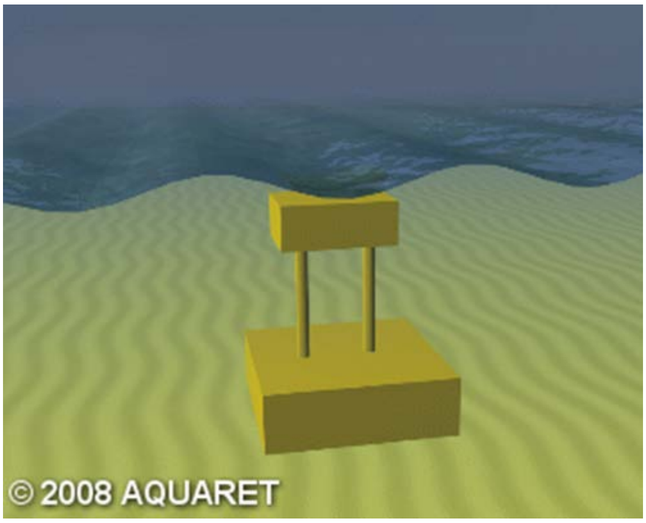


**Figure 16 Submerged pressure differential device. Source: http://www.aquaret.com/**

## Bulge wave

Bulge wave technology consists of a rubber tube filled with water, moored to the seabed heading into the waves. As the wave comes, the tube flexes with it in the same motion, rather like a snake (Figure 17). The water enters through the stern and the passing wave causes pressure variations along the length of the tube, creating a 'bulge'. As the bulge travels through the tube it grows, gathering energy which can be used to drive a standard low-head turbine located at the bow, where the water then returns to the sea. The Anaconda wave device, developed by Bulge Wave Power is an example of this type of device.

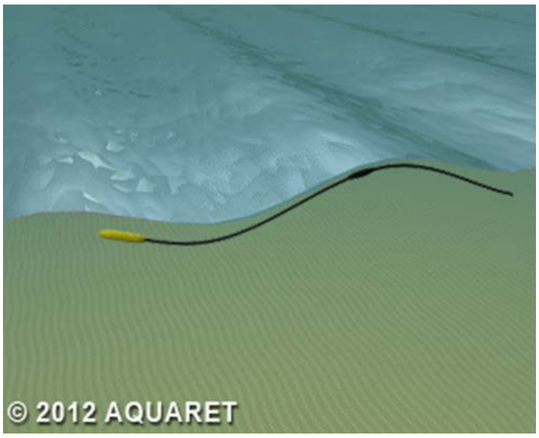


**Figure 17. Bulge wave device. Source: http://www.aquaret.com/**

## Rotating mass

Two forms of rotation are used to capture energy by the movement of the device heaving and swaying in the waves. This motion drives either an eccentric weight or a gyroscope and the movement is attached to an electric generator inside the device, creating mechanical energy. Figure 18 shows a cross section of the device floating on the water surface and moving with the motion of the waves. The dynamic rotor is fully enclosed within the inside of the device. The Penguin by Wello is an example of this type of device.

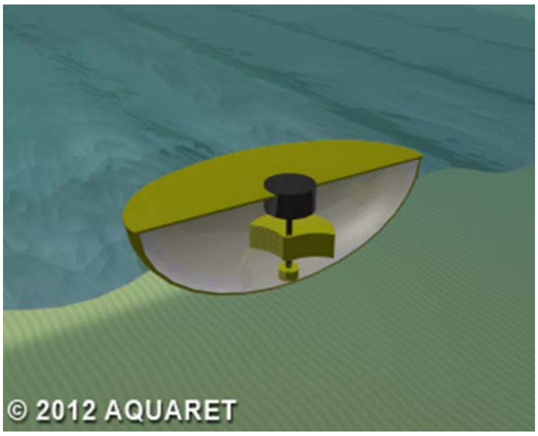


**Figure 18. Rotating mass device. Source: http://www.aquaret.com/**

Table 3 summarizes the status of wave devices in the OSPAR countries. Based on the knowledge available to the members of the ICES working groups MBRED and MRE, OSPAR contracting parties not present in the table have no developments of tidal devices at this time.

**Table 3. Status of wave devices in the OSPAR region.**

| | | **Wave: offshore** | | | | **Wave: coastal infrastructure** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Parameter | operational | Under construction | licensed | Planned | operational | Under construction | licensed | planned |
| **Belgium** | No. of devices | 0 | 1 | 7-160[3] | 0 | 0 | 0 | 0 | 0 |
| | Areal extent (km²) | 0 | 0.0004 | 16.3 | 0 | 0 | 0 | 0 | 0 |
| | Capacity (MW) | 0 | 0.005 | 5 | 0 | 0 | 0 | 0 | 0 |
| **Norway** | No. of devices | 1-2 | 2 | 1 | 2 | / | / | / | / |
| | Areal extent (km²) | 2 | 2 | 2 | TBD | / | / | / | / |
| | Capacity (MW) | <0.5 | 0.5 | 0.2 | 0.2 | / | / | / | / |
| **Spain** | No. of devices | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | Areal extent (km²) | 0,001 | 0 | 0 | 0 | 1.4 | 0 | 0 | 0 |
| | Capacity (MW) | 0.03 | 0 | 0 | 0 | 0.3 | 0 | 0 | 0 |
| **UK – test centres only** | No. of devices | Variable[4] | 0 | 0 | Variable[5] | 0 | 0 | 0 | 0 |
| | Areal extent (km²) | 112 km² | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Capacity (MW) | Variable[6] | 0 | 0 | TBC | 0 | 0 | 0 | 0 |
| **Ireland** | No. of devices | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 |

[3] The number of devices will depend on the type chosen (Wavestar C6, Poseidon P60, Weptos 350 kW, FlanSea 80 kW Wave Pioneer or Seabased were among those initially considered)
[4] Includes test sites with variable number of operational devices
[5] Depending on the type of devices selected
[6] Includes test sites with variable number of operational devices

| | | Wave: offshore | | | | Wave: coastal infrastructure | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Parameter | operational | Under construction | licensed | Planned | operational | Under construction | licensed | planned |
| | Areal extent (km²) | 0 | 0 | 0 | TBC | 0 | 0 | 0 | 0 |
| | Capacity (MW) | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| **France** | No. of devices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | No. of devices | 0 | 1 | 2 | 1 | 1 | 1 | 2 | 1 |
| **Portugal** | Areal extent (km²) | - | 0,4 | 0,52 | 1,3 | 0 | 0,0009 | 0,0028 | 0,5 |
| | Capacity (MW) | - | 0,35 | 1,05 | 5,6 | 0 | 0,35 | 1,05 | 5,6 |

## 2.3 Energy Storage Systems

The need to store renewable energy generated at sea is currently mainly associated with offshore wind farms (OWF). Energy production by these OWFs is dependent on the prevailing weather conditions, which are fluctuating daily. Hence, there is a need to adapt the stochastic power production from OWFs to the actual power demand. This can be achieved through coupling the devices generating power with energy storage systems. Today, two large types of storage technologies are suitable to manage the large electrical quantities produced from OWFs (Katsaprakakis, 2016): Pumped Storage Systems (PSS) and Compresses Air Energy Systems (CAES). Below, we describe the general principles behind these technologies, and provide some examples of marine applications of these technologies. Examples of technologies coupled with the wet renewable devices described above are not available now.

### Pumped Storage Systems

PSS are technically the most mature and economically most competitive energy storage systems for large power plants and are largely used on land (Katsaprakakis, 2016). The operating principle is based on connecting two water reservoirs situated at different altitudes in nearby locations (Katsaprakakis, 2016). When there is a surplus of energy, it is used to pump water from the lower reservoir to the reservoir at the higher location. By doing so, the energy surplus is stored as gravitational energy. When there is a demand for power, water is released from the upper reservoir to the lower reservoir, while passing through a hydro power plant, producing the necessary energy (Figure 19).

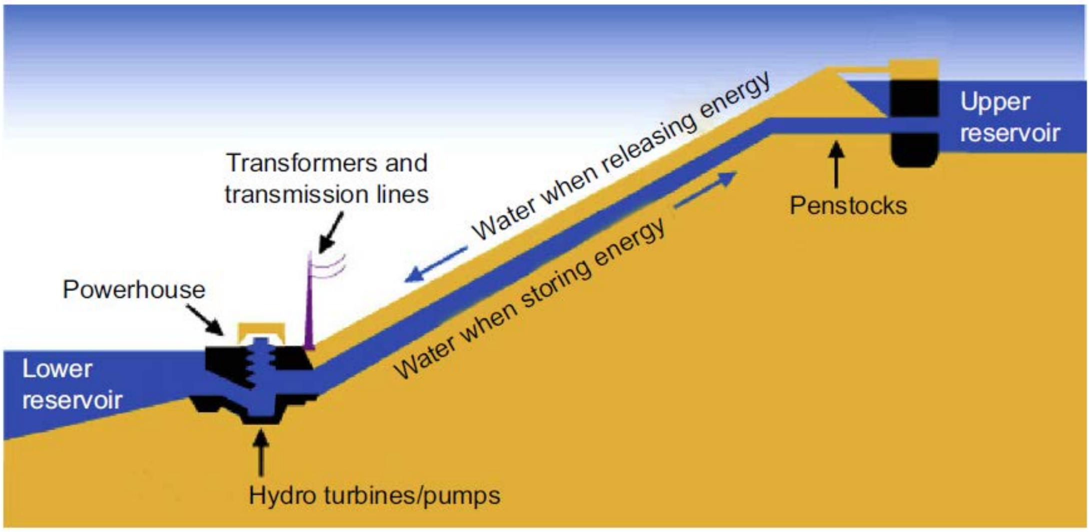


**Figure 19. Basic structure of a pumped energy storage system.**

*Seawater-pumped storage systems*

Seawater-pumped storage systems makes use of seawater in the lower reservoir. This seawater is pumped to a reservoir at a higher location. At that higher location, the risk of leaking seawater into the environment should be minimised. An examples of a seawater-pumped energy storage system is in place in the Greek island Ikaria, where the energy to pump the water to the higher reservoir is derived from land-based wind farms (Papaefthymiou, Karamanou, Papathanassiou & Papadopoulos, 2010). However, as these seawater-pumped systems need to be located close to the coast, coupling with offshore renewable energy devices would be a possibility (Katsaprakaki,s 2016); the developments of such innovations are expected within the period 2020–2050 (EIA, 2012). To the best of our knowledge, a seawater-pumped storage system connected with offshore renewable energy devices is not in place yet. Other seawater-pumped storage systems include the so-called 'energy atolls' or 'energy islands' (Figure 20).

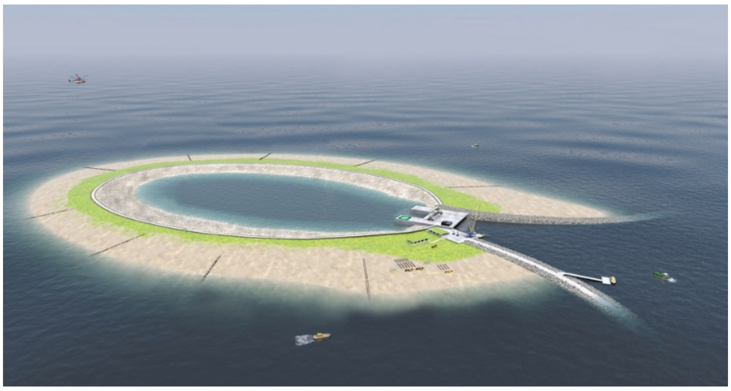

**Figure 20. Render of an energy island (https://www.iland-energystorage.be)**

When there is an energy surplus, the energy can be used to pump the seawater out of the central area of the artificial island to lower the water level there below the level of the surrounding sea. When the energy demand exceeds energy production, seawater can enter the central area while passing through a hydropower installation (EIA, 2012). A request for a license for such an energy island off the Belgian coast was submitted in 2014 and the first Belgian Marine Spatial Plan (2014–2020) included a location for this project. Due to local opposition the application was withdrawn in 2015.

*Derived concepts*

Buoyant Energy is another offshore energy storage solution, which is largely based on the principles of the seawater-pumped energy storage systems (Klar, Steidl, Sant, Aufleger & Farrugia 2017). In contrast to the earlier described seawater-pumped energy storage systems, buoyant energy makes use of a smaller reservoir (the inside space of a floating structure) inside a larger reservoir (the surrounding sea) (Figure 21).

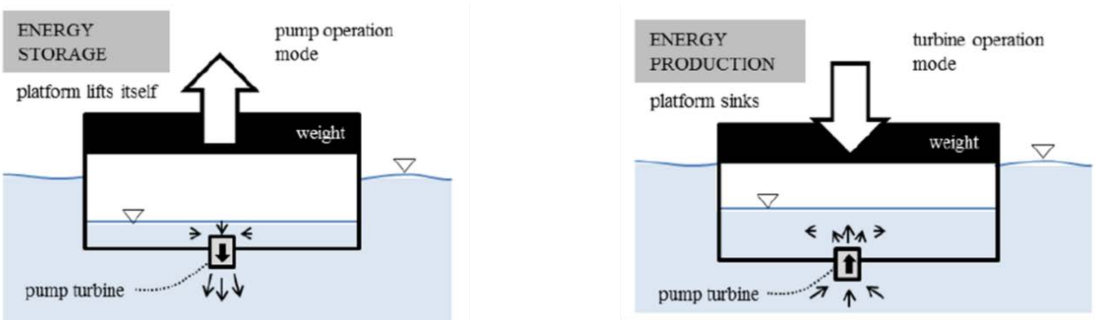


**Figure 21. Basic concept of buoyance energy storage system. Left panel: energy storage. Right panel: energy production (Klar *et al.*, 2017).**

A pump is installed in the lower part of the floating structure and used to pump water from the central space to the surrounding ocean. The surplus on energy is used for this process. As the volume of water inside the structure decreases, it will become more buoyant and it will move up. When power generation is needed, the surrounding seawater is allowed to enter the structure and drives a power generating turbine that is integrated in the lower part of the structure as well. Klar *et al*. (2017) suggest that these structures can be located in between offshore wind turbines or integrated in the design of floating wind farms. To date, there is no information about buoyant energy storage systems being in place in the marine environment.

Building on the concept of buoyance energy storage systems, (Klar, Steidl & Aufleger, 2018) introduced the concept of the "light" buoyance energy storage systems. They are largely similar to the buoyance energy storage systems but constructed out of light construction material (waterproof fabric), which can result in reduced investment costs. In contrast to the buoyancy energy storage device, the water level inside the floating structure is above the level of the surrounding sea (Figure 19).

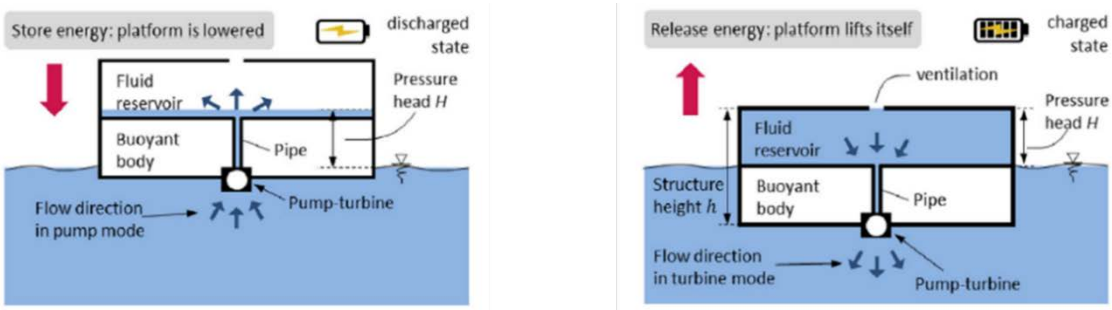


**Figure 22 "Light" buoyancy energy storage system. Left panel: energy storage. Right panel: energy production (Klar *et al.*, 2018).**

To store energy, water is actively pumped into the central device, thereby increasing its weight and lowering the platform into the water. In this way, electric energy needed for pumping is converted to potential energy. To generate electricity, the water is allowed to flow back to the surrounding sea through a turbine integrated in the lower part of the structure. Thereby, the stored potential energy can be converted back to electric energy. As clearly stated in Klar *et al*. (2018), the design is still conceptional and has never been tested in realistic scenarios. (Slocum, Fennell, Dundar, Hodder, Meredith & Sager, 2013).

The Ocean Renewable Energy System (ORES) builds on similar principle, but is located on the seabed or could act as mooring systems for floating wind farms or can be connect to any type of renewable energy device (Slocum *et al.*, 2013). In short, spheres are mounted on the seafloor, excess power is used to pump water out of the spheres. As the spheres are located at the seafloor, the hydrostatic pressure can be used to allow the water to flow back in through a turbine to generate electricity (Figure 23). According to Slocum *et al*. (2013), deployment depth should be > 200 m which limits the application of these devices to deep-water marine renewable energy devices such as floating wind farms.

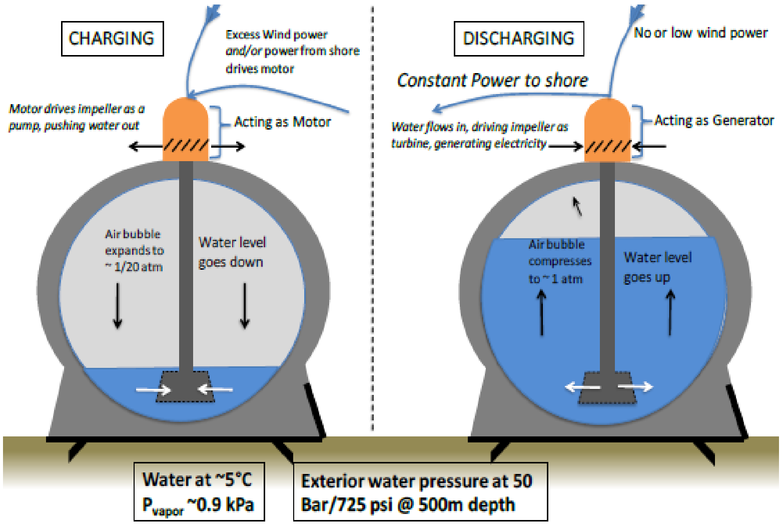


**Figure 23. Internal view of the bottom-mounted ORES concept (Slocum *et al.*, 2013)**

## Compressed Air Energy Storage Systems

Compressed Air Energy Storage Systems (CAESs) are based upon compression of air to high pressures using surplus energy, expansion of the compressed air flowing over the turbine generates electricity when needed (Katsaprakakis, 2016). Underwater CAESs takes the advantage of the hydrostatic pressure associated with water depth. Two categories of underwater storage vessels have been considered to date: rigid vessels (e.g. submerged caissons anchored to the seabed), and cable-reinforced fabric bags anchored to the seabed, known as Energy Bags (Figure 23, Pimm *et al.*, 2014). For both device types, there is the need to have a connection with a land-based or floating facility to connect with compression and expansion machinery. Proposals for deployment and testing of rigid vessels have been put forward in California. Energy bags have been tested both in the lab and offshore at the 25 m deep European Marine Energy Centre (EMEC) off the coast of Orkney and are currently being tested in Lake Ontario. In addition, a modeling study (Sheng *et al.*, 2017) investigates the use of underwater CAESs to store energy generated by a tidal turbine farm to support an isolated island, disconnected from a main grid. However, there is no evidence that underwater CAESSs are active at the moment in the marine environment.

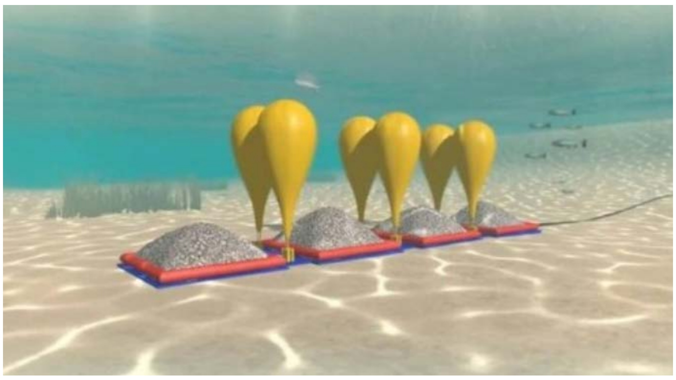

**Figure 23. Visualisation of Energy Bag type of underwater CAESs (source: Greentech Media)**

Apart from storing energy, there is increasing interest in the 'power to molecules' pathway where electrical power is converted to hydrogen gas using electrolysis (World Energy Council Netherlands, 2017). Hydrogen gas can be stored and transported. It can be used as fuel or combined with $CO_2$ and converted into methane or liquid fuels. Conversion of power to hydrogen gas can be done onshore or offshore. Offshore conversion can be done on retired oil and gas platforms, but on the long term it is expected that this conversion will take place at large "artificial islands". In that case, cables will always be needed to transport electricity to the users on the main land.

# 3 The future prospects

## 3.1 Tidal Devices

Across the OSPAR region tidal energy development is again moving forward following recent industry setbacks relating to withdrawal of investment and dissolution of tidal energy companies. A total of 43 MW of tidal energy (stream and flow) is now operational across the OSPAR area, with more than 320 MW under construction, consented or in planning phases (see tables 1, 2).

### 3.1.1 In-Stream Tidal Energy

The UK has the greatest level of deployment of tidal energy, at test centres in Scotland (EMEC), and Wales, and at commercial sites are under development in Scotland (Meygen + Nova). At EMEC, Orbital Marine's (formerly ScotPowerRenewables) SR2000 generated 3 GWh in 2018, while Spanish company Magallanes Renovables tested their 2 MW floating tidal energy platform. Two commercial arrays have also been deployed at different scales: the Nova Innovations array at Bluemull Sound Shetland, aimed at community-scale energy generation; and the SIMEC Atlantic Meygen Array (4 MW) in the Pentland Firth, aimed at national-grid scale generation. Both schemes are undertaking work to extend their capacity in 2019 and 2020.

In France, in-stream tidal energy developments are also progressing in France, where the Sabella D10 turbine (1 MW) was re-installed and grid-connected at the Ushant Islands in 2018 for a further three years.

Belgian developments focus predominantly on low-flow devices.

### 3.1.2 Tidal energy barrages and lagoons

Within the OSPAR area, tidal energy barrages have tended to exist as part of historical barrage developments, for example at la Rance in France (240 MW), and more recently as part of flood protection infrastructure in the Netherlands (1.55 MW). While new tidal-energy specific barrages are unlikely to be constructed in the OSPAR region because of environmental impact concerns, tidal turbine installation in existing infrastructure continues to be attractive.

Tidal lagoon technology has not progressed following the withdrawn of UK government support for the Swansea Bay tidal lagoon in Swansea, Wales. The developer continues to seek support from private investors.

## 3.2 Wave devices

Wave energy developments have not reached the same level of commercial deployment across the OSPAR region as has been achieved by tidal energy technologies. The majority of offshore technologies are test devices being trialed at the region's many test centres, although coastline infrastructure (fixed) wave energy plants are now exporting electricity to the Spanish grid.

### 3.2.1 Coastal infrastructure wave energy devices

The Mutriku wave energy plant in Spain is currently the only commercial, grid-connected wave energy plant within the OSPAR region. It was connected to the grid in 2011, and is owned by Ente Vasco de la Energia (the Basque energy agency). The Mutriku plant has a 300 kW generating capacity and consists of 16 turbines housed in a breakwater at the port of Mutriku.

A previous 250 kW coastal oscillating water column plant on the Island of Islay, Scotland, was decommissioned between 2012 and 2018.

### 3.2.2 Nearshore fixed and floating wave energy devices

To date, there are no operational commercial-scale nearshore fixed and floating wave energy developments within the OSPAR region. There are planned sites for commercial development although to date no commercial licenses to operate have been issued. Two previous projects which were given consent to deploy approximately 90 wave energy devices along the west coast of the Scottish Outer Hebrides have now been cancelled, following the collapse of device developers Pelamis and Aquamarine power. The intellectual property from these commercial scale devices has now been taken up by Wave Energy Scotland, a publicly funded organisation designed to support the commercialisation of wave energy technology.

In Sweden, 36 wave energy devices (50 kW) were installed at the Sotenäs Wave Energy Park by Seabased, however the company took the decision not to pursue further development in 2017, and no buoys are currently attached to the installed foundations.

### 3.2.3 Test sites

Companies from across the OSPAR region continue to test their wave energy technologies at the European Marine Energy Centre (EMEC). Finnish company Wello Oy has deployed their 500 kW Penguin device at EMEC since 2011, and is set to deploy a second device as part of the European Horizon 2020 funded CEFOW project. Other wave energy developers with devices deployed at or soon to be deployed at EMEC include the Swedish CorPower Ocean and Belgian company Laminaria.

The Spanish marine energy test site BiMEP (Biscay Marine Energy Platform) has also also added new facilities to support the development of commercially viable technologies. These include the Marine Corrosion Test Site "El Bocal", a new offshore facility to test materials called HARSH-LAB, and off-grid wave buoy testing at PLOCAN and Punta Langosteira Test Site (a new test site at the Galician coast). BIMEP hosts the MARMOK-A-5 device, the first floating wave energy device connected to the grid in Spain. The Basque company Oceantec Energías Marinas, promoted by TECNALIA and Iberdrola, has recently deployed its first Wave Energy Converter (WEC) at BiMEP, and ARRECIFE plans to test its first AT-0 1:2 scale prototype in BiMEP during the summer of 2019 (Figure 24a, b)

The Oceanic Platform of the Canary Islands (PLOCAN), located on the island of Gran Canaria is a marine test site for ocean energy converters prototypes, with an initial site capacity of 15 MW, planned to be extended to 50 MW by 2020. The installation of two submarine cables (5 MW/13,2 kV) started in 2017 and were commissioned during 2018. There are expected to be grid connected in 2019.


**Figure 24a. MARMOK-A-5 device deployed by IDOM at BIMEP after refitting with OPERA innovations.**

**Figure 24b. HarshLab deployed by TECNALIA at BIMEP during an inspection**

In France, the SEM-REV test site is located off the mouth of the Loire river on the Atlantic coast, it is part of the research infrastructure THeoREM (Ifremer and Centrale Nantes). It is hosting a prototype of autonomous powering platform, the WAVEGEM© developed by GEPS TECHNO (Figure 25); the testing started at the beginning of 2019 for an 18-month period. The platform is powered by a wave energy converter with a maximum capacity of 1MW. The SEM-REV is also hosting a number of environmental monitoring buoys looking at wind and waves, and at biological compartments, as well as the first French floating wind turbine. In the Mediterranean area, the new MISTRAL test site is located off the industrial harbour of Fos-sur-mer. While no wave energy devices have been deployed there, research programs for environmental monitoring of MRE are ongoing since 2018.

**Figure 25. the WAVEGEM© prototype at its transfer from Saint Nazaire harbour to SEM-REV test site (source: https://www.geps-techno.com/wavegem/)**

In the Nordic countries, swedish company Waves4Power has deployed their device as part of the WavEL project at Runde, Norway.

Other wave energy test sites in the OSPAR Region include the Atlantic Marine Energy Test Site in Ireland (AMETS, currently no device deployments); Wave Hub (currently no device deployments) in Falmouth and Pembrokeshore, UK; FabTest (currently no device deployments) in Falmouth, UK.

## 3.3 Outlook

The large number of developments in planning stages across ICES countries reported suggests that there is a strong industry-led potential for increasing developments into the future. However, it should be noted that a large number of applications have been withdrawn due to financial or logistical limitations, so the potential is likely not being met.

Opportunities for future developments:

- New developments in MSP DSTs
- Projects dealing with the environmental impact of marine renewables will reduce the uncertainty about these impacts or at least increase the knowledge about them.
- EU renewable energy targets
- Non-grid connected systems for offshore energy provision to multi-use systems, for example offshore aquaculture or metocean buoys
- Microgrid supply in remote and/or developing regions

Barriers:

There are still several barriers to overcome. Ocean energy needs to demonstrate the ability to improve on efficiency, reliability and feasibility to be considered as a potential contributor to the future energy mix supply. Similarly, there is a need for a stable legal framework and proactive policy to push forward the development of the sector. Further barriers include:

- Uncertainties about environmental impacts of marine renewables.
- Inconsistent consenting processes.
- Site selection and places for new developments.
- Investment conditions & finance

# 4 Potential changes to the environment

The potential changes to the biotic and abiotic factors are summarized in Table 4. For each receptor, the knowledge base supporting the statements in Table 4 is provided below. Within this section, we describe how MREDs can cause changes in the environment, there is no judgement whether this change is considered 'positive' or 'negative'. A 'positive" effect for one component can lead to 'negative' effects for another component.

**Table 4. Potential interactions between stressors associates with renewable energy devices and biotic and abiotic receptors.**

| | Stressors | | | | | |
|---|---|---|---|---|---|---|
| **Biotic and abiotic receptors** | **Static component** | **Dynamic component** | **Cables** | **Sound** | **Energy removal** | **Contaminants** |
| **Hydrodynamics** | Acceleration of flow around structure and potential for vortex shedding and increased turbulence downstream. Surface waves could break or be attenuated if component is close to the water surface. | Turbine blades will form turbulent wakes. | Very localised and small flow disturbance (acceleration) close to seabed cables. | N/A | Removal of energy from the tidal stream will alter near-field tidal dynamics and large tidal farms could lead to far-field changes. Such large-scale changes could lead to changes to the extent of vertical mixing and stratification in shelf seas. Removal of surface wave energy will reduce wave heights downstream of the development in the near-field and could change the wave field at the shoreline. | N/A |
| **Physical seabed and sediment transport** | Acceleration of flow around structure could lead to localised scour of bed sediments. These sediments will be transported by currents and deposited elsewhere. | Any increase in bed shear stress due to enhanced turbulence may entrain bed sediments. | Seabed cables are most likely to be buried but if they have a seabed presence then localised scour of bed sediments could occur. | N/A | Reduction in near bed shear stresses, due to either tidal or wave energy removal, could lead to increased sediment deposition.<br>Any far field changes to near bed shear stresses could lead to changes in sediment transport pathways. | Contaminants could get trapped in marine sediments and follow established sediment transport pathways. |
| **Benthos** | Changes in seabed habitat<br><br>Exclusion of fisheries<br><br>Biofouling and Artificial reefs<br><br>Non-native species<br><br>Sediment resuspension | Hydrological changes<br><br>Non-native species | Installation of cables<br><br>Sediment resuspension<br><br>Emission of EMF<br><br>Emission of heat<br><br>Emission of sound<br><br>Potential for biofouling and creation of shelter / artificial reef<br><br>Colonisation by non-native species | Impacts of sound pressure and particle motion from construction, operational and decommissioning stages on benthic invertebrates | Impacts of wave energy removal<br><br>Impacts of removal of tidal energy removal | Effects of contaminants on benthic invertebrates from the devices and cables |

| | Stressors | | | | | |
|---|---|---|---|---|---|---|
| **Biotic and abiotic receptors** | **Static component** | **Dynamic component** | **Cables** | **Sound** | **Energy removal** | **Contaminants** |
| **Fish** | Fish aggregation: potential links to predation<br><br>Fisheries: both benefits and disbenefits | Fish strike: of particular concern for large or migratory fish species. | EMF emissions: barrier effects. Largely mitigated by burial of cables although tidal turbines may generate detectable EMF and cables through the water column will not be mitigated via burial. | Underwater sound: both sound pressure and particle motion. Potential for physical or behavioural effects on marine fish species | May contribute to fish aggregation effects listen under static component | |
| **Marine mammals** | Changes in marine mammal behaviour; may act as aggregation devices<br><br>Barrier to movement (a real or perceived obstacle to normal movement of sea life during migration or day to day activities), and displacement of activities such as feeding, mating, rearing, or resting habitats<br><br>entanglement and collision with cables and mooring lines | Collision risk is the primary environmental concern.<br><br>Other considerations are potential displacement and/or barrier effects. | No perceived impact | Construction phase: Potential for disturbance, and for physiological injury (i.e. Temporary or Permanent Threshold Shifts (TTS/PTS) in hearing), depending on activities.<br><br>Operational Phase: Potential for disturbance, masking of biologically important sounds (e.g. echolocation in cetaceans).<br>Other considerations across both phases is potential displacement and/or barrier effects. | No perceived impact | No perceived impact |
| **Birds** | Above surface structures, potential for attraction in some species (use for roosting) or displacement in others.<br>Potential for collision above (birds in flight) and below water (diving birds) and displacement. | Collision risk for parts moving at speed. | Possible collision risk for diving species. EMF not likely to be a significant risk. | Very little known in birds, potential for disturbance and injury. | Ecosystem impacts may change prey species abundance and distribution leading to changes in bird foraging behaviour. | |

| | Stressors | | | | | |
|---|---|---|---|---|---|---|
| **Biotic and abiotic receptors** | **Static component** | **Dynamic component** | **Cables** | **Sound** | **Energy removal** | **Contaminants** |
| **Seascape/public perception** | Visual disturbance from devices above the sea surface. Both visible from shore and perceived. Concerns about loss of access to area. | Visual disturbance from devices above the sea surface. Both visible from shore and perceived<br>Some concerns about collision risk to megafauna | Planning objections to onshore sub-stations, and cable landing point. | N/A during operation. Possible concerns over construction noise and infrastructure (vessel traffic etc.) | Objections from leisure users e.g. surfers – Wave Hub | No perception |
| **Others :**<br>**Bats**<br>**Otters**<br>**Sea Turtles** | Possible change in **turtle** behaviour; exclusion/attraction to new habitat<br><br>**Otters:** unknown | **Turtles**: Possible collision risk with moving parts; exclusion/advoidance of new habitat<br><br>**Otters**: unknown | EMF may disorienate **turtle** navigation; exclusion/avoidance;<br>Entanglement<br><br>**Otters:** Unkown | May change **turtle** behaviour;<br><br>**Otters:** Unkown | ecosystem impacts may result in changes to **turtle** behaviour<br><br>**Otters:** Unkown | |

All of them have common aspects that are subject to act as **stressors** (action of the project that can generate impacts) over different **receptors** (environmental factors that can be affected by the project actions) of the marine environment.

## 4.1 Hydrodynamics

Hydrodynamics include waves and currents and how they interact together and with the bathymetry and structures in the marine environment. The two predominant wet marine renewable energies being exploited to date are tidal and wave energy, each of which directly remove energy from the tidal current and wave fields, respectively. Any disturbance to the hydrodynamics may alter the levels of mixing within a region. This could have an effect on the local density structure including the levels of stratification. The two predominant processes reviewed here are tides and surface waves. Tidal processes include the range, speed and phase of the tide and it is likely that tidal energy developments will impact these processes to some extent, as tidal energy is being directly removed. Surface waves will be altered to an extent by any offshore structure with a near surface presence through wave breaking, shoaling, reflection, refraction, and/or diffraction. Wave energy converters are likely to have a large near-field effect on the wave field as energy will be removed from the wave field.

It is important to consider how hydrodynamic processes may change as a result of wet renewables because (i) they include the underlying renewable energy resource, and (ii) they control a whole range of physical and ecological processes and therefore can act as pathways of wider ecological change.

There are a variety of ways to measure hydrodynamic processes in the marine environment, from in situ instrumentation on moorings or vessels, to remote sensing from land or space. However, small developments are only likely to lead to very small localized changes to the hydrodynamics. Large scale developments are more likely to lead to far field changes, and since there are no large developments it is impossible to measure the magnitude to change. For this reason, numerical modelling of the hydrodynamics is an extremely useful tool for understanding the impact of larger scale developments.

The static component of a wet marine renewable energy development refers to the foundation structures in most cases. For this reason, there is a lot of overlap with literature on the foundations of offshore wind farms. When a foundation is placed on the seabed, the hydrodynamic field will experience local accelerations around the structure (Whitehouse *et al*., 2011) as well as decelerations downstream and immediately in front of the structure (Rivier *et al*., 2017). Such changes to the hydrodynamics can lead to scour of the marine sediments (Whitehouse *et al*., 2011). The dynamic components of a horizontal axis tidal turbine are the turbine blades which extract energy from the flow. This leads to a downstream wake where the flow speed is significantly reduced.

### 4.1.1 Energy Removal

Tidal energy developments directly remove energy from the tide and will therefore alter tidal processes to some extent. Qualitatively, tidal currents will be slowed down by tidal stream devices and there may be some acceleration in the flow around devices/arrays. A head drop in tidal water level may also be experienced across tidal stream devices and arrays. Tidal range developments, including barrages and lagoons, will change the range of the tide to some extent, especially in within the barraged region, but may also change the phase and timings of the tide. The tides within the barraged region will be disrupted leading to changes to the timings and range of the tide, and this could have significant impacts on the intertidal habitat within the barraged region (Wolf *et al*., 2009). Tidal lagoons would change the tide in a similar manner to tidal barrages but are potentially orders of magnitude smaller in size and power output. Lagoons therefor have the potential to have far less impact on hydrodynamics and tides than tidal barrages. However, a large number of lagoons within a region could have a significant cumulative impact on the tides.

Wolf *et al*. (2009) modelled potential barrage schemes in the eastern Irish Sea and predicted that such large-scale schemes could lead to a significant change in tidal range along the Irish coastline. They also found that the Bristol Channel bed shear stress would be reduced, and that the intertidal area behind a barrage is significantly reduced.

Initial studies of tidal processes in tidal sites focused on quantifying the available tidal resource, both tidal range (e.g. Burrows *et al*., 2009) and tidal stream (Black & Veatch, 2005; e.g. Blunden & Bahaj, 2007; Bryden *et al*., 2007). Much early work on tidal stream energy focused on the simplistic scenario of an idealized channel modelled using one-dimensional analytical models (Garrett & Cummins, 2005; Bryden & Couch, 2007). This work showed that tidal channels typically have limited available resource. Whilst the extractable power at first increases with the number of free stream turbines, it eventually plateaus out and decreases once the maximum extractable power for the channel has been reached. Tidal stream turbines in idealised channels have also been modelled using more sophisticated hydrodynamic models, modelling the flow in either two or three dimensions (e.g. Walkington & Burrows, 2009; Yang *et al*., 2013). Such idealised models predict a redistribution of flow speeds within the channel, which decreases in the immediate vicinity of the tidal turbines and increases around the turbines.

Since these early resource and impact assessments, more sophisticated regional hydrodynamic models have been developed for many sites of particular interest, such as the Pentland Firth and Orkney Waters, Scotland (e.g. Easton *et al*., 2012; Adcock *et al*., 2013; O'Hara Murray & Gallego 2017). These models can resolve in detail the complex hydrodynamic conditions around many tidal stream sites, enabling much more realistic resource assessments to be conducted. These models can now represent the energy extraction of tidal stream turbines and other feedbacks of such devices on the tidal flow (e.g. Yang *et al*., 2013; Roc *et al*. 2013). This not only improves the resource assessment and array design, but also allows the impact of tidal stream developments on the tidal stream, and potentially other physical processes, to be investigated. Due to the lack of development and the challenges of making measurements in and around tidal stream sites, hydrodynamic modelling has to date provided the most insight into how large (commercial) scale tidal developments could change the physical marine environment. Shapiro (2011) modelled a large tidal stream farm in the eastern Celtic Sea and found there to be large scale changes in current speed. The highest magnitude changes were confined to around 20 km from the tidal farm, but there were changes to the residual circulation observed up to 100 km away. O'Hara Murray and Gallego (2017) examined how large developments in the Pentland Firth could impact tidal processes and transport in the region. It was found that smaller developments, totalling around 1 GW mean extracted power, are unlikely to lead to significant changes in the physical marine environment, whereas larger developments, > 1.5 GW mean extracted power, could change the transport by 10% or more. It was also found that the amount of change, and where it occurs, is dependent on array layout, including the vertical positioning of tidal stream turbines. De Dominicis *et al*. (2017) modelled a large tidal stream farm in the Pentland Firth and investigated the far-field physical impacts. Far field changes to the tidal range and currents were predicted, with changes of around 1 cm in range and 0.25 cm/s in current speed down the east coast of the UK. Far field changes in stratification were also predicted, meaning that some tidal mixing fronts in the North Sea may be shifted.

Spectral wave models have been used to explore the impact of wave energy converters (WEC) and arrays on the wave field. Early studies represented arrays as partially transmitting barriers.

Millar *et al*. (2007) modelled the Wave Hub site 20 km off the Cornish coast in the UK, with the wave farm represented as a 90% transmitting barrier. They found that the significant wave height at the shoreline was reduced by an average of 1 cm (< 1%). Later studies developed more sophisticated ways of representing WECs in spectral wave models, by making the transmission coefficient wave frequency dependent (e.g. Smith *et al*., 2012). This is more realistic as WECs are likely to remove more energy from specific frequencies than others. Rusu *et al*. (2013) modelled Pelamis wave attenuator devices approximately 15 km off the Portuguese coastline using a spectral wave model. They explored two scenarios with a total of 5 and 10 devices in 1 and 2 rows, respectively. Immediately down wave of the devices, the two scenarios produced decreases of around 10% and 20%, respectively, and the shadow zone for the second scenario (10 devices) was larger than the first. At the shoreline, the two scenarios decreased the significant wave height by around 2–3% and 5%, respectively. It was also found that the shape of the nearshore waves was modified, as well as the wave induced longshore currents. These studies showed that small arrays of WECs, 15–20 km offshore, are likely to only lead to a shoreline change of a few percent. More recently, Venugopal at al. (2017) modelled much larger arrays of wave attenuators and wave surge converters off the west coast of Orkney, northern Scotland, in order to investigate the cumulative impact on the wave climate. The changes to the wave field were significant in some cases, with up to 1 m change in significant wave height. This change did reduce with distance from the array, as diffracted wave energy propagated into the lee of the arrays.

## 4.2 Physical seabed and sediment transport

This section considers how the physical seabed and sediment transport pathways could change as a result of wet renewable energy developments. Changes to the natural sediment transport patters could lead to changes to net deposition and erosion of coastlines and offshore sand banks as well as larger scale bathymetry and geomorphological changes. Sediment transport occurs via a variety of mechanisms but can be broadly split into bedload and suspended load. Changes to shear stress at the bed may result in changes to net (bedload) migration of sediment at the bed, but also the amount of sediment re-suspended. Wet renewable energy developments in sediment rich areas are most likely to have some impact on the near-field sediment dynamics, such as scour around foundation structures. However, large tidal stream and tidal range developments are likely to cause far-field changes to the flow field and bed shear stresses, which could influence far-field sediment transport pathways. The bed shear stress has a quadratic dependence on the flow speed so even a small change in slow speeds could lead to a significant change in net erosion and sediment transport.

The surficial seabed sediments present on the European continental shelf vary spatially in character and thickness. Much of the sediment on the UK continental shelf is the product of the erosion during the last glacial maximum. The transport of these sediments is controlled by currents and waves, and the initial mobilization of sediment into the water column is controlled by the local level of shear stress imposed on the seabed by these hydrodynamic forces. Once sediment is mobilized, it can be transported, and tends to be deposited where the local water velocity reduces, meaning the shear stress at the bed is no longer sufficient to pick-up sediment of that grain size. This way, sediment, in time, can become sorted into a dynamic state of equilibrium where smaller grain sizes are found in areas of low energy, and larger grain sizes are found in areas of high energy.

Static components, such as foundation structures, moorings and anchors, are likely to lead to the scouring of bed sediments, due to the local increase in the hydrodynamic field around the structure which can result in flow separation and the generation of turbulent vortices. Scour around marine structures has been well studied as it can lead to important engineering issues. Often scour protection is used, by placing objects such as rocks around foundation structures. Such interventions, whilst solving the engineering issue, can lead to secondary scour around the scour protection (CEFAS 2006).

The change in hydrodynamics resulting from the dynamic component of a tidal stream turbine could alter the erosion and deposition of sediment in the proximity of devices. Tidal turbines are likely to increase turbulence close to the bed, and also increase flow speeds around the device(s), leading to enhanced bed shear stresses and sediment entrainment. However, the decrease in speeds within the wake of turbines could create a region that favours the deposition of sediment and could lead to long term accumulation of coarse sediments within tidal stream farms (Martin-Short *et al*., 2015). Most tidal stream sites are likely to be extremely dynamic and when bed sediments are present there is likely to be significant natural sediment entrainment during the tidal cycle. For this reason, the far-field impacts on sediments due to the removal of tidal stream energy are likely to have more of an impact on regional sediment transport.

Seabed cables are most likely to be buried but if they have a seabed presence then localised scour of bed sediments could occur (Taormina *et al*., 2018). Strong tidal stream sites may have little or no seabed sediments, and in these cases, cables are often run along natural features in the bedrock in order to offer then some protection.

### 4.2.1 Energy Removal

Neill et el. (2009) used a one-dimensional numerical model of the Bristol Channel to study the impact of tidal stream turbines on large scale sediment dynamics. They demonstrated that removing a relatively small amount of energy from the tidal system can lead to significant impact on sediment dynamics. This is because tidal asymmetry can play an important role in sediment transport in estuaries, with sediment being entrained at peak flow and settling at lower flows. Any difference in the timing and magnitude between the peak and ebb peak flows can lead to significant net sediment transport. Any disturbance to the asymmetry, due to energy removal, can therefore change net sediment transport. Neill at al. showed that in the Bristol Channel changes to the bed morphology could change of the order 50 km away.

The Pentland Firth, northern Scotland, is an area of high tidal currents and has received a lot of attention as a perspective site for significant tidal stream development. Whilst it is classified as a sediment starved region (Shields *et al*., 2009), mainly comprised of bedrock, there are some areas of coarse sand and gravel, and these sediment patches have been studied by several authors (Martin-Short *et al*., 2015; Fairley *et al*., 2015; Chatzirodou *et al*., 2016; Mcilvenny *et al*., 2016). The flow patterns in the area have most likely sorted the available sediment into these two areas (Chatzirodou *et al*., 2016; Mcilvenny *et al*., 2016), and the complex hydrodynamics maintain them in a state of equilibrium over long periods of time. Any changes to this flow structure will therefore most likely result in a change to the sandbanks. Fairley *et al*. (2015) modelled the morphodynamic impact of 4 arrays of tidal stream turbines in the Pentland Firth, UK, using a three-dimensional numerical model. The bed level of the mobile sediment patched changed by less than 0.2 m over the month that was simulated. Fairely *et al*. argued that this was insignificant compared to natural bed level changes of over 5 m, but noted that the arrays simulated only extract a fraction of the total tidal stream resource and that higher energy extraction rates could lead to more substantial changes in the morphodynamics in the region. Martin-Short *et al*. (2015) modelled an array of tidal turbines in the Inner Sound of Stroma, an Island close to the southern shore of the Pentland Firth, and concluded that tidal arrays larger than 85 MW within the Inner Sound would most likely effect natural patterns of sediment transport.

# 4.3 Landscape (abiotic factor)

## 4.3.1 Static components

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

# 4.4 Benthos

## 4.4.1 Static Component

### 4.4.1.1 Changes in seabed habitat

The introduction of artificial structures on the seabed may affect local hydrodynamics. These changes in hydrodynamics may alter patterns of sedimentation, particle size and nutrient content and thus impact benthic communities. The deployment of a device may result in the total loss of a community or a disturbance. If disturbed, it may be re-colonised by the original or another community. Habitat fragmentation may result from loss or disturbance (MacLeod, 2014). The foundations of devices on the seabed are likely to have a local impact on the benthic environment. The scale of this impact will largely depend on the seabed substrate and type of foundation, i.e. gravity base, pin-piling or anchoring, number of devices and spacing. Gravity based structures have large heavily weighted foundations made from concrete or similar materials, placed directly on the seabed. The seabed habitat directly underneath a gravity base will be lost. Pin-piling, which involves piling several steel pipes into the seabed, results in a smaller area of total loss of habitat. Seabed impacts associated with anchored foundations, on the other hand, will depend on the size and type of anchor. Movement of anchor chains, in particular, can scour the seabed and cause substantial damage to benthic habitat around an anchor point. As an example, the habitat loss from a single wave energy converter (WEC) can be relatively small (between 8 and 40 $m^2$), but the footprint can be much larger when seabed levelling is involved (up to 1 $km^2$) or when scaled up to a 10 MW wave power farm (> 2 $km^2$) (MacLeod, 2014). Impacts of large-scale deployment of devices on the seabed are unknown and require both long-term studies and modelling (Langhamer, 2010).

Loss of habitat may be considered critical when it is protected and is valued for its ecosystem services. Off the western and northern Isles of Scotland, areas of high wave energy designated for the deployment of WECs often coincide with rich kelp bed habitats (MacLeod, 2014). Kelp habitats found in high-energy environments are listed as Annex I habitats in the Council Directive 92/43/EEC. Beds of *Laminaria hyperborea* form an exceptionally rich habitat and have an imperative role in coastal protection (Smale *et al*., 2013). Shore-based WECs, which require modification of the shoreline or creation of a breakwater, are particularly concerning due to the direct loss of subtidal habitats, and irreversible changes to hydrodynamic conditions. Where WECs are in shallow water (10 to 30 m), short-term habitat damage or loss may occur from activities such as site preparation, deployment of infrastructure and mono-piling. Resuspension of sediments as a result of the construction phase can indirectly impact kelp beds by hindering reproduction, recruitment and photosynthesis and favour establishment of less diverse seaweed communities (Roleda, 2011; MacLeod, 2014). Even in deeper water sites (> 40 m), which do not coincide with kelp beds, there may be damage where a cable route runs to the shore (MacLeod, 2014).

#### 4.4.1.2 Fisheries Exclusion

Fisheries exclusion zones are often put into place around marine renewable energy devices to prevent fishing vessel collisions or gear entanglement with infrastructure, in effect transforming these areas into '*de-facto*' marine protected areas (Inger *et al*., 2009). Exclusion of bottom fishing activity, and particularly trawling gear, will remove an important source of disturbance to benthic habitats (Kaiser *et al*., 2006), and could enable seabed habitats damaged by trawling to recover (Tillin *et al*., 2006). At the test site of Lysekil in Sweden trawling was prohibited, balancing loss of habitat associated with the construction of WECs with positive effects of local enhancement of fish and a partial recovery of the benthic habitat (Langhamer, 2010). However, 'fishing the line', or fishing activity targeting the edge of exclusion zones in order to exploit spill over (the export of juvenile and adult fish to the unprotected waters; Kellner, 2007), remains a threat to benthic habitats. It is worth noting, however, that these effects are much more likely to be associated with wave energy developments rather than tidal energy developments, where high current flow rates may preclude trawl fisheries.

#### 4.4.1.3 Changes in hydrological regime

Changes in hydrology affect distribution of sediments, patterns of sedimentation and seabed bathymetry, all of which directly influence benthic fauna. Hydrological changes influenced by wave and tidal devices are discussed under 'energy removal' but tidal barrage and tidal stream are considered here.

The construction of a tidal barrage is designed to control water flow. The ideal location for a tidal barrage is where tidal range exceeds 6 m (Kirby and Retière, 2009). However, tidal barriers that were originally constructed for the purposes of coastal protection may subsequently be modified to include a turbine, such as those in the Netherlands at Oosterscheldekering (Leopold & Scholl, 2018). A tidal barrage causes gross changes to the hydrological regime of the water body and a cascade of interactions which impact bathymetry, tidal current regime, seabed sediment distribution, infauna and consequently the local food web (Kirby & Retière, 2009; Dadswell *et al*., 1986). Furthermore, the exchange of saline and fresh water is massively altered. When the tidal barrage at La Rance in north Brittany was constructed, a mass mortality of marine species followed, and the intertidal zone became devoid of fauna because they were unable to adapt quickly enough to these extreme changes. Subsequently, the sediments changed from sands and muds, to gravels and back to mud. Only the most tolerant species of low salinity regimes were able to re-colonise such as *Nereis diversicolor* (the ragworm) and *Mytilus edulis* (the blue mussel), which filled the empty niches left by other marine species. When the tidal barrage was reopened and marine water was able to enter La Rance, a new hydrodynamic regime meant that the water levels were raised by 2.5 m, the tidal range was reduced by 40%, the water volume exchanged with the sea was reduced by 30% and the saline proportion of the Rance region increased. As a consequence, the intertidal zone became subtidal, substrates became muddier and the carrying capacity of the intertidal zone increased and became more diverse (Kirby & Retière, 2009). The vast changes experienced by the construction of the tidal barrage at La Rance have been used to predict environmental consequences of other proposed schemes such as a tidal barrage across the River Severn in southern England.

Tidal lagoons are under review in the U.K. Due to their scale, tidal lagoons could significantly alter tidal current regimes. Given that tidal flow rates have been demonstrated to have a strong effect on benthic assemblage composition (REF), these developments may have a substantial impact on nearby benthic assemblages. Designs could, however, include opportunities for ecosystem restoration. For example, developers of tidal lagoon areas in Swansea Bay have suggested that the development would create new sheltered environments with low wave action and high-water clarity, which would be suitable for the development of seagrass meadows. Seagrass meadows provide a valuable ecosystem service through nutrient cycling, fisheries production and provision of biodiversity (Calloway, 2017) and are recognised as Annex I habitats under the EU Habitats Directive.

#### 4.4.1.4 Biofouling and artificial reefs

Introduction of a hard substrate to an environment with a soft seabed creates new niches for species that would not otherwise occupy that environment. The arrival of new species may change in local food webs. Infrastructure associated with wet renewable energy developments is typically constructed from steel and/or concrete, providing newly available surface area for colonisation by marine organisms. Organisms can arrive at this new habitat either by planktonic larvae settling on the structure, or by migration from neighbouring man-made structures or naturally occurring reefs (Langhamer, 2009). Organisms that have been recorded on man-made structures include oysters and mussels, anemones, barnacles, macroalgae, sponges and soft corals.

The community of organisms residing on man-made infrastructure is collectively known as biofouling. The presence of a biofouling community can provide new food and shelter resources for other organisms such as mobile invertebrates, fish, marine mammals and seabirds. In this way, renewable energy structures could be considered to be artificial reefs, associated with a greater density and biomass of fish when compared to surrounding soft bottom areas (Wilhelmsson & Malm, 2008). In cases where nearby natural reefs exist in proximity to wave or tidal energy developments, biofouling communities on artificial structures may facilitate recruitment of reef-associated species into the area, boosting local populations. However, these structures may alternatively attract mobile adult organisms away from other habitats and act as aggregating devices rather than enhancing biomass production (Grossman *et al*., 1997). Current wave and tidal energy structures have not been designed to act as artificial reefs with specific conservation or ecological outcomes in mind. Present designs are unlikely to offer sufficient structural complexity to provide the diversity of ecological niches associated with natural reefs, and are unlikely to harbour as much biodiversity as more complex natural and purpose-built artificial reefs (Menge, 1976).

Tidal lagoon developments represent a special case of infrastructure development where walls constructed around lagoons could provide new intertidal and subtidal habitat, attracting reef-associated species. Although no tidal lagoon projects have been awarded consent for development, environmental statements have been produced for proposed developments which were subsequently put on hold (e.g. the Swansea Bay Tidal Lagoon). It was suggested that the wall constructed around the proposed Swansea Bay tidal lagoon site could provide habitat for numerous hard-substrate species, and may eventually act as artificial reefs. The honeycomb worm, *Sabellaria alveolata*, is a species which forms biogenic reefs and has been reported in association with other coastal defence structures in the vicinity, and may also colonise the tidal lagoon walls. The lagoon will also offer opportunities to restore oyster beds to the area by constructing spatting ponds which promote settlement of oysters, a focus of nature conservation in the U.K. (Firth *et al*., 2013; Calloway 2017) and other OSPAR countries (Kerckhof *et al*., 2018; Christianen *et al*., 2018).

#### 4.4.1.5 Non-native species (NNS)

The arrival of NNS is a threat to biodiversity and ecosystem functions and can have considerable socio-economic impacts (OSPAR 2017, Pederson *et al*. 2017). A new structure provides an opportunity for colonisation without competition from the indigenous population (Tyrrell & Byers, 2007). Within the OSPAR region, the potential vectors for dispersal of NNS are through deliberate release of organisms for cultivation purposes (Pederson *et al*., 2017); discharge of water, sediment and biofilm from ships' ballast-water tanks (Drake *et al*., 2007); colonising the hulls of recreational boats (Ashton *et al*., 2006) or by 'rafting' on floating items over the sea surface to areas where they might not otherwise reach (Thiel & Gutow, 2005; Coolen *et al*., 2016). On wave and tidal energy devices, it is possible that NNS may make up a substantial component of the biofouling community (De Mesel, 2015), although studies on wind turbines in the north sea have shown that NNS are not as prevalent on artificial structures as predicted (Coolen, 2018). A new structure provides an opportunity for colonisation without competition from the indigenous population (Tyrrell & Byers, 2007). Provision of a hard substrate in a previously soft sediment environment, creates niches for species that would not otherwise be present in that environment and aids secondary dispersal. Once settled on these structures, they can source propagules to other areas or simply migrate to nearby natural habitats (Adams *et al*., 2014). The proliferation of marine renewable devices together with other forms of ocean sprawl, such as aquaculture or offshore wind, may have created networks of artificial structures which act like 'stepping stones' for the establishment of new populations of non-native species (De Mesel, 2015; Nall *et al*., 2015). These stepping stones bridge natural barriers to dispersal, such as expanses of soft sediment habitats, allowing non-native species to establish new populations (Sheehy & Vik, 2010).

The type of devices, their spacing and position on a structure influence the type and abundance of species which settle (Adams *et al*., 2014; Kerckhof *et al*., 2018). A tidal device, for example, provides a habitat from the seabed upwards to part way through the water column while a floating wave device mainly provides substrate at the surface of the water column, in addition to its anchor. At the site of a Dutch windfarm, many NNS were reported found on the intertidal surfaces but only one, the slipper limpet *Crepidula fornicata*, was found sub-tidally (Kerckhof *et al*., 2018). High levels of shipping traffic, as is often experienced during the construction and maintenance phase of a development, could facilitate further introduction and spread of NNS. In a study focussing on NNS in harbours, number of fouling NNS was positively associated with presence of floating structures and vessel activity (Nall *et al*., 2015).

The growing maritime industry, including wet renewables is contributing to the spread of NNS (Adams *et al*., 2014; De Mesel *et al*., 2015; Kerckhof *et al*., 2018). Once established, it is very difficult to eradicate them. Therefore, the best mechanism for prevention of NNS is to instigate measures on the likely dispersal vectors, such as the International Convention for the Control and Management of Ships' Ballast Water and Sediments. Mitigation measures for reducing the risk of NNS should be considered by the industry and its regulators. Lists of NNS have been compiled by many countries (e.g. Nall *et al*., 2015; Bos *et al*., 2016) and organisations such as ICES (Pederson *et al*., 2017), which should be used as a baseline dataset for monitoring spread of existing NNS and future invasions.

### 4.4.2 Dynamic components

#### 4.4.2.1 Biofouling and artificial reefs

Components of marine renewable devices are rapidly colonized by fouling fauna. This is largely discussed under 'static components' but an example specific to tidal is described here. Tidal devices require areas containing strong currents which are often characterised by tide-swept rock. A tidal device at the Falls of Warness tidal race site in the Orkney Isles was characterised by gravel and pebbles with large strands of kelp and faunal turf and peak mean tidal flows of up to

3.5 m/s (Broadhurst & Orme, 2014). Baited pots and towed video cameras were used to assess habitat composition, diversity and abundance over three time periods. The device acted as a localised artificial reef structure although there was evidence of temporal effects. It contained a higher biodiversity and species composition than a control site. Crustaceans, such as the crabs, *Necora puber* and *Cancer pagurus*, and the lobster *Homarus gammarus* were found at the tidal device site. Such artificial structures provide shelter from fishing and natural predators and may enhance their local population.

In contrast to most tidal energy sites, wave energy sites are usually set in a greater diversity of environments, ranging from highly energetic sites along the west coast of Scotland to the more benign environment at Lysekil in Sweden. At Lysekil, a succession of epifaunal colonisers was observed on the foundation of the device over a period of three years (Langhamer *et al*., 2009). By year two, a greater abundance and diversity of species was found on the vertical surfaces than on the horizontal. Species typical of hard bottoms were reported, including fish, crabs and lobsters. Crabs and fish inhabited the holes of the structures. The fouling communities on the wave buoys were dominated by *Mytilus edulis* (the blue mussel), but also included a variety of other species, such as crustaceans, molluscs, hydroids, bryozoans and sponges. For other wave energy developments, the type of community present on the device is likely to depend on the environment in which the device is deployed (Macleod *et al*., 2016; Miller *et al*., 2013)

Conversely, consideration of the environmental effects on the device is critical to its performance and longevity. The extra weight of biological matter may conflict with the efficiency of the device and be considered a technical burden. The ability of a wave device to extract energy from the sea is reliant on its shape and mass. If it is weighed down by epibiotic assemblages, which increase its mass, volume and the flow of water around it, its technical function may be impaired. The additional weight of biomass from biofouling was found to be 140 kg per buoy (Langhamer *et al*., 2009). This is relatively small compared to the 10 tonne weight of the entire translators/buoys and was not considered problematic. Moreover, the mass is not expected to increase over time because the colonisation by mussels quickly reaches a maximum. However, the biofouling will increase the roughness of the surface which may result in greater turbulence and increase the energy dissipation but in this case, it was not considered cost-effective to clean the wave power buoy for this purpose. If however, a device does require cleaning of fouling communities, the ecosystem services provided by the fouling and associated artificial reef may be reduced or lost temporarily. The associated debris may cause smothering on the seabed, attraction of scavengers and detritivores, as is seen below mussel farms. Similarly, when the device comes to the end of its lifetime and requires decommissioning, the benefits of the artificial reef will be lost.

#### 4.4.2.2 Hydrological changes

Presence of a moving structure in the water or on the seabed will serve to affect current patterns (discussed under 'static components'). Wave and tidal devices are designed to extract energy from the water column (discussed under 'energy removal').

#### 4.4.2.3 Non-native species

Any hard substrates in the marine environment, whether dynamic or static, are colonised by fouling fauna including NNS (see 'static components').

### 4.4.3 Cables

Installation of cables to transport electricity back to the shore may have multiple impacts depending on the length of cable and the substrates traversed. The installation will result in habitat loss in the subtidal and intertidal, create noise and cause sediment resuspension. Once operational the cables will generate electromagnetic fields (EMF), noise and potentially heat. Cables exposed to the surface may attract biofouling including NNS (discussed under 'static components').

#### 4.4.3.1 Cable installation

The route of a cable back to shore may cover a variety of seabed substrates and habitats and require different methods to install it appropriately. Cables are usually buried under the seabed using techniques such as trenching with a cutting wheel in rocky sediments and ploughing or water jetting in soft sediments. Cables may require protection from fishing gear, anchors or wave action. If trenching is not possible, cables may be covered using methods such as rock-mattresses, ducting, or rock dumping. Such methods may cause a loss of benthic habitats. Back-filling the trench with a similar material may enable habitat recovery to some extent, but back-filling using a different material, such as rock dump on soft sediment, may result in development of an alternate community. A trenching plough varies in size between 2 and 8 m. In the intertidal zone, the use of mechanical excavators can disturb an area in the order of tens of metres. Alternatively, horizontal directional drilling (HDD) runs the cable 10 m below the surface and can be used for distances of between 70 and 1000 m. The disturbance is only limited to a few square metres at the exit points of the cable. Maintenance and decommissioning are expected to have similar effects as the installation (Taormina *et al*., 2018).

#### 4.4.3.2 Resuspension of sediment

The disturbance of soft substrate, such as when using a trenching plough to install a cable, can lead to remobilisation of sediments (referred to as siltation or sedimentation) and accumulation of sediments on the seabed. Duration of sedimentation and turbidity in the water column are dependent on hydrological conditions, particle size and type and duration of deployment. Impacts of sediment resuspension are lower in coarser grained areas because these sediments usually sink out of suspension quickly. Dispersal models of calcareous sediment, suggest relatively short-term (60 hours) and localised effects (0.09% of an offshore wind farm area) (Didrikas and Wijkmark, 2019).

Accumulation of sediment on the seabed can smother benthic organisms. The majority of benthic infauna occupy the top 5 to 10 cm of sea surface substrate and the top 15 cm in the intertidal zone (Eleftheriou & McIntyre, 2005). The depth of sediment overburden that biota can tolerate is species and particle-size dependent. Often communities of benthic infauna can recover on soft sediments, such as seagrass beds, where there is frequent natural variability in sedimentation (Vermaat, NSR., MD., JS, CM, N, S. & van Vierssen, 1997) but recovery on hard substrates, such as kelp beds may be less likely (MacLeod, 2014). Efficiency of filter-feeding in invertebrates such as *Pecten maximus* (king scallop) may be impaired (Szostek *et al*., 2013). Further research into effects of sedimentation specific to impacts of wet renewable devices are required together with thresholds that impacted species can tolerate.

#### 4.4.3.3 Reef effects

The extent of biofouling and development of reef is dependent on the materials used to trench a cable, whether it has been left exposed on the surface and the neighbouring ecological communities. When a cable is laid upon an existing area of hard ground, changes caused by the reef effects are limited. However, when a cable is laid on soft sediment and is protected by concrete mattresses or rock dump, reef effects may be evident (Taormina *et al*., 2018). Communities typical of hard substrate have been reported on oil and gas pipelines in the northern North Sea (Harrald *et al*., 2018) and reef effects have been observed on offshore wind platforms and oil and gas platforms in the southern North Sea. Moreover, species richness was higher on more complex structures such as rock dump than straight steel due to the greater habitat complexity provided by this surface (Coolen *et al*., 2018).

#### 4.4.3.4 Electro Magnetic Fields (EMF)

Within the marine environment, the predominant source of magnetism comes from the Earth's geomagetic field. Examples of species that use this geomagnetic field to navigate are *Anguilla anguilla* (glass eels) (Cresci *et al*., 2017), the spiny lobster (Ernst & Lohmann, 2016) and loggerhead turtles (Lohmann *et al*., 2012; Brothers & Lohmann, 2015). Electric fields can also be induced in an organism itself and be detected by the electroreceptors of elasmobranchs or the ampullary organs of catfish (Whitehead *et al*., 2015).

With development of the wet renewables industry, anthropogenic EMF is becoming more frequent. EMF has two components; the electric field and the magnetic field. However, an induced electric field can occur when an animal or water body passes through the magnetic field or through the rotation of the magnetic field transmitted in an AC cable (Gill *et al*., 2014). The strength of the magnetic field and the distance that it radiates from the cable axis are project specific and dependent upon whether a cable is carrying alternating current (AC) or direct current (DC), the cable capacity and the material properties used to make the cable. AC power cables are the industry standard for offshore renewable energy facilities, but DC cables will often be used for projects further offshore (Normandeau, 2011). Shielding of cables can aid enclosure of the direct electric field of the cable; however, the magnetic field component is still present and therefore can result in the generation of an induced electric field in the surrounding environment. Even small magnetic fields (in the microTesla range) can be detected by some organisms. Elasmobranchs use electroreceptors to detect their prey and for orientation purposes (Hutchinson *et al*., 2018) and thus an EMF from a cable may be detected and result in a change in behaviour. Burial of cables increases the distance from the source to the organism in question, thereby reducing the peak intensity but this will not mask the EMF completely (Gill *et al*., 2014). In addition to burial depth, several other factors affect levels of EMF. These include cable materials (e.g. insulation, permittivity), number of conductors, cable configuration distance between cables, current flow and cable orientation relative to Earth's magnetic field. Ultimately, these factors are project and site-specific with relation to both the magnitude of the EMF emitted and the ecology of the area affected.

Species-specific effects have also been reported in benthic invertebrates such as crustaceans, bivalve molluscs, urchins and some benthic fish (Normadeaux *et al*., 2011; Hutchison *et al*., 2018). The magnetic field produced by an electric current is usually expressed in terms of Magnetic Flux Density for which the applicable SI unit is the Tesla (T) or micro-Tesla (μT, one millionth of a Tesla). Few ecological studies on the consequences of EMFs exist and reports of ecological effects are mixed Bergström *et al*, 2012 concluded that the local increase in crustaceans and fish around artificial structures was more likely due to a reef effect rather than any potential known impact from electromagnetic fields. There are physiological and behavioural studies which have reported effects of either magnetic fields or electric fields within the intensity range associated with the EMF of cables. Whilst not directly comparable they do give some insight into how magnetic and electric fields can affect the behaviour of organisms. In a study using magnetic fields of between 300 to 100 μT, changes in the shape of immunocytes in the Mediterranean mussel were reported (Ottaviani *et al*., 2002). At 100 μT, the embryonic development of the purple sea urchin was delayed (Zimmerman *et al*., 1990). These levels are all within the normal range of EMF produced by a HVDC when buried. At 25 000 μT the hatching rate of the brine shrimp increased (Shckorbatov *et al*., 2010) but this level of EMF is far greater than that usually experienced as a result of a cable. A recent behavioural study assessed responses in benthic organisms to the EMF from a buried HVDC cable, 300 MW (1175 Amps). In response to a maximal 14 μT deviation from the Earth's magnetic field (total of 65 μT), there was a subtle behavioural response in the American lobster, *Homarus americanus*, which stayed closer to the seabed and changed its direction of travel in response to EMF from the cable (Hutchison *et al*., 2018). This study found a stronger response in the Little skate, *Leucoraja erinacea* than the American lobster.

The skates travelled further, turned more often and were also closer to the seabed, which suggested greater exploratory behaviour (Hutchinson *et al*., 2018).

In order to evaluate the effects of EMFs on specific organisms, it is desirable to measure and model EMFs and put into the context of Earth's natural magnetic fields and other EMFs in the area. Studies have demonstrated that there are behavioural and physiological effects on benthic organisms, but further studies are required to assess the thresholds of priority species at important life stages in a given area. There are few studies on the sensitivity of benthic organisms and there have been no confirmed reports of changes in community composition or species assemblage changes as a result of EMF, noting this is difficult to determine given the other factors that lead to community dynamics.

#### 4.4.3.5 Heat emission

When a cable transports electricity, some of it is lost as heat which leads to an increase in temperature at the cable surface and its immediate environment. Water flow around the cable dissipates the heat but thermal radiation does emit heat to surrounding sediments even 10s of cms away. Heat emission is dependent on the physical characteristics and the electrical tension of the cable, the burial depth and the seabed type. For example, cohesive sediments will emit more heat than coarser sediments at an equal level of transmission and AC cables will emit more heat than DC cables (Taormina *et al*., 2018). Shielding the cable and cable burial will reduce the amount of heat reaching the surface sediments significantly. At the offshore wind array of Nysted, in an area of medium sand and a burial depth of 1 m, one 33 kV AC cable and another 132 kV AC cable resulted in a maximal temperature increase of 2.5 $^0$C at a depth of 50 cm beneath the cable (Meißner, 2006).

Such temperature changes near the surface sediments can modify chemical and physical properties of the substratum (Emeana *et al*., 2016), the oxygen concentration profile and the development of communities of microbes and bacteria. This may impact the physiology of benthic organisms living in the surface sediments (Taormina *et al*., 2018). Very few studies exist on the impact of thermal emission from cables on the benthic communities. Further experimental studies combined with modelling of thermal radiation are urgently required to fill this knowledge gap.

### 4.4.4 Sound

Underwater sound travels far in the marine environment, particularly low frequency intense sounds. Sound is generated during the pre-deployment, deployment and operational phases of wet renewable development (Gill *et al*., 2012). The intensity of the sound generated during the pre-deployment and deployment phases is much greater than that generated during the operational phase but is shorter lived. The sources of sound may be operational vessels, drilling of anchor points, armouring of cables using concrete mattresses, rock dumping, pile driving and seismic surveys. The latter two are particularly noisy (Fox *et al*., 2018). The operation of wet renewable devices produces sounds with the operational phase being up to 25 years this will have a long-term presence on the sound scape but will be at relatively low levels of sound intensity. The ambient sound at sites of high wave or tidal energy may mask the sound created by the device.

Sound is transmitted through the water column in two ways: 1. Particle motion – which is the actual movement in three dimensions of the water particles and 2. Sound pressure coming from the transmission of the pressure wave between the particles of water as they move. Sound also propagates through movement of solid particles such as sediments in the sea floor, which is known as vibration (Thomsen *et al*., 2015). The distinction is important for impact assessments as marine life in the water column will mainly experience sound measured as pressure and particle motion, whereas benthic organisms will experience sound pressure and particle motion through the water column and vibration through the seabed. The amount of vibration on the seafloor which results from construction and operation is unknown and it is unclear if vibrations will lead to measurable impacts on benthic organisms (Thomsen *et al*., 2015).

Notable effects of sound on some benthic invertebrates have been reported. The physiology and behaviour of *Carcinus maenus* (the shore crab/ European green crab) was affected by the experimental playback of ship noise (Wale, 2013a, b). Ship noise resulted in crabs being distracted from food, taking longer to shelter from predators and consuming more oxygen indicating potentially higher levels of stress. The effect was greater in larger crabs and they did not exhibit habituation to repeated levels of exposure.

Changes in predator evasion behaviour were reported in the Caribbean hermit crab (*Coenobita clypeatus*) in response to boat motor noise. Simulated predators could get closer to the crabs during playback of noise (Chan *et al*., 2010). The author proposed this was due to noise distraction and preventing the crab from responding to a threat. Changes in feeding behaviour were also observed in American lobster (*Homarus americanus*) as a result of exposure to high levels of seismic sound (Payne *et al*., 2007). These studies suggest that high levels of anthropogenic sounds may put invertebrates such as these at risk of elevated predation and greater oxygen consumption potentially leading to risk of starvation. Further studies are required on invertebrates in response to sound intensities and frequencies at levels experienced during the operation and construction phases of wet renewable devices. Small-scale behavioural experiments should be put into the context of population level impacts on species (Williams *et al*., 2015).

## 4.4.5 Energy removal

### 4.4.5.1 Wave energy removal

WECs are normally located in high wave energy environments with low current strength. Thus, changes in hydrological regimes are likely to be lower than around a tidal device but may be more significant depending on the seabed type they are built upon. Soft sediment communities are sensitive to small shifts in sediment size which is directly influenced by physical processes. At Lysekil in Sweden, presence of the WEC resulted in an accumulation of organic matter inside the study area due to the debris generated by mussel growth the device (Langhamer *et al*., 2009). This addition of organic matter appeared to stabilise the sediment and support more macrofauna than coarser, less stable sediments. The sediment composition at the test site was found to develop smaller particle sizes than at the reference site (Langhamer, 2010). Development of fouling communities, such as mussels, on the WEC and associated deposition of organic matter resulted in a biological enrichment of the sediments and entrapment of smaller grained material which was found to support a greater and more diverse community. In contrast, the grain size at the reference site became coarser than at the wave energy site and species density, abundance and diversity reduced. Coarse-grained communities are often too mobile to support a dense soft bottom communities (Langhamer, 2010).

WECs remove energy from waves and thus lower the impact on the intertidal zone, which may result in a change in ecological communities. In areas off the coast of Scotland, which coincide with kelp forests, the clearing of kelp beds in order to facilitate the installation of WECs, may have the opposite effect. In Norwegian waters, forests of *L. hyperborea* reduce wave heights by up to 60% (Mork, 1996). This loss in a coastline’s ability to buffer waves may result in greater coastal erosion on shore, although the effect may be dampened by a reduction in wave energy from the WEC (MacLeod, 2014). Installation of many wave energy devices may reduce the wave height of long waves thereby reducing stress on the seabed (Shields, 2011). These changes in wave action may result in a shift away from *Laminaria hyperborea*, which prefers exposed areas to other species of seaweed, such as *Saccharina latissima* and *Saccorhiza polyschides*, which support a lower diversity (Burrows, 2012).

Presence of a structure in the environment can change the physical processes operating around it and directly influence substrate type and composition of the ecological communities. Both tidal energy extractors and WECs are designed to extract energy from the sea and thus reduce current or wave energy respectively to the surrounding seas and shorelines. The effect of a single tidal energy extractor may be minimal but to make a significant amount of energy, an array of 10s to 100s may be required (Kregting *et al*., 2016) and collectively, these may cause a significant reduction in current velocity or wave energy on the environment. Several studies have investigated the effect of current reduction from tidal energy extractors but have found minimal ecological effects.

Tidal energy extractors require high flow rates of > 1.5 m/s (Kregting *et al*., 2016). Typically, these environments are characterised by bedrock or boulders with tide-swept communities of soft corals, sponges and anemones or alternatively they may be characterised by coarse grained sediment (Broadhurst, 2014; O'Carroll *et al*., 2017). A study designed to emulate the effect of SeaGen, a single, full-scale, tidal stream turbine, located in the Strangford Lough narrows in Northern Ireland, was carried out using a hydrodynamic model and drop-down video survey (Kregting *et al*., 2016). The benthic communities that were present over a range of current velocities (between 1.5 to 2.4 m/s) in a depth range of 25 to 30 ,m were compared but no effect of a reduction in current speed on the composition of the benthic communities was found.

A further study at Strangford Lough modelled the turbulence in the wake of the tidal stream turbine 'SeaGen' created by the hydrodynamic perturbations on the leeward side of the device. The study used the WFD's index of Ecological Status (ES) as a proxy for assessing change related to simulated hydrodynamic changes and concluded that there would be no significant change to ES other than immediately between and adjacent to the device quadrant legs (O'Carroll *et al*. 2017). These high velocity environments are already adapted to strong physical disturbance associated with high and variable current flows and thus a hypothetical reduction was not found to have a significant effect on the benthos in either study on SeaGen (Kregting *et al*. 2016).

In a study of the benthic impacts of a tidal kite located in Strangford Lough, which moves in a figure of eight through the water column, no significant effects were found on the benthic communities, no species barren periphery were observed around the kite and no evidence of a single species dominating the ecological community (Kregting *et al*., 2018).

### 4.4.6 Contamination

During construction, operation and decommissioning of devices, the seabed may be disturbed resulting in the mobilisation of contaminants from the sediment (Matthiessen & Law, 2002; Gill, 2005; Cada, Ahlgrimm, Bahleda, Bigford, Stavrakas, Hall, Moursund & Sale, 2007; Bonar, Bryden & Borthwick, 2015). Furthermore, vessel traffic during these activities may increase the risk of collisions or otherwise induced spills of contaminants (Bailey, Brookes & Thompson, 2014). Toxins may leach from anti-fouling paints, impacting planktonic species (Witt, Sheehan, Bearhop, Broderick, Conley, Cotterell, Crow, Grecian, Halsband, Hodgson, Hosegood, Inger, Miller, Sims, Thompson, Vanstaen, Votier, Attrill & Godley, 2012). These may then be consumed by filter feeding benthic species, indirectly affecting the benthic community. Contamination by diesel fuel for example, can result in shifts in the benthic food web (Carman, Fleeger & Pomarico, 1997). Contaminants from the sediment, as well as originating from leaching and spills, may bioaccumulate in benthic species (Morrison *et al*., 1996). It has been suggested that zinc contamination from sacrificial anodes on vessels results in ecological damage (Matthiessen, Reed & Johnson, 1999). Zinc anodes are also applied on renewable energy devices (Momber, 2011; Titah-Benbouzid &

Benbouzid, 2017), which may result in a further increase of contamination by cathodic protection systems. The sheath of cables may be made of heavy metals such as copper and lead that are potential sources of contaminants particularly if old cables are not removed. Heavy metals may dissolve and spread into the sediment and present a risk to sediment communities (Taormina *et al.*, 2018).

## 4.5 Fish

### 4.5.1 Static Component

#### 4.5.1.1 Aggregation

Immersed WECs may affect ocean and tidal currents, swell and sediment dynamics (di Milano *et al.*, 2015), alter habitat, create artificial reefs and act as fish aggregation devices. The 2008 assessment of aggregation resulting from OWFs highlighted available evidence to suggest that some fish are likely to aggregate within an OWF array and reported that this will only be a local redistribution of fish so there will not be an increase in fish numbers, therefore this is of local interest bit low ecological significance. One wonders the implications such a redistribution of fish may have on localised population structure, particularly as foraging efficiency (the capture of prey by a predator) controls both adult and juvenile survival and condition, changes in foraging efficiencies could have widespread impacts on populations (Hutchinson, 1978). This may be of particular importance when considering species that show a degree of sight fidelity such as Atlantic cod and pouting which have been found to aggregate around offshore wind turbine foundations (Reubens *et al.*, 2013; Reubens, 2013b; Reubens, 2011) with large aggregations of juvenile Atlantic cod at the foundations of wind turbines during summer and autumn, during which they exhibited crepuscular movements relating to feeding activity, and pouting which were found to show a dietary preference for prey species that lived on the turbines. Foraging opportunities appear to be the main attractor to marine megafauna, likely driven by an enhanced prey abundance, vulnerability and diversity (Benjamins *et al.*, 2015) with potential for MREIs to have a significant anthropogenic influence on marine ecosystems, and the positive and negative effects are likely to interact in complex and unpredictable ways with potential for trophic cascade effects (Witt *et al.*, 2012). Marine mammals, diving birds and large fish that swim close to the surface (e.g. basking sharks) may also be at risk of collision or entanglement with underwater elements of WECs (Wilson *et al.*, 2007) particularly where there are predator prey interactions.

Our understanding of fish behaviour, which may contribute to these risks, around wave and tidal installations is limited - although studies such as those utilising DiDSON cameras (Viehman and Zydlewski, 2017), Echosounder (Williamson *et al.*, 2017, Fraser., 2018) and video footage with ADCP survey techniques (Broadhurst *et al.*, 2014) have provided an insight to fish behaviour around these technologies, further work is still required. It is therefore important that consideration be given to both fish aggregation and behaviour around wave and tidal renewables devices when undertaking environmental impact assessments, not only with regard to fish populations, but also with regard the effects that this may have on the ecosystem.

#### 4.5.1.2 Fisheries

The Horizon 2020 MUSES project report (Kafas *et al.*, 2018) considers fishing within offshore wind farms in the North Sea, providing multi-use perspectives from Scotland and Germany. This study utilises up to date information and publications and finds that establishing offshore wind farms in carefully selected areas can contribute to fisheries management initiatives (e.g. reduction of fleet segment in certain areas; promotion of sustainable fishing practices). Here consideration is given to factors that affect the commercial fishing sector, including both positive effects from the introduction of offshore wind farms (e.g. protected habitats for marine species, which may increase the available biomass in the immediate surroundings with positive knock-on effect for fishing; offering opportunity for alternative gears such as creels to proliferate due to spatial restrictions to competing fleet segments (e.g. mobile gears)) and negative effects (e.g. increase in safety risk from unburied / exposed sections of power cables, with the potential for loss of life; and various potential negative impacts on target species, such as those from underwater noise or electromagnetic fields). It is likely that many of these will be similar for wave and tidal developments, although there may further impacts on the ability to utilise certain fishing gears, given the nature of moving components or to anchoring methods.

## 4.5.2 Dynamic component

### 4.5.2.1 Fish strike

A review of environmental effects of tidal energy development (Polagye *et al.*, 2011b) reported that the presence of singular or multiple tidal turbines in the marine environment will create the potential for a number of physical interactions with the water, seabed, and species or habitats in the surrounding area. Based on project monitoring to date, there is no direct evidence of blade strike mortality, or adverse interactions between marine animals and operating turbines, and reports that these monitoring results are supported by flume and field experimental data which show high survival rates for fish passing through rivers or flumes with tidal turbines (Copping *et al.*, 2014). There are currently no large scale arrays of wave or tidal technology that would allow *in situ* field observations of blade strike on fish, indeed a number of investigators have cautioned that migratory fish passing through an entire hydrokinetic power project with large numbers of closely spaced turbines may not be able to completely avoid turbine interactions (Amaral *et al*., 2015), this may be either actively or passively. Bevelhimer *et al.* (2015) found some evidence that the presence of an operating turbine affected the swimming trajectories of fish, for the most part there was little evidence that individual fish made drastic changes in direction, location, or swimming speed in response to an operating turbine.

The findings of Hammar *et al.* (2014) indicate low risk for small sized fish. However, at large turbines (≥ 5 m), bigger fish seem to have high probability of collision, mostly because rotor detection and avoidance is difficult in low visibility. Risks can therefore be substantial for vulnerable populations of large-sized fish, which thrive in strong currents. This is supported by Amaral *et al*. (2015) whereby strike mortality has been shown to increase with the ratio of fish length to blade thickness with conventional turbines (i.e., for a given blade thickness, larger fish will have a higher probability of mortality) when strike speeds are sufficiently high to cause lethal injuries.

There is currently insufficient evidence to accurately assess the risk posed to fish from direct interactions, including blade strike (Polagye *et al*., 2011b; Copping *et al*., 2014, Amaral *et al*., 2015) however the potential effects of blade strike should be considered, particularly for larger fish species that reside within the local area, or that migrate through the area. Further work is required on the potential effects of blade strike, including long term effects of injury.

## 4.5.3 Cables

### 4.5.3.1 Electromagnetic fields

The previous assessment on offshore wind, as provided in 2008, highlighted available evidence suggesting that the only impacts from electromagnetic fields of concern are changes to behaviour of electro-sensitive species and species sensitive to magnetic fields, and noted that the significance of such behavioural changes were unknown but potentially high.

Since 2008, there have been a number of reviews and studies undertaken that consider these impacts on decapods (e.g. *Homarus americanus* (Hutchison *et al*., 2018), *Cancer pagurus* (Scott *et al*.,

2018) ), elasmobranchs (e.g. *Leucorjaj erinacea* (Hutchison *et al*., 2018), Catsharks (Kimber *et al*., 2011) ), teleost fish (e.g. *Oncorhynchus tshawytscha* (Wymen *et al*., 2018), *Anguilla anguilla* (Kropp, 2013, Orpwood, 2015), Chinook salmon (Kavet *et al*, 2016) Atlantic salmon (Armstrong, 2015)) that have improved our understanding of the effects of EMF on those species, but there still remain many knowledge gaps.

It has been suggested that EMF from subsea cables could serve as an impediment to migration or movement for fishes moving near the seafloor (Claisse *et al*., 2015). Baring-Gould (2016) report that since the source of EMFs is the cable on the sea floor, benthic and demersal species, which are closer to the source, are considered more likely to be exposed to higher field strengths than pelagic species. However, the nature and the variety of wet renewable technologies means that some will have cables suspended in the mid-water column, potentially creating larger EMF emissions than devices that have buried cables (Freeman *et al*., 2013), which may interact with pelagic species or species that move between the demersal and pelagic environment. It should be noted that whilst cable burial is often referred to as a mitigation and has been used as such by offshore developers to reduce potential impacts this is not supported by any current studies as it assumes that the peak EMF needs mitigated. In general, the magnetic field passes through the seabed and the water column in the same way hence burial does not reduce it. What burial does is reduce the physical distance between the surface of the cable and the receptor organism on the seabed. Therefore the receptor will not encounter the maximum field but will encounter a field within the range of detection and within the range of potential effects (whether behavioural, physiological or other). For some receptors the EMF will come within the range of attraction, hence burial will not act as any mitigation, furthermore receptors that bury in the seabed will experience a different intensity. It is a complicated scenario which requires targeted studies to address the key potential effects. Note that some fish species such as plaice (*Pleuronectes platessa*) and flapper skate (*Dipturus* cf *intermedia*) have shown vertical movements within the water column (Fox *et al*., 2017) and may therefore also be affected.

### 4.5.4 Sound

Pile-driving noise during construction is of particular concern as the very high particle motion levels (and for some species very high sound pressure) could potentially cause permanent or temporary hearing damage, prevent fish from reaching breeding or spawning sites, finding food, and acoustically locating mates (Mueller-Blenkle *et al*., 2010). It should be noted that whilst the installation of many tidal stream device designs will not require pile driving, drilling of anchor points and armouring of cables using concrete mats or rock-dumping are also potentially noisy activities (Nedwell *et al*., 2007) and that noise during the operational phase of wave farms is likely to have a less acute effect (Witt *et al*., 2012). In a review of environmental impacts for marine and hydrokinetic projects to inform regulators, Baring-Gould *et al.* (2016) report that although full-frequency sound propagation and animal receptor sensitivity is a complicated relationship, the likely impacts of measured radiated sound from single marine hydrokinetic devices are small and confined to limited areas near devices. Thus far, observed radiated sound levels are below those that are considered likely to cause physiological damage.

Effects of noise may depend upon the fish species with physiology, life stage or life event potentially affecting the impacts that underwater noise may have. There remain many key knowledge gaps on the topic, often requiring a precautionary approach to assessments or mitigation. There are however some interesting studies that provide some information on key areas of concern.

Highlighting the need to consider each species individually, Schramm *et al.* (2017) evaluated changes in fish position relative to different intensities of turbine sound as well as trends in location over time. Results varied depending on species with redhorse suckers (*Moxostoma* spp.) responding to sustained turbine sound by increasing distance from the sound source, Freshwater drum (*Aplondinotus grunniens)* showing a mixed response and largemouth bass (*Micropterus salmoides)* and rainbow trout (*Oncorhynchus mykiss)* not indicating any likely response. The importance of future research to utilize accurate localisation systems, different species, validated sound transmission distances and to consider different types of behavioural responses to different turbine designs is highlighted.

Mueller-Blenkle *et al*. (2010) undertook studies involving playback of offshore wind pile-driving noise to cod *(Gadus morhua)* and sole *(Solea solea)* held in large pens, movements of fish were analysed and sound pressure and particle motion were measured. It was found that there was a significant movement response to the pile-driving stimulus in both species at relatively low received sound pressure levels, for sole: 144–156 dB re 1 μPa Peak; and cod: 140–161 dB re 1 μPa Peak and particle motion between 6.51×10-3 and 8.62×10-4 m/s 2 peak. The results indicate that a range of received sound pressure and particle motion levels associated with pile-driving will trigger behavioural responses in sole and cod. It is noted that the exact nature and extent of the behavioural response needs to be investigated further and that future studies should investigate the response at critical times (e.g. spawning and mating) and the effects of pile driving on communication behaviour.

It was concluded by Skaret *et al.* (2007) when studying vessel avoidance of herring (*Clupea herengus* L.) to vessel noise that a higher priority given to reproductive activities seems to overrule the avoidance response to a passing vessel. Vessel avoidance was interpreted as a response to a perceived threat and herring are known to exhibit strong avoidance reactions to survey vessels during wintering and spawning migration. Whilst generalised comments cannot be made on one study of a single species this may mean that, during spawning, herring behaviour does not align with the statement made by Nedwell *et al*. (2007) that, provided animals are free to flee the noise, those within the area bounded by the 90 dBht (Species)* level contour will strongly avoid the noise. Behavioural responses of spawning fish to noise has been a concern for EIA for activities during the construction of offshore wind developments, forming the basis for the requirement for some conditions of consent where impact piling is required.

Popper *et al.* (2014) report few publications consider the effects of sound or vibration on fish eggs and larvae with two produced since the 2008 assessment for offshore wind. These focus on the effects of pile-driving noise on fish larvae, including common sole (*Solea solea*), herring (*Clupea herengus*), and plaice (*Pleuronectes platessa*) (Bolle, 2012, 2014). The results of the larval studies showed no significant differences in mortality between the control group and the exposure groups for any of the species or larval stages. These studies did not, however, consider potential long-term effects.

Whilst the number of studies on the effects of noise on fish is limited, consideration of underwater noise within offshore renewables EIA has focused on sound pressure, although the need to consider particle motion has been raised. Nedelec *et al*. (2016) report that because the majority of aquatic animals' sense sound using particle motion, this component of the sound field must be addressed if acoustic habitats are to be managed effectively. Indeed, Popper and Hawkins (2018) find that currently, sound exposure criteria for fish and invertebrates have been derived from often poorly designed and controlled studies that have not taken account of the sensitivity of these animals to particle motion. It is also found that there have been very few measurements made of different fishes and invertebrates to particle motion (e.g. hearing thresholds at different frequencies, including infrasound) which makes assessment of the potential effects of particle motion difficult. In Scotland, applicants for offshore energy developments have recently been advised that consideration to particle motion should be given. This has resulted in desk-based reviews that generally find that particle motion propagation mapping in relation to offshore developments remains unfeasible and direct measurement is the only method of accurately determining particle motion at a given location (ICOL particle discussion document, 2017[7]).

Sound pressure has, until recently been considered in accordance with the dBht (Species) metric proposed by Nedwell *et al.* (2007) that expresses the level of perceived sound pressure weighted by a filter that reflects the frequency-dependent sensitivity of hearing for the species of interest. Popper *et al.* (2014) considers the use of this metric and find that whilst the general concept may have some value in the context of behavioural responses by fish, its application and adoption requires far more scientific validation and the inclusion of those species that primarily respond to particle motion. They report that the application of weighting requires reliable measures of hearing sensitivity versus frequency (audiograms), but these are only available for a few fish species and that confidence in the validity of audiograms for many species is limited because of poor acoustic conditions surrounding the experiments, uncertainties as to whether particle motion or pressure is the relevant sound dimension, and the methodologies applied to determine thresholds. They suggest that it may be more appropriate to apply generalised weighting functions for defined functional hearing categories[8].

Particularly given the lack of species-specific audiograms, the guidance provided by Popper *et al.* (2014), that provides the categories and exposure criteria to assess impacts by, has recently been adopted for use within EIA for offshore renewables. Used in conjunction with updated sound propagation models, as considered by Farcas *et al.* (2016) that take into account bathymetry, sediment and water column data to provide better predictions of noise exposure, this provides the most up to date consideration of the potential effects of sound pressure on fish species. It should be noted however that propagation models are only as good as the input data. Indeed, Farcas *et al.* (2016) report that the most important factor to reduce uncertainty in noise exposure predictions is the sound level of the noise source with Frid *et al*. (2012) finding that many sources of underwater noise are yet to be well described by measurements, particularly novel sources such as wave and tidal energy devices. Lepper *et al*. (2011) has undertaken operational noise assessment on the Pelamis P2 system at the EMEC wave site but further studies will be required to take into account the varied technologies associated with the wave and tidal renewable energy industry.

As found by Baring-Gould *et al.* (2016), the biological implications of sound and particle motion remain highly uncertain; even though thresholds have been established for harassment for cer-

---

[7] https://www2.gov.scot/Resource/0052/00528521.pdf

* dBht (Species) metric proposed by Nedwell *et al.* (2007) that expresses the level of perceived sound pressure weighted by a filter that reflects the frequency-dependent sensitivity of hearing for the species of interest

[8]*Popper et al. (2014)* categories

*Fishes with no swim bladder or other gas chamber* (e.g., dab and other flatfish). These species are less susceptible to barotrauma and only detect particle motion, not sound pressure. However, some barotrauma may result from exposure to sound pressure.

*Fishes with swim bladders in which hearing does not involve the swim bladder or other gas volume* (e.g., Atlantic salmon). These species are susceptible to barotrauma although hearing only involves particle motion, not sound pressure.

*Fishes in which hearing involves a swim bladder or other gas volume* (e.g., Atlantic cod, herring and relatives, Otophysi). These species are susceptible to barotrauma and detect sound pressure as well as particle motion.

*Sea turtles*

*Fish eggs and larvae*

tain species, the biological response and behavioural context for sound emissions are still unknown. Identifying any direct biological responses to radiated noise from marine hydrokinetic devices continues to be difficult and a precautionary approach should be taken until key knowledge gaps are addressed.

## 4.6 Marine Mammals

### 4.6.1 Introduction

In general, there has been more concern about the effects of tidal energy developments on marine mammals than the effects of wave energy. This is primarily due to concerns about the potential for collisions between marine mammals and the moving parts of tidal energy converters. Most wave energy devices have not been considered to pose the same risks of injury or mortality, although there have been concerns raised about the potential for entanglement with mooring lines, including the effects of 'ghost fishing' where loose fishing gear can get tangled in mooring lines and pose a risk of snagging and drowning marine mammals. Most research on the effects of wet renewables on marine mammals has focused on the effects of tidal stream, horizontal axis rotor type turbines but the summary of impacts below will provide details about device type wherever possible. The Annex IV 'State of the Science Report' provides a useful summary of knowledge of the impacts of marine renewable energy devices on a number of receptors, including marine mammals (Copping *et al*., 2016). The review provided below is intended as an update of information published since the publication of the Annex IV report.

Marine mammals are covered by a large degree of legal protection and all cetaceans are listed on Annex IV of the EU Habitats Directive as European Protected Species and as such are afforded protection from killing, injury and significant disturbance. A number of European marine mammal species are also listed on Annex II which requires the designation of protected sites for their protection.

### 4.6.2 Dynamic parts of MRE structures

#### 4.6.2.1 Collision Risk

The risk of collision with the moving parts of MRE structures has been the primary environmental concern in relation to renewable devices and marine mammals, and as such, is the topic around which most research and monitoring effort has focused to date.

Much effort has gone into developing and refining quantitative predictive collision risk models which can be used in the environmental impact assessment (EIA) phase for proposed projects to provide an estimate of the degree of risk posed by tidal energy devices. Examples of these models developed specifically for marine animals include Wilson *et al*. (2014), Scottish Natural Heritage (2016) and Band *et al*. (2016). These efforts have largely focused on horizontal axis turbines although a number of bespoke collision risk models have been developed for other types of turbine. For example, both Booth *et al*. (2015) and Schmitt *et al*. (2017) have used 4D simulation approaches (3D model over time) to model the risk of a marine mammal colliding with the 'flying kite' Deep Green Minesto turbine. As part of the site wide environmental appraisal for the EMEC site in Orkney, Scotland, EMEC (2014) adapted an existing collision risk model to account for two additional device types: 1) An annular device with an open core through which animals could pass without collision, and 2) a device with contra-rotating rotors – i.e. two blades operating in reverse rotational directions.

Where marine mammals and a device occur in the same place, the probability of a strike will depend on the physical characteristics of the device (blade shape, size and speed), the characteristics of the animals (swimming behaviour, body size, approach angles), and the ability of animals to take evasive action to avoid a strike. Appraisal of modelling efforts (e.g. Band *et al.*, 2016, Joy *et al.*, 2018) have demonstrated that the predictions of these models are most sensitive to assumptions about the density of animals at a site, turnover, degree of avoidance/evasion and the consequence of collisions. In particular, this body of work highlights the degree to which animals can detect and avoid the moving parts of turbines remains uncertain, despite being one of the most important parameters required for more accurately estimating collision risk (e.g. Band *et al.*, 2016; Joy *et al.*, 2018).

For tidal lagoons/barrages where turbines are not situated in open water, and instead are enclosed in structures, the assumptions of random distribution and passage that most collision risk models rely upon are unlikely to hold and therefore these quantitative models may be less useful. Lagoon projects have additional concerns with entrapment and the enclosed nature of bulb[9] turbines in this setting mean that close-range evasion may be less likely. Bulb turbines are commonly used in conventional river hydro projects and have also been used in tidal range projects (e.g. the Sihwa Project in South Korea).

A number of efforts worldwide in recent years have been developing technology to provide new tools to monitor fine scale interactions around tidal energy devices in order to better characterise and understand collision risk. This includes application of telemetry (tagging), camera technology as well as active and passive acoustic monitoring (Hastie, 2012; Hastie *et al.*, 2014; Joslin *et al.*, 2014; Polagye *et al.*, 2014; Cotter *et al.*, 2015; Sparling *et al.*, 2016; Williamson *et al.*, 2016; Williamson *et al.*, 2017). So far there are only a limited number of studies where these technologies have been deployed at active tidal sites where data have been published (Sparling *et al.*, 2017; Williamson *et al.*, 2017; Malinka *et al.*, 2018). A number of other devices including Nova Innovation turbines in Bluemull Sound, Shetland, various devices at the Scottish test centre EMEC as well as an OpenHydro turbine at FORCE, have had monitoring conducted around them using a variety of methods including multibeam sonar, underwater cameras and hydrophones, but so far little of the resulting data or information has made it into the public domain (Copping *et al.*, 2016). An exception to this is Malinka *et al.* (2017) which reports on passive acoustic monitoring around an operational tidal turbine in Ramsey Sound in Wales. The period of turbine operation was relatively short so low sample size limited any analysis with respect to changes in porpoise behaviour or occurrence in relation to turbine operation. The study did reveal that the monitoring system successfully detected and localised porpoise and dolphin vocalisations and that analysis of tracks suggested that individuals of both species were capable of detecting the structure and responding to it.

There has been some work on understanding consequences of collisions. Carlson *et al.* (2012) used a finite mesh modelling approach to predict the consequences of a killer whale being struck by an Open Hydro device as part of the assessment of the SnoPud project in Snohomish, Washington, US. The study concluded that a strike from the proposed Open Hydro device would not result in significant injury to a killer whale. Researchers at the Sea Mammal Research Unit in Scotland have carried out a series of collision trials, using a vessel-mounted turbine blade and seal and porpoise carcasses to mimic blade strikes. MRI scans of carcasses after the trials demonstrated that significant skeletal damage occurs at speeds above 6 m/s (Onoufriou *et al.* in press). Below these speeds there was no evidence of skeletal trauma or obvious indicators of extensive soft tissue damage, although due to the difficulties in assessing soft-tissue damage such as bruising and tissue oedema in previously frozen carcasses, these soft-tissue assessments were not

[9] http://www.tidallagoonpower.com/tidal-technology/turbine-technology/

considered reliable indicators. Grear *et al*. (2017) tested two mechanical properties of harbour seal tissues to better understand the ability of the skin and blubber to resist blunt force trauma. They found significant differences in response between test speeds and age of the animal, but not the orientation of the tissue relative to the strike. Tissues were either frozen or fresh, where in the case of the former, they found an increase in stiffness and strength of the skin, but there was no conclusive trend in blubber material properties. They concluded that frozen tissue, especially skin, cannot serve as an accurate replacement for testing fresh material. The other caveat to note, regarding these approaches outlined in Onoufriou *et al*. (in press) and Grear *et al*. (2017) is that there remains no reliable assessment of concussion as a result of blunt force trauma, which has the potential to be fatal (i.e. the animal loses consciousness and drowns). Copping *et al*. (2017) combined the results of these tissue experiments with 1) estimates of the force that a tidal turbine blade might exert as a result of a strike and 2) simple estimates of the probability of encounters between seals and tidal turbines to attempt to quantify the level of overall risk to harbour seals. As with previous modelling exercises with little empirical basis, the authors concluded that more information on the behaviour of seals in the presence of a turbine and on the physical consequences of a strike were required to fully understand the potential for death or injury.

As well as monitoring around tidal energy projects and research to better understand the consequences of collision, there has been a focus on understanding baseline marine mammal use of tidal environments. An understanding of baseline functional habitat use is important to enable prediction of future risk, both from the perspective of collision risk but also to understand the potential consequences of any displacement. Until recently, studies of marine mammals in tidal environments were relatively sparse. A number of studies have been carried out using a variety of techniques; telemetry, passive acoustic monitoring (PAM) and visual surveys, to document the patterns of marine mammal usage in tidal environments.

Recent investigations into fine-scale porpoise density and use of the water column at a variety of tidal sites in Scotland have provided a substantial data set on porpoise depth distribution and underwater behaviour in tidal rapids that shows a large degree of variation between sites. These data and the methodological and analytical developments associated with them are summarized by Macaulay *et al*. (2015) and Macaulay *et al*. (2017). This study showed that the depth distribution of harbour porpoise was typically bimodal with maxima between 0–5 m and at 22–24 m, which was similar across sites regardless of differences in seabed depth, thereby providing insight into the potential separation of the porpoise from the depth of a tidal turbine blade. At the only site where measurements were taken at night (Kyle Rhea), porpoises were generally located near the sea surface, highlighting the importance of understanding diurnal variation in depth distribution for accurate prediction of collision risk (Macaulay *et al*., 2015). Complicating our ability to predict risk, Benjamins *et al*. (2017) demonstrated that the distribution of harbour porpoise can vary in tidal habitats at very small spatial and temporal scales.

Seal tagging studies have increased knowledge about the way that harbour and grey seals behave in tidal environments. In the narrow, tidal channel of Kyle Rhea on the west of Scotland, harbour seals are present between April and August and haul out during the ebb tide, then spend a high proportion of their time during the flood tide period actively foraging in the high current areas (Hastie *et al*., 2016). In this study between 50% and 100% of the seals' dives were to the seabed. Another telemetry study (Joy *et al*., 2018) revealed that in the tidal currents of Strangford Narrows in Northern Ireland, harbour seals predominately swam against the prevailing current during both ebb and flood tides. Similarly, as reported in Band *et al*. (2016), harbour seals in the Pentland Firth also apparently predominately travelled against the current, where slow speed movement in the opposite direction of the current demonstrated that they were either swimming against the current or taking advantage of local scale tidal features and eddies to maintain station against the flow. Similar to the seals at Kyle Rhea, not all dives were to the seabed and there was a proportion of mid-water diving. This behaviour is in contrast to previous studies where most diving was thought to be to the seabed. In contrast to the behaviour of Kyle Rhea harbour seals, Lieber *et al*. (2018) reported that harbour and grey seals in the Strangford Narrows were more likely to be distributed on the periphery of high current areas where there is the highest vertical shear (i.e. the largest difference between fast moving surface and slower near-seabed flows). However, this was based on a limited sample of observations from a vessel conducting repeat line transect surveys over two days (one on a Spring and one on a Neap tide). As at-surface sightings without any correction for differences in sighting probability with respect to flow rates provide limited reliable evidence for preference or habitat use below the surface, it makes inference on the potential for collision risk with sub-sea devices difficult.

In the Netherlands, the Oosterscheldekering, a storm surge barrier that has five integrated tidal turbines, is sited in an area where harbour porpoise, grey seals and harbour seals occur (Leopold & Scholl, 2018). Prior to installation of the turbines (December 2015), the surge barrier was already in place (from 1986). Pre-installation of the tidal turbines, a telemetry tagging study of a small number of seals did show that individuals were passing through the storm surge barrier, suggesting that it was not acting as a physical barrier to movement; however, it is not known how they passed through the storm surge (e.g. at the surface, near the bottom, at slow or fast tides or during which phase of the tide). Counts from aerial surveys pre- and post-installation suggest that there is no significant deviation from the baseline trends in seals, but the authors acknowledge that there is a lack of statistical power, and that to detect a change, it would have had to be quite severe. Post-mortem studies of seals post-installation were undertaken on seven carcases; cause of death could not be determined for two, and for the other five, potential collision with the turbines was not the causal factor in their death. With respect to porpoise, population estimates and strandings records suggested that it was a stable population in the area. There were some indications of collision with objects in two stranded porpoises, which may have been the turbine, but other objects could include vessels, the storm surge wall. The initial work post-installation suggests that the impact of these tidal devices is minimal; however, caution should be exercised due to small sample sizes and low statistical power.

The implication of most of these studies is that it is difficult to generalise between species and sites in relation to marine mammal usage of tidal sites. Therefore, it is likely that some degree of site information will be required to characterise risk at sites of future development. Other aspects for consideration are, as devices start to become more viable in lower flow environments, could this potentially increase the risk of collision between marine mammals and operating MRE devices, whereby, in lower flow environments, fish could potentially aggregate around the device and therefore attract marine mammals (see below for more discussion of potential fish aggregation).

Despite these knowledge gaps regarding collision risk, particularly with respect to scaling demonstration sites to arrays, consideration is being given to the development of potential mitigation of collision risk. For example, the UK NERC funded MANTIS project is investigating sound propagation of acoustic deterrent devices (ADDs) in tidal environments to inform the potential for the future use of ADDs around tidal energy devices, should collision risk require mitigation.

### 4.6.3 Sound: Underwater noise

Underwater noise is also a concern, with the potential for noise generated during the construction and operation phases of marine energy projects to cause disturbance/displacement/barrier to movement. While small scale single devices may not be a concern due to the scale over such effects would operate, this is a concern for future commercial scale arrays where several hundred devices may be deployed across a site. Noise during construction (vessels, noise associated with installation procedures e.g. drilling, piling, cable laying) and the noise associated with turbine operation can be of concern, the latter because of the long-term nature of the operational phase. A growing number of devices have been characterised acoustically, reviewed in Robinson and Lepper (2013), as well as Schmitt *et al*. (2018) and Lossent *et al*. (2017), more recently. Listening Space Reduction (LSR) has been quantified for two devices, based on in-situ recordings of the quarter-scale Minesto Deep Green sea kite and the full-scale SCHOTTEL IST horizontal axis turbine, for harbour seal and harbour porpoise (Pine *et al*., 2019). Pine *et al.* (2019) define LSR as the listening space decay that occurs around the tidal turbines, and uses the audiograms of the species of interest to assess the LSR; these are presented as distances at which a percentage of LSR occurs. Their findings demonstrated that the LSR was influenced by type of turbine, species and season. As might be expected, for both species, LSRs were highest during winter, which was characterised by low ambient noise conditions. In the summer, higher levels of ambient noise effectively 'masked' the noise from the device.

Malinka *et al.* (2018) reported on passive acoustic monitoring at a tidal turbine in Wales. This study revealed that the device would have been clearly audible to marine mammals in the vicinity, largely as a result of regular, loud 'clanging' noises from metal flaps designed to reduce the flow of silt into the turbine frame. Another distinctive and clearly audible mechanical source of noise came from the hydraulic pumps used to rotate the turbine into the current. In contrast, other studies (Ben Wilson *et al*, EU MaRVEN project) recorded very quiet levels. Quiet enough to suggest that there is a potential risk of marmams not being able to detect a potential hazard.

Empirical studies of responses to date have indicated small scale, local avoidance in some cases to construction and operational noise (Savidge *et al*., 2014; Hastie *et al*., 2017; Joy *et al*., 2017; Joy *et al*., 2018) with other studies revealing a diminishing response over time (Robertson *et al*. 2018). In the case of the latter, Robertson *et al*. (2018) reported a response in harbour porpoise to playbacks of turbine sound that decreased over time: porpoises were initially observed responding at ~300 m from the playback location during trial 1, which decreased to 100 m during trial 2 and disappeared in trial 3. Unfortunately, during this study, a vessel was only present during playbacks and not during control periods so the observed responses could be due to the playbacks, the vessel presence or a combination of both. Differences between studies and species is likely related to the level and nature of the sound and the hearing ability of species. Some response to operating turbines may be good (to reduce collision risk) but over large areas, even small-scale responses could result in habitat exclusion, displacement and/or barrier effects. There has been no pile driving involved in the installation/construction of wave or tidal MRE devices to date, but its future use cannot be ruled out, particularly if the use of gravity bases reduces due to cost reduction measures. This would pose a more significant concern, particularly at the scale of large commercial arrays.

### 4.6.4 Cables

#### 4.6.4.1 Electromagnetic fields

The potential impacts from electromagnetic fields are changes to the behaviour of electro-sensitive species and species sensitive to magnetic fields. Marine mammals are generally thought to be relatively insensitive to electric fields but are likely to be sensitive to magnetic fields, particularly species that undergo large scale migrations. However, the occurrence and nature of any effects of EMF from MRE cables are unknown for marine mammals. If large scale behavioural changes were to occur, the significance of such changes may be potentially high. However, given the current scale of deployment, and the highly mobile nature of marine mammals, this has not been a big concern, particularly in the context of the potential for more direct impacts through collision. However, if they did respond to cables then mammals would more likely detect EMFs from DC cables than from AC cables, because the former characteristically have static B-fields (similar to the geomagnetic field) and they are of higher intensity than the latter. The likelihood of exposure will also be a function of the depth of the water above the cable and the depth of swimming because field strength dissipates with distance (Copping *et al*., 2016).

#### 4.6.4.2 Mooring lines and Cables: Entanglement

The entanglement of marine mammals in mooring lines and cables has been raised as a potential concern, but there is very little evidence upon which to draw any conclusions. According to a review and risk assessment published by Scottish Natural Heritage (Benjamins *et al*., 2014), entanglement does not pose a significant threat to marine mammals. Large baleen whales were considered to be at a higher risk of entanglement but this could be minimised by ensuring tension is applied to make sure cables are taut. There was a further concern that if derelict fishing gear becomes entangled in moorings, this would pose a risk for a wide range of species (including fish and diving seabirds). Benjamins *et al*. (2014) called for a more in-depth assessment of the snagging risk and subsequent presence of derelict gears amongst moorings. However, no such further review has been carried out.

#### 4.6.4.3 Aggregation of fish leading to indirect effects

Indirect effects mediated through effects on prey – e.g. if significantly affecting fish behaviour, may influence marine mammals indirectly. For example, see Section X on potential for fish aggregation as a result of the static component. In this respect, the key issue for marine mammals is that any fish aggregation may result in attraction to the structure for marine mammals, but evidence so far suggests that these effects are mainly seen at slack tides, which may mean risk to marine mammals is not increased, in this instance.

### 4.6.5 Cumulative impacts

If collision is found to be a concern for marine mammals (i.e. even small numbers of animals at risk), it is likely that mitigation measures will be required to be developed and implemented before the industry can scale up to a level at which cumulative impacts, with respect to collision risk, will be a concern. Device designs vary considerably for wet renewables, which is a further consideration to variation in environmental parameters (and their effects on species behaviour) and, more generally, variation in species' behaviour and ecology (e.g. considerations/ input parameters for assessment of harbour porpoise collision risk would be considerably different as compared to bottlenose dolphin). Other concerns, in regard to scaling up of arrays are the potential for large scale displacement and/or barrier effects. However, for all of these concerns, it is very difficult to predict based on the current scale of developments, yet any studies to date suggest small-scale, local displacement. Nonetheless, future array design and co-location will be important to minimise any potential significant cumulative impacts.

Considerations for future data collection include, better functional baseline information, which could include information on site fidelity (individual turnover), fine-scale behaviour (spatial and temporal), functional use of habitat (e.g. foraging ground, corridor/transit route), relevant to interpretation of consequences of any displacements.

More work is needed to understand the hearing thresholds of marine mammals and occurrence of physiological injury (Temporary or Permanent Threshold Shift (TTS/PTS) in hearing); although this is not thought to be an issue for operational noise, it is possibly an issue for noise during the construction and decommissioning phases. Consequently, further work on behavioural responses to loud impulsive noises in relation to construction and decommissioning activities (e.g. pile driving and explosions), is required. More broadly, with respect to applicability to other receptors, both defining thresholds of acceptable change and developing frameworks for cumulative impact assessment (or cumulative effect assessment) remains a challenge (see Section 4.9 for further information on the latter).

## 4.7 Seascape/public perception

There is limited research on the how WEC or TEC might affect seascapes or how public perception might impact their deployment (Devine-Wright, 2011; Bailey *et al*., 2011; Dreyer *et al*., 2017), with the vast majority of studies investigating public acceptance of offshore wind energy (Wiersma & Devine-Write, 2014).

Public acceptance is recognised as an important issue in the implementation of renewable energy technologies and in meeting energy policy goals (Devine-Wright, 2007). A recurring theme considered to be a conditioning factor in the public's perception and attitude towards offshore energy projects is the power they have to provoke oppositions by strongly affecting the concept of place attachment of individuals. This complex and emotive relationship between the public and marine areas may pose some challenges to MRE in general, and to wave energy in particular (Bailey *et al*., 2011). The attachment relationship of communities to the ocean is also argued by Arnold (2004) who concluded that people tend to associate the sea to familiar shorelines and care less about offshore areas due to limitations of personal interactions and lack of deeper sea knowledge. It would be expected that the distance and visual impact reduction factors (inspired by the expression “out of sight, out of mind”) associated with ocean energy projects would increase the social acceptance of this type of energy source compared to wind power projects and other sources. While seascape or visual disturbance is cited a potential concern for wave and tidal devices, there does not appear to exist any evidence that the concern has been realised. However, concerns do not diminish, and existing research is not yet sufficient to establish the effects of this “out of sight, out of mind” on individuals' perceptions. As wave and tidal devices are likely to be offshore and do not project far above the sea surface, they are unlikely to be seen from the shore and thus visual impacts are usually considered less significant when compared to those of offshore wind energy. Although less visible than offshore wind energy devices, the visual impact of wave power technologies should not be overlooked. One of the concerns raised is the signalling light and buoys used to delineate exclusion zones around the sites, which may disrupt the place attachment of the local people (Devine-Wright, 2009). Visual impacts of tidal barrages and tidal lagoons can, however, be large, with often strong negative perception from these developments

Onshore infrastructure such as sub-stations, and especially overhead cables, can also have effects that endure throughout the lifetime of the wave or tidal projects. These can occur from shore to sea and vice versa and may be linked to different phases of the project. Visual impacts from installation or decommissioning may have an effect on heritage assets, though it will only be of limited duration. During operation where the device itself is submerged but is supported by structures that remain visible, or when the device is present at the surface during operation, visual effects on the historic environment have been recommended to be assessed (Firth, 2013).

The degree to which a WEC or TEC scheme has visual impacts on the historic environment is strongly related to the appearance of the proposed devices and supporting structures. At sea, steps have to be taken to ensure that devices and structures are visible to other sea users for safety of navigation and to enable legitimate activities to carry on. Since safety of navigation requirements are not compromised, mitigation measures such as micro-siting (relocation of devices on site), screening or paint schemes that can reduce the visibility of devices and structures might apply (Firth, 2013).

Besides visual impacts research available on WEC and TEC public acceptance focuses mainly on the following areas:

1. Reduction in access to or availability of wave resources typically for leisure activities such as surf. At Wave Hub, stakeholder interviews revealed that initial concerns by local

surfers (e.g. Stokes, Beaumont, Russell & Greaves, 2014) were calmed by the report from Millar *et al.* (2007) stating there would be no impact on surf waves, however, concerns still existed by surfers from outside of the area (West, Bailey & Whithead 2009). Indeed, local surfers suggested benefits including better wave data to improve local surf forecasts.

2. Environmental impacts, potential adverse effects on marine flora, fauna and habitats is one of the top concerns listed by stakeholders; marine mammals and seabirds are the most relevant species mentioned to be affected (Simas *et al*., 2012);
3. Effects on tourism; test centres are located in peripheral coastal regions, so offer the prospect of diversification from low-skill and low-wage traditional industries, such as tourism, agriculture and fishing (Bailey *et al*., 2011). In most cases, however, there is the important proviso, especially among local business representatives, that existing interests would not be adversely affected (Simas *et al*., 2012);
4. Marine space use conflicts e.g. with commercial fisheries and shipping. Concerns over displacement of fishing activity, loss of fishing income and compression of fishing effort into areas outside of the developments (West *et al.*, 2009; Simas, Muñoz-Arjona, Huertas-Olivares, De Groot & Stokes, 2012) have been raised at multiple developments. Fishers in Ireland felt similar, however, they also felt the MRE and fishing could co-exist provided development was managed appropriately (Reilly, O'Hagan & Dalton, 2014).

Research in UK island communities found generally positive attitudes to MRE, but these were strongly shaped by place-related values including seascape, and conflicts with these values was often a major reason for concerns about MRE (de Groot, 2016).

In general, it can be concluded that stakeholders expressed support for the concept of ocean energy. The main reasons for this are reducing fossil-fuel dependence and tackling climate change and reducing dependence on energy imports, which is an evident opinion from stakeholders surveyed in southern European wave energy test centres. The main concerns identified for all test centres, meanwhile, were conflicts in shared-use sea areas, visual impacts and the potential adverse environmental effects of wave-energy projects (Simas *et al*., 2012; Dreyer *et al*., 2017).

## 4.8 Birds

### 4.8.1 Introduction

A bird will be exposed to a potential pressure if there is an overlap between its foraging, resting, or breeding areas and the area where a wet renewable energy development is constructed. Spatial overlap can be quantified at different scales, from whether birds are present in the general region of a development, to whether birds forage at a development site. For underwater devices (e.g. tidal stream devices) potential exposure to a pressure requires quantification of diving parameters, e.g. whether birds spend time at the depths where a tidal stream turbine operates.

Several reports and papers have reviewed the potential impacts of wet renewable developments on birds (*inter alia* Clark *et al*., 2006; Furness *et al*., 2012; Grecian *et al*., 2010; Langton *et al*., 2011; Copping *et al*., 2016), most of these focussed on tidal turbines and wave energy convertors (WECs), including a relatively recent international report (Copping *et al*., 2016). However, very little empirical data exists on the actual impacts of wet renewable developments and devices on birds, thus potential impacts are currently mostly inferred from knowledge of bird ecology and behaviour and from known impacts of other marine industries (e.g. offshore windfarms and shipping).

The risk of negative impacts on birds from wet renewable developments can be quantified from the probability of an interaction between a bird and a wet renewable device occurring in combination with the severity of any negative consequence of such an interaction (ranging from direct mortality to a temporary increase in energy expenditure) (Furness *et al*., 2012; Copping *et al*., 2016). It is important to distinguish between actual risk, i.e. where a risk is quantifiable from empirical observation and/or empirically tested models, and perceived risk, i.e. where uncertainty and lack of empirical data mean that risk cannot be accurately assessed. For wet renewables many risks currently fall into this latter category owing to a lack of sufficient empirical data to quantify risks, with additional data some risks may be possible to 'retire' if found to be biologically insignificant (Copping *et al*., 2016).

For wave and tidal stream devices it is primarily diving bird species that are at risk from negative impacts, while for tidal range developments a broader range of species could be impacted (inter alia waders, gulls, and waterfowl). Further, species may be impacted indirectly through ecosystem changes (e.g. in prey species abundance and distribution) or directly by devices including elements above the sea surface. A wider range of species may be disturbed by vessel traffic and general activity throughout a development cycle from construction, to operation and maintenance, and to eventual decommissioning.

The likelihood of marine birds to be significantly impacted by offshore renewable developments has been classified using sensitivity scoring approaches which predict the risk of a species being negatively affected by a development by using a combination of an understanding of a species ecology and behaviour (Furness *et al*., 2012; Wade *et al*., 2016). As the potential impact pathways differ between development types a single sensitivity score for a species cannot be used. Furness *et al*. (2012) produced sensitivity scores for species occurring in Scottish waters separately for tidal stream turbine devices and wave energy convertors (WECs). Similar approaches have been applied for sensitivity to offshore wind farms in both German and Scottish waters (Garthe & Hüppop, 2004; Furness *et al*., 2013) and such approaches could be applied in other areas for new development types in future. Sensitivity scores for birds have not been calculated for tidal lagoons and barrages, however the species likely to be affected has been reviewed (Clark, 2006).

Pressures can lead to lethal effects (e.g. collision mortality) or sub-lethal effects (e.g. displacement from foraging areas and disturbance). Pressures may also act indirectly through changes to physical processes affecting prey species thus affecting foraging birds. Some pressures may act independently while others may interact, e.g. diving birds could forage more in a development area if prey abundance increased (e.g. through a reef effect) but this could increase exposure to other possible pressures (e.g. collision with tidal turbines).

The level of impact is likely to increase the larger the scale of development, an array of multiple devices will generally pose a higher risk to a population than a single device or small-scale development (Copping *et al*., 2016). For instance, displacement effects are expected to be minor for a single WEC device but may become significant for larger scale arrays. How risk scales up from developments with a single or a few devices to large scale commercial arrays is unclear, this is especially case for dynamic devices (Copping *et al*., 2016).

The main potential stressors for birds from wet renewable development are described further down. There are other possible stressors but these are unlikely to lead to significant population-level impacts for bird species: EMF, Energy Removal, and chemical discharge or leaching (Copping *et al*., 2016).

While there is a good general understanding of the range of potential risks, there remains large uncertainty on the likelihood of impacts and of the potential severity of impacts. As such, it is important that robust monitoring programmes are setup when developments are constructed, such that uncertainty can be reduced to inform the permitting of later developments. This model is applied in Scotland through the policy of 'Survey, Deploy and Monitor' (Scottish Government, 2016), where consents for developments include conditions for post-construction monitoring in addition to pre-construction pre-consent site surveys to collect baseline data on how birds use an area.

Pre-construction surveys for wet renewables should ideally both classify to what extent a proposed development site is used by birds (i.e. bird densities) and more fine-scale associations of activity of birds in relation to the type of development proposed. For tidal stream developments understanding fine scale habitat associations (tens-hundreds of metres) may allow fine-scale siting of devices to avoid tidal current features used by diving birds, such as high turbulence and downward vertical current features used by several pursuit-diving seabird species (Wagitt *et al.*, 2016). Similar principles may be relevant to other wet renewables, such as WECs, though this remains to be explored.

As sites for wet renewable developments are often inshore, shore-based observations may be chosen to determine baseline distributions of birds, however such surveys may produce biased estimates of bird distributions (Copping *et al.*, 2016; Wade, 2015; Waggitt *et al.*, 2014), especially for sites with fast tidal currents (Waggitt *et al.*, 2014). As such it is advised that if shore-based observations are made, viewsheds should not exceed 1.5 km (Wade, 2015). Alternatively, boat or aerial surveys may be used to provide observations that are not biased against birds more distant from shore.

Monitoring of interactions between birds and wet renewables is increasingly possible with underwater platforms developed incorporating detection systems including acoustic sensors and cameras (Williamson *et al.*, 2016, 2017; Polagye *et al.*, 2014). While biologging devices including GPS tracking and dive loggers are improving our understanding of the foraging behaviour of birds including during dives, which can help inform on e.g. collision risk (Masden *et al.*, 2013).

### 4.8.2 Overview of possible impacts of wet renewables on birds

### 4.8.3 Static Component

Wet renewable developments may lead to displacement of birds. Some species will avoid the structures, while for others attraction may occur. Birds may be attracted to manmade structures at sea as artificial roosting sites (Dierschke *et al.*, 2016; Tasker *et al.*, 1986), while at night and under low visibility condition artificial illumination may also attract birds (Montevecchi, 2006). Attraction could increase the likelihood of other stressors impacting birds by increasing the density of birds in an area or increasing foraging activity. At a demonstration WEC device an autonomous camera system recorded several species roosting on the device, including black guillemot (Jackson, 2014), a pursuit diving species potentially vulnerable to underwater collision.

For devices including parts above the water surface birds could also collide during flight (Grecian *et al.*, 2010). Collision between flying birds and rotor blades of offshore wind turbine generators has been a major concern for offshore wind development (e.g. Masden & Cook, 2016), however it is likely to be a significantly lower risk for wet renewables as parts above the surface will likely be stationary or moving at much slower speeds than the rotors of wind turbine generators.

### 4.8.4 Dynamic Component – collision risk

Underwater collision between diving birds and wet renewable devices may lead to direct mortality thus is considered a high priority risk. However, to date no collision between a wave and tidal device and a seabird has been observed (Copping *et al.*, 2016). Unlike marine mammals, birds will generally only dive when foraging (flightless species such as penguin being absent in the OSPAR area), thus collision is only likely to occur where wet renewable developments overlap with areas where seabirds forage. Devices that have parts moving at speed underwater are most likely to lead to mortality in diving birds, thus tidal stream devices (both kites and turbines) are the main types of wet renewable developments considered to pose a collision risk to birds.

The potential for collision mortality is assessed through collision risk modelling (CRM), for on- and offshore wind turbine generators CRMs are quite well developed and are widely applied in environmental assessments for proposed wind developments, though uncertainty remains on likely levels of collision mortality owing to uncertainty in avoidance rates, flight heights, and flight speeds (Masden & Cook, 2016; Johnston *et al*., 2014; Masden *et al*., 2015). For tidal current devices there is much greater uncertainty and no consensus on likely levels of mortality nor of how collision risk should be quantified.

For tidal current devices a variety of CRMs have been developed with three main approaches: Band adapted (Davies & Thompson 2011), SRSL encounter model (Wilson *et al*., 2007), and exposure time population modelling approach (Grant *et al*., 2014). Collision risk arises from a combination of tidal device parameters (e.g. turbine swept area), site usage by diving birds, bird diving behaviour, and bird biometry. Alternative CRM modelling approaches use different subsets of these parameters to quantify collision risk.

Tidal stream devices usually rely on strong tidal currents, so are likely to be sited at relatively inshore sites often proximate to headlands and islands. The probability of a species interacting with tidal stream devices is dependent on an overlap in habitat use with tidal stream device development sites. However, general overlap between bird distribution and development sites may be insufficient to suggest risk as to have a risk of collision with tidal turbines, birds must be diving at the location of turbines and to the depths where these operate, i.e. sharing the same microhabitat (Waggitt & Scott, 2014; Waggitt *et al*., 2016). For the MeyGen tidal turbine development (Orkney, Scotland, UK) several species of seabird were observed in the development area (MeyGen, 2012), yet more detailed observations suggest that only a subset of these species were regularly diving in the area (Wade, 2015).

Collision risk models usually include a flux component, that is the number of birds moving through an area over a given time period. For flying birds this may be a realistic simplifying assumption, but for diving birds this may be less applicable as these dives are usually performed in a repeat sequence as the birds have to surface to breath and/or handle prey captured. Some species may use a strategy termed 'tidal conveyor', diving into a current and drifting downstream with the current, then flying up current before diving again (observed by Roger (2014) cited by Copping *et al.* (2016)), such behaviour has the potential to increase probability of interactions with sub-surface wet renewables for individual birds foraging in a development area.

While CRM models attempt to predict the potential number of birds colliding with devices, and ultimately mortality, other modelling approaches look to increase our mechanistic understanding of seabird collisions with tidal current devices. Chimienti *et al.* (2014) modelled how diving behaviour may vary depending on prey distribution, the seascape, and the presence of underwater devices. Such approaches may allow CRMs to be refined to incorporate more realistic models of diving behaviour. These modelling approaches, when informed by empirical studies of diving behaviour (e.g. Chimienti *et al*., 2016; Masden *et al*., 2013), may reduce uncertainty in CRM parameter values and quantify variation around parameter means. Such information could allow for underwater CRMs to provide collision estimates with a measure of uncertainty in a similar way to recently developed stochastic CRMs for aerial collision of seabirds in flight with offshore wind turbine generators (Masden, 2015; McGregor *et al*., 2018).

### 4.8.5 Sound

Noise may arise from vessel traffic, installation, operation, and decommissioning activities (Copping *et al*., 2014). Other than operational noise most noises will be short in duration, though may be significant, e.g. if piling is required for device foundations. Existing measures of operational noise levels from both wave and tidal devices suggest that operational noise levels are unlikely to cause injury or significant behavioural effects (Copping *et al*., 2016). As diving birds operate both above and below water these species are exposed to both underwater and aerial noise.

The vulnerability of marine birds to acoustic disturbance is poorly understood. Experimental work suggests some diving bird species may have relatively good underwater hearing (Johansen *et al*,. 2016) though to what extent hearing is used by diving birds during foraging is not well understood. African penguin (*Spheniscus demersus*) were recently found to change their foraging areas during periods of intense underwater noise (seismic surveys) (Pichegru *et al*., 2017), which suggests that other pursuit diving seabird species could potentially be vulnerable. Similar to marine mammals, there are two main potential impacts for sound, damage to hearing either temporary or permanent (temporary or permanent threshold shift respectively) and changes in behaviour, e.g. displacement from an area, or avoidance/escape flights, as well as potential indirect impacts such as changes in the distribution of prey in response to noise. Acoustic disturbance is expected to be more detrimental when birds have limited mobility, e.g. if flightless during moult or for adults accompanying flightless young (i.e. they cannot fly to escape). Operational noise also has the potential to be a positive effect by providing an audible cue that may lead to birds increasing avoidance of a development, and thus reducing the probability of interacting with a device (Inger *et al*., 2009).

## 4.9 Others

### 4.9.1 Turtles

Five species of sea turtle are known to occur within the OSPAR Regions: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), Kemp's Ridley (*Lepidochelys kempii*), and leatherback (*Dermochelys coriacea*). The two species of main concern within the OSPAR Regions are *C. caretta* (OSPAR Commission 2009b) and *D. coriacea* (OSPAR Commission 2009a). There are no turtle nesting sites along the Western European margin. All species of sea turtle are protected in the OSPAR Regions under various international legislation including, *inter alia*, the EU Habitats (European Commission, 1992) and Marine Strategy Framework (European Commission, 2008) Directives; the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention, 1979); the Convention on International Trade in Endangered Wild Fauna and Flora (CITES, 1984); and the OSPAR Convention on the Protection of the Marine Environment of the North-East Atlantic (OSPAR, 1992).

*C. caretta* are found in high numbers around the Azores (Region V) but are also occasional storm-blown vagrants to the Celtic Seas (Region III) and the Bay of Biscay/Iberian Coast (Region IV). This restricted distribution of *C. caretta* may limit the impacts on this population to those which are likely to result from installations developed in those waters.

The occurrence of *D. coriacea*, however, is more widespread within the North Atlantic, and thus all waters of the OSPAR Maritime Area are considered part of their natural foraging range, with the offshore waters of Region IV suggested as an area of high use within the NE Atlantic (Eckert, 2006; Doyle, Houghton, O'Súilleabháin, Hobson, Marnell, Davenport & Hays, 2008). In the NE Atlantic, their presence is seasonal, with highest numbers occurring during the late summer and autumn. They are less frequent visitors inshore but are still occasionally recorded in the coastal waters of UK and Ireland (Doyle *et al.*, 2008; Rogan, Breen, Mackey, Cañadas, Scheidat, Geelhoed & Jessopp, 2018).

Populations of both species are thought to be in decline, primarily due to bycatch in fisheries (Ferreira, Martins, Da Silva & Bolten, 2001; Deflorio, Area, Corriero, Santamaria & DE METRIO, 2005; Hamelin, James, Ledwell, Huntington & Martin, 2017), loss of breeding/nesting habitat (Witherington, Kubilis, Brost & Meylan, 2009; Witt, Hawkes, Godfrey, Godley & Broderick, 2010; Bolten, Crowder, Dodd, Macpherson, Musick, Schroeder, Witherington, Long & Snover, 2011; Willis-Norton, Hazen, Fossette, Shillinger, Rykaczewski, Foley, Dunne & Bograd, 2015), and plastics (Mrosovsky, Ryan & James, 2009; Campani, Baini, Giannetti, Cancelli, Mancusi, Serena, Marsili, Casini & Fossi, 2013; Barreiros & Raykov, 2014; Schuyler, Wilcox, Townsend, Wedemeyer-Strombel, Balazs, van Sebille & Hardesty, 2016). The health of the North Atlantic population of *D. coriacea* is of particular importance in light of the > 90% decline in the Pacific nesting population over the past three decades (Crowder, 2000; Spotila, Reina, Steyermark, Plotkin & Paladino, 2000; National Marine Fisheries Service & US Fish and Wildlife Service, 2013). Thus, any potentially new threats need to be critically evaluated to determine their possible impact on sea turtle populations, and to allow managers to design and implement effective management plans.

#### 4.9.1.1 Static Component

There is no clear risk of animals colliding with static components (Copping, Sather, Hannah, Whiting, Zydlewski, Staines, Gill, Hutchinson, A, Simas, Bald, Sparling, Wood & Masden, 2016). This should hold true for sea turtles, due to their slow swimming speed of sea turtles and easy avoidance of static structures. Dense arrays of MRE devices may result in the avoidance of areas previously utilised by sea turtles, excluding them from habitats used for foraging or causing displacement along migratory routes (Copping *et al.,* 2016). Static components of MRE devices, such as foundations, may promote the growth of reef habitat. This could increase foraging opportunities for turtles such as *C. caretta* and *D. coriacea* (Duarte, Pitt, Lucas, Purcell, Uye, Robinson, Brotz, Decker, Sutherland, Malej, Madin, Mianzan, Gili, Fuentes, Atienza, Pagés, Breitburg, Malek, Graham & Condon, 2013; Makabe, Furukawa, Takao & Uye, 2014; Barnette, 2017). In addition, arrays of MRE devices may create de-facto marine protected areas, thereby reducing the pressure on sea turtles from fisheries bycatch (Copping *et al.,* 2016). Overall, there is a lack of specific knowledge on how turtles specifically may be impacted by static components of MRE devices.

#### 4.9.1.2 Dynamic Component

There is some risk of collision, or inability to avoid, the moving parts of tidal device. It is possible sea turtles could become trapped, maimed, or otherwise harmed in the dynamic components of a tidal device, e.g. the blades of a submerged turbine (Copping *et al.* 2016), which may lead to mortality. According to Copping *et al*. (2016), there has been a general lack of concern expressed regarding the potential for harm from the dynamic components of a WEC device. However, it is possible that those devices with a large surface expression and oscillating parts could pose a collision risk to sea turtles.

#### 4.9.1.3 Cables

Sea turtles have been shown to use the Earth's magnetic field in navigation (Lohmann, Putman & Lohmann, 2012; Brothers & Lohmann, 2015). Cables carrying electric current (and which thus emit an electromagnetic field (EMF)) could disorientate sea turtles, particularly hatchlings (Copping *et al.,* 2016). This is of greater concern for floating MRE devices, which may have electric cables hanging down through the water column. However, there is very little research published on the impacts of EMF on turtles, and thus the level of impact is uncertain.

The physical presence of mooring lines, anchor lines, or power cables may all act to directly entangle or entrap sea turtles within an MRE device array (Copping *et al.*, 2016). Furthermore, the possibility of "ghost" fishing gear becoming caught on cables could result in the indirect trapping and subsequent drowning of sea turtles. However, there is a paucity of literature on interactions between sea turtles with wave and tidal energy devices, and limited knowledge of such interactions with offshore wind farms (Copping *et al.*, 2016).

#### 4.9.1.4 Sound

Piniak *et al*. (2012) demonstrated that the hearing sensitivity of *D. coriacea* overlaps with the frequency and source levels of many anthropogenic noise sources, including seismic airgun arrays, drilling, low-frequency sonar, shipping, pile driving, and operating wind turbines, with the greatest sensitivity shown to be between 100–400 Hz in water and 50–400 HZ in air. Martin *et al*. (2012) found a very similar degree of sensitivity in *C. caretta*, with the greatest sensitivity also recorded at 100–400 Hz. This finding was supported by Lavender *et al*. (2014).

While little to no research has yet been carried out to determine the physiological and behavioural responses of sea turtles to noise pollution (Popper, Hawkins, Fay, Mann, Bartol, Carlson, Coombs, Ellison, Gentry, Halvorsen, Løkkeborg, Rogers, Southall, Zeddies & Tavolga, 2014), it has been suggested that turtles may be impacted by the masking of auditory cues (Copping *et al.*, 2016). Sea turtles have been observed exhibiting an escape/startle response when in the vicinity of active airgun arrays (Deruiter & Larbi Doukara, 2012). In their review of publication patterns on the impacts of anthropogenic noise on marine life, Williams *et al*. (2015) noted that sea turtles remain understudied, with "only two abstracts solely mentioning them".

#### 4.9.1.5 Energy removal

The removal of kinetic energy on a large scale has the potential to impact a diverse range of physical processes. Any change to the flow of water may result in changes to primary production, with cumulative effects on higher trophic levels. Of significance for sea turtles would be any change in the occurrence, density, and abundance of species upon which they predate, e.g. various jellyfish species. This may act to alter the behaviour of turtles, possibly causing them to be attracted or to avoid MRE device arrays (Copping *et al.*, 2016). Doyle *et al*. (2008) described contrasted the recorded movements of two *D. coriacea*, tagged off the south west of Ireland: T1 immediately travelled south to feeding grounds west of Africa via Madeira and the Canaries; T2 travelled south to the Bay of Biscay, where it remained for 66 days. The movement of the latter coincided with a mesoscale eddy feature (evident from satellite imagery), which may have proven to be a rich feeding area. Thus, it is not unlikely that leatherback turtles could be attracted to areas where jellyfish (their main prey) begin to occur more regularly, in denser numbers.

#### 4.9.1.6 Contaminants

Again, a lack of turtle specific information exists within the literature. It possible that bioaccumulation of toxins could occur for turtles which prey on species of jellyfish. This could be of particular relevance for near shore tidal devices which may use stronger biocides or antifouling paint (Copping *et al.*, 2016), and those toxins could then be absorbed by organisms upon which jellyfish predate. It is also possible that leakage of lubricants, fuels, hydraulic fluids or other liquid hydrocarbons could cause acute damage to turtles (suffocation, poisoning) on a local scale (Copping *et al.*, 2016). These threats are extrapolated from those which may exist for marine mammals and fish.

### 4.9.2 Otters

The impact of MRE on otters (*Lutra lutra*) has not been well studied. When assessing the environmental impact of proposed MRE projects, if likely to be present in the vicinity, otters will be included in the assessment, typically under the 'terrestrial and intertidal ecology heading'. Like cetaceans, otters are European Protected Species (listed on Annex IV) so are afforded strict protection. The potential for impact is likely to be restricted to disturbance and habitat loss from onshore and intertidal construction and O&M activities, although if devices were deployed near to shore, there is the potential for collision related impacts, given that coastal otters are assumed to forage up to 100 m from the shore, diving to depths exceeding 10 m (Conroy & Jenkins, 1986, McCafferty, 2004).

### 4.9.3 Polar bears

There is very little information on the potential for any impact of MRE on polar bears (*Ursus maritimus*) and the extent to which tidal energy developments may happen in polar bear habitat is unknown, although likely to be small given that these areas are subject to extensive and shifting sea ice which may damage MRE devices. Similar to otters, impacts may be primarily related to disturbance and habitat loss from associated onshore construction activities. Collision and underwater noise disturbance may be potential impacts, but these are unlikely to significantly impact on polar bears given their semi-aquatic habits.

## 4.10 Cumulative impacts

From the sections above, it is clear that there is an emerging knowledge base that allows assessing the effect of the deployment of marine energy devices on many receptors. However, marine renewable energy devices are generally installed in marine areas where a plethora of other activities (fishing, aggregate extraction, oil and gas exploration, navigational dredging, building of artificial hard structures for coastal defence, harbour walls) are already in place. Hence, receptors are not only subjected to the stressors associated with the marine renewable energy devices, they are subjected to the combination of stressors originating from the sum of the ongoing activities. Cumulative Effect Assessment (also: Cumulative Impact Assessment) – holistic evaluations of the combined effects of human activities and natural processes on the environment (Stelzenmüller, Coll, Mazaris, Giakoumi, Katsanevakis, Portman, Degen, Mackelworth, Gimpel, Albano, Almpanidou, Claudet, Essl, Evagelopoulos, Heymans, Genov, Kark, Micheli, Grazia, Rilov & Rumes, 2018) – theoretically offer a tool to investigate the integrated effect of multiple human activities on the ecosystem. However, Cumulative Effect Assessment (CEA) is currently an umbrella term for a broad range of methodologies, driven by multiple drivers (Willsteed, Gill, Birchenough & Jude, 2017), suffering from in inconsistent terminology (Stelzenmüller *et al.*, 2018). Rather than discussing the problems and solutions in the entire scientific field of CEA methodologies, this report will focus on CEA with respect to renewable marine energy devices. Currently, most of these devices are offshore wind farms, but the principles and guidelines are assumed to be similar to CEAs associated with the wet renewables described in the current report.

Willsteed *et al*. ((Willsteed *et al*., 2017), in an attempt to establish common ground for CEAs of marine energy developments, listed 6 considerations to be taken into account when conducting CEAs: (1) temporal accumulation of cumulative effects; (2) spatial accumulation of cumulative effects; (3) endogenic and exogenic sources of pressures; (4) ecological connectivity; (5) receptors at the centre of assessments and (6) purpose and context of the CEA. In a review of 9 CEAs conducted for 9 offshore wind farms in the UK, (Willsteed, Jude, Gill & Birchenough, 2018) found that the spatial aspect of activities and pressures was dealt with more comprehensively then the temporal aspect. Applied spatial boundaries were straightforward to understand and applicable to the receptors identified for the assessment. Temporal boundaries scored less well, as they followed the assumption that temporal pressures exist for the duration of the activity and did not consider the temporal aspects of pressures relative to the receptors. Endogenic pressures are those created within the system that can be managed, while exogenic pressures are emanated outside the system or operate at scales beyond the system (Elliott, 2011). Climate change is such an exogenic pressure, and needs to be taken into account CEA, as it can interact with endogenic pressures, given the time scales of MRED lifecycles. Ecological connectivity refers to the fact that ecosystem components are interacting (i.e. changes in prey abundance can affect food-web properties). This requires a shift in CEA, where currently the effect of stressors is assessed to unlinked receptors in the environment. The road forward is to move away from assessing effects on individual species and take a broader perspective considering the existing connections between ecosystem components and how they affect the functioning of the marine environment. Establishing clear cause-effect relationships, cascading through different components of the ecosystem can be a way forward (Dannheim *et al*., 2019). In addition, there is an urgent need to place receptors at the basis of assessments. Generally, CEAs follow a stressor-led approach, assessing how a single stressor from one development and the same stressor associated with another activity in a proximal development would affect a receptor (Duinker, Burbidge, Boardley & Greig, 2012). However, it should be acknowledged that receptors experience a wide range of stressors, originating from a single or multiple activity. Hence, CEAs should investigate the combined effect of these stressors on the receptor, which in turn can lead to improved consistency between CEAs as it will enable the development of unified metrics that can be applied to a receptor or an ecological function (Segner, Schmitt-Jansen & Sabater, 2014). All of the above calls for CEAs taking into account the ecosystem approach to management. As such, it is advised that context of CEA moves away from a sectorial point of view, recognising that the combined sources of pressures, rather than isolated sectors, require an integrated management to achieve sustainable use of the marine environment (Elliott, 2011).

Taking into account the considerations listed for CEAs for MRED (Willsteed *et al*., 2017) is however not straightforward. First of all, the marine ecosystem needs to be investigated on a three-dimensional spatial scale to take into account the connectivity between geographically separated areas caused by large dispersal distances of eggs and larvae of a large number of marine species (Barbut, Grego, Delerue-Ricard, Vandamme, Volckaert & Lacroix, 2019). Secondly, despite a large body of research there is still a lack of clear understanding on the link between ecosystem structure and functioning in the marine realm (Daam, Teixeira, Lillebø & Nogueira, 2019), but recently MRED related cause-effect relationships resulting in altered ecosystem functioning have been mapped (Dannheim *et al*. in press). However, the interactions between ecosystem components and multiple (exogenic) effects can be complex, (additive, synergistic or antagonistic (Crain, Kroeker & Halpern, 2008)) and non-linear, requiring deeper consideration (Stelzenmüller *et al*., 2018). Both Stelzenmüller *et al*. (2018) and Willsteed *et al*. (2017) suggest making use of trait-based information on receptor organisms to identify and predict multiple stressor effects. Public databases collecting and sharing trait information (i.e. Biotic – www.marlinac.uk/biotic, WoRMS – www.marinespecies.org) are considered crucial for the development of such trait-based approach in CEAs (Stelzenmüller *et al*., 2018). Furthermore, data collection for the purpose of assessing the effect of MRED (and other human activities) is very often pursued by monitoring programmes that are not necessarily structured around scientific sound cause-effect relationships. As such, they provide little useful data in relation to ecosystem-scale related changes and are therefore considered 'Data Rich, Information Poor – DRIP' (Wilding, Gill, Boon, Sheehan, Dauvin, Pezy, O'Beirn, Janas, Rostin & De Mesel, 2017). Data collection should be at the relevant spatial scale (often beyond the local scale of the MRED) (Wilding *et al*., 2017), based on established cause-effect hypotheses (Dannheim *et al*. in press) and should be fit for contribution to quantitative models mapping the vulnerability of ecosystem components to specific pressures (Stelzenmüller *et al.*, 2018). Data should then be made freely available through easily accessible interfaces, including web portals (i.e Emodnet, www.emodnet.eu) to allow conducting CEAs at the relevant spatial scales.

As a consequence of the lack of data, CEAs suffer from uncertainty (Stelzenmüller *et al.*, 2018). Regarding CEA for MRED developments, uncertainty is often considered as the uncertainty about the likelihood of other future activities and whether them to include or exclude in the CEA (Willsteed *et al.*, 2018). However, other sources of uncertainty include a lack of (good-quality) data and knowledge, low predictive ability of ecosystem behaviour, natural variability and changing policies (see (Stelzenmüller *et al.*, 2018). Taking them into account using standardised methodology (Stelzenmüller, Vega Fernández, Cronin, Röckmann, Pantazi, Vanaverbeke, Stamford, Hostens, Pecceu, Degraer, Buhl-Mortensen, Carlström, Galparsoro, Johnson, Piwowarczyk, Vassilopoulou, Jak, Louise Pace & van Hoof, 2015) would support decision-makers in making determinations of environmental risk associated with the developments of MRED (Masden, McCluskie, Owen & Langston, 2015).

# 5 What can we do next?

It is now clear that wet renewable energy devices will be installed at increasing speed. While these devices will reduce $CO_2$ emissions associated with energy production, there is no doubt that these devices will have an effect on multiple components of the marine environment. In addition, current technologies will have to be decommissioned at a certain moment, while newly emerging technologies will create new challenges towards an environmentally friendly exploitation. This will require science-based marine spatial planning that allows to reconcile the installation of wet renewables with the desire to keep the marine environment in a healthy state. Below, three emerging topics for the future are discussed.

## 5.1 Towards assessing the effects of wet renewables using the ecosystem approach

The ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. This approach differs from most of the current studies investigating the effect of wet renewables, as they are generally targeted towards investigating the effect of the device on a single receptor of interest. However, interactions between renewable energy devices and ecosystem components can cause changes that are of a sufficient scale to change ecosystem services provision, particularly in terms of fisheries and biodiversity and, change the distribution of fish, birds and mammals through changes in the trophic linkages (Wilding *et al.*, 2017). To our knowledge, there is no evidence yet on how wet renewables affect the provisioning of ecosystem services to society. Pioneering work on the effect of offshore wind farms on the provisioning of marine ecosystem services showed that these offshore wind farms have mixed impacts across ecosystem services, with negative effects on the sea-scape and the spread of non-native species and positive impacts on commercial fish and shellfish (Hooper, Beaumont & Hattam, 2017). However, the same authors stressed the need for a better understanding of long-term and population effects of offshore wind farms on species and habitats, and how these are placed in the context of other pressures in the environment. Such increased understanding will not be achieved through the execution of standard monitoring programmes, designed for assessing change in selected receptors after the installation of the renewable energy devices. Many monitoring programmes lack clarity and rigour and are unrelated to justified temporal or spatial scales, and therefore did not contribute to an increased understanding of the interactions between marine renewable energy devices and the marine ecosystem at relevant scales (Wilding *et al.*, 2017). Most monitoring programmes focus on assessing structural aspects (density, diversity, occurrence, *etc.*) of selected component of the marine ecosystem and no not focus on how the structural changes can affect important ecosystem processes underpinning the provisioning of ecosystem services (Duncan, Thompson & Pettorelli, 2015). An increased understanding of the effect of marine energy renewable devices on the provisioning of ecosystem services will need a mapping of the multiple direct and indirect effects on ecosystem processes on how these processes relate to the delivery of ecosystem services (Figure 26, Causon & Gill, 2018)

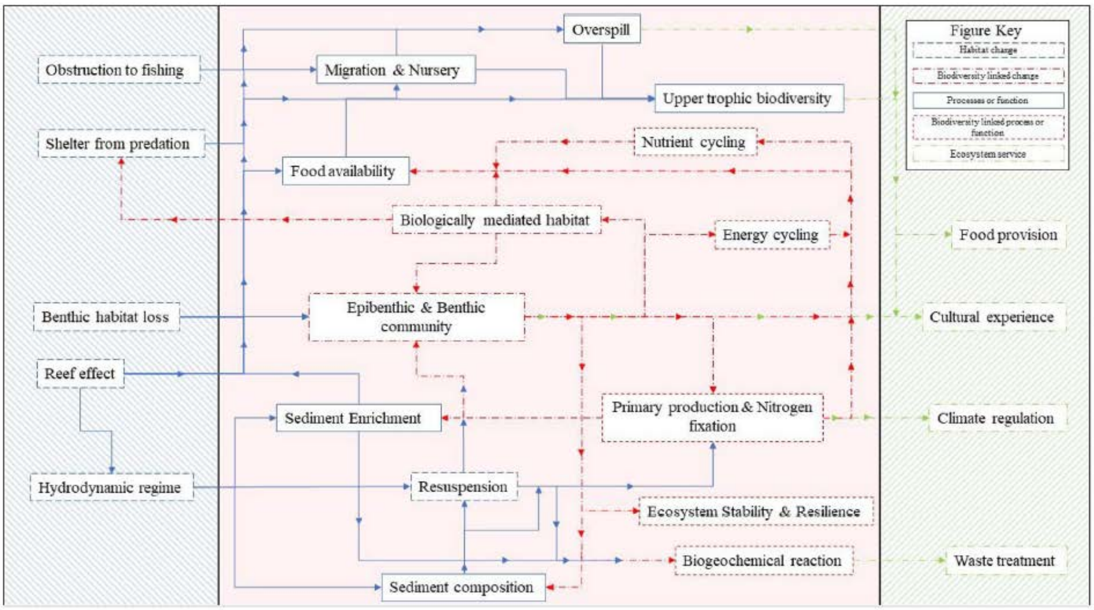


**Figure 26. Biodiversity mediated linkages between habitat modification, ecosystem processes and functions, and the provision of ecosystem services in relation to offshore wind farm structures. Zones represent direct changes (blue hatching – left), secondary changes effecting processes and functions (red – centre), and linked ecosystem services (green hatching – right) (Causon & Gill, 2018).**

Based on such mapping, cause effect relationships can be formulated (Dannheim *et al*. in press) that can serve as the basis for hypothesis-driven research (versus monitoring), at relevant temporal and spatial scales and yield useful data to assess relevant ecosystem-level change (Wilding *et al*., 2017), which will at the same time help overcome the current problems (uncertainty due to lack of relevant data) faced in the Cumulative Effect Assessment procedures (see above).

Such data, reflecting changes in the biotic and abiotic components of the ecosystem can be used to further develop or fine-tune ecological and oceanographic models to allow a sound estimation of the effects of multiple wet renewables (and future technologies, see below), in combination with other human uses, on the health of the marine ecosystem, and it's capacity to deliver ecosystem services.

However, at the moment there are no harmonized (response variables, methodology, data storage) data collection, data storage and exchange procedures in place, and a coordinated research agenda is lacking as well. Setting up regional databases where relevant information (generated by both academia and industry) is compiled and made accessible to researchers, policy levels and industry would be a major step forward (Wilsteed *et al*., 2017). A second key challenge is setting up a cross-border coordinated and multidisciplinary research agenda that enables for generating a scientific sound knowledge base that allows to combine the aim to reduce greenhouse gas emission with the drive to ensure a healthy marine environment.

## 5.2 Decommissioning

Regardless of the technique applied, all offshore renewable energy installations in the OSPAR region will need to be removed during decommissioning at the end of their productive life (Smyth *et al*., 2015; Fowler *et al*., 2018). The impact of this removal has not been included in the review performed here. The activities performed during decommissioning and removal, will result in changes to the environment. For example, vessel traffic will increase temporarily, seabeds will be disturbed when objects are removed from the sediment and artificial habitats will change back to natural habitats. To date, only a few renewable energy farms have been decommissioned (Gourvenec, 2018) and little consideration has been given to the best environmental options for decommissioning of offshore renewables (Smyth *et al*., 2015). A recent study showed that, although aiming to restore pre-existing conditions via removal, full removal is not considered the best option in all situations by many scientists (Fowler *et al*., 2018). Alternatives include toppling of structures, leaving parts of the foundation *in situ*, as well as relocation to a central location (Smyth *et al*., 2015; Fowler *et al*., 2018). Several scientist's pleas for the application of a multi-criteria decision analysis to provide the best solution after considering all options and their environmental, social and economic impacts (Fowler *et al*., 2015; Gourvenec, 2018), which again should be based on the best scientific evidence possible and taking into account the provisioning of multiple ecosystem services to society.

## 5.3 Emerging technologies

In addition to the wet renewable techniques assessed in this report, techniques are emerging that might in the future be applied offshore in the OSPAR region. These techniques are at various technology readiness levels, with some still in the proof-of-concept phase or laboratory validation while others will be tested with offshore pilots in the near future. They include floating offshore solar farms, in which existing floating solar technology is developed for projects at lakes and for protected sea sites such as lagoons and harbours. The first offshore floating solar pilot for the OSPAR region is currently being prepared for the North Sea in The Netherlands (Bellini, 2018). Energy production is expected to be 10–15% higher than land-based solar systems due to the reflection and cooling effect of the seawater (Grech *et al*., 2016; Sahu *et al*., 2016). Additional techniques include salinity gradient power generation, at locations where a gradient between saline and fresh water is present. Electricity is generated using membrane-based techniques such as pressure-retarded osmosis and reverse electro-dialysis (Jia *et al*., 2014). Applications of the technique have been limited to only a few projects outside controlled environments (REDstack, 2019). Combinations of techniques, such as wave energy combined with energy storage systems, is expected to arise in the future. The Ocean Grazer, for example, combines wave energy converter technology with on-site energy storage, around wind turbines. The intention is to increase energy production while storing excess energy from both the turbine and wave system as liquefied hydrogen (Ocean Grazer B.V., 2019).

# 6 Conclusions

Although the bulk of the renewable energy generated by marine devices is produced by offshore wind farms, it is clear that wet renewables will be increasingly installed in the marine environment in the near future. The installation of wet renewable devices will lead to changes in both the abiotic and biotic components of the marine ecosystem. The static part of the devices will tend to affect the abiotic components, benthos, fish and possibly turtles and birds. There is little mention of impacts of the static component on marine mammals. The dynamic parts of wet renewables affect both the abiotic environment and all biota, mainly through the risk on collision. Cables are likely to affect the abiotic environment locally, with electromagnetic fields associated with the cables having an effect in terms of acting as a barrier for migrating fish and turtles when not sufficiently buried. There is little evidence that there will be EMF impacts on mammals or birds. Underwater sound has been shown to have an impact, mainly on fish and marine mammals, and mainly during the construction phase. During the operational phase, underwater sound generated by the wet renewables can mask biologically important signals (i.e. affecting echolocation in cetaceans). Energy removal affects both the water column and sediment dynamics, and can result in changes in benthos and associated prey species for higher predators such as seabirds and marine mammals, resulting in changes in distribution. Risks associated with contaminants are largely linked to sediments, where they can become trapped and redistributed through sediment transport mechanisms. While benthos is the immediately affected biotic group, bioaccumulation and biomagnification of contaminants may result in impacts further up the food chain.

Assessing cumulative impacts (the integrated effect of wet renewables and other human activities) remains problematic due to a lack of available data and the general practice of stressor-based assessments. The suggested way forward is to move towards receptor-based assessments, considering both the ecological links between the abiotic and biotic components of the marine ecosystem and the feedback links between the different biotic components. This can be achieved by hypothesis-driven research, taking into account the link between structural components and the functioning of marine ecosystems, as this ultimately determines the provisioning of marine ecosystem services to society. This calls for cross-border coordination and cooperation in setting standards on data collection, sharing and setting research agendas.

# 7 References

Adams *et al*. 2014 Offshore marine renewable energy devices as stepping stones across biogeographical boundaries. Journal of Applied Ecology 51:2. https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.12207

Adcock TAA, Draper S, Houlsby GT, Borthwick AGL, Serhadlioğlu S (2013) The available power from tidal stream turbines in the Pentland Firth. Proc R Soc A Math Phys Eng Sci

Arnold, A. (2004) A Review of Public Attitudes Towards Marine Issues Within and Beyond New Zealand. New Zealand Government - Department of Conservation - DOC Science Publishing.

Ashton, G., Boos, K., Shucksmith, R., Cook, E. 2006. Rapid assessment of the distribution of marine non-native species in marinas in Scotland. Aquatic Invasions 1: 209–213.

Bailey H, Brookes KL & Thompson PM (2014) Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquat Biosyst 10:8.

Bailey, I., West, J., Whitehead, I. (2011). Out of sight but not of mind? Public perceptions of Wave Energy. Journal of environmental Policy and Planning 13(2): 139-157

Barbut L, Grego CG, Delerue-Ricard S, Vandamme S, Volckaert FAM & Lacroix G (2019) How larval traits of six flatfish species impact connectivity. Limnol Oceanogr 0.

Barnette MC (2017) Potential impacts of artificial reef development on sea turtle conservation in Florida. NOAA Tech Memo NMFS-SER-5:36 pp.

Barreiros JP & Raykov VS (2014) Lethal lesions and amputation caused by plastic debris and fishing gear on the loggerhead turtle Caretta caretta (Linnaeus, 1758). Three case reports from Terceira Island, Azores (NE Atlantic). Mar Pollut Bull 86:518–522.

Bellini E (2018) Dutch consortium plans world’s first “off-shore” floating PV plant for the North Sea – pv magazine International. PV Mag. https://www.pv-magazine.com/2018/02/07/dutch-consortium-plans-worlds-first-off-shore-floating-pv-plant-for-the-north-sea/ Accessed 04-02-2019

Bergström L, Kautsky L, Malm T, Ohlsson H, Wahlberg M, Rosenberg R & Capetillo NÅ (2012) The effects of wind power on marine life on marine life - A synthesis. REPORT 6512 October 2012.

Black & Veatch (2005) Phase II UK Tidal Stream Energy Resource Assessment. Prepard for Carbon Trust. Report Submission 107799/D/2200/03.

Blunden LS, Bahaj a. S (2007) Tidal energy resource assessment for tidal stream generators. 221:137–146

Bolten AB, Crowder LB, Dodd MG, Macpherson SL, Musick JA, Schroeder BA, Witherington BE, Long KJ & Snover ML (2011) Quantifying multiple threats to endangered species: An example from Loggerhead Sea turtles. Front Ecol Environ 9:295–301.

Bonar P a. J, Bryden IG & Borthwick AGL (2015) Social and ecological impacts of marine energy development. Renew Sustain Energy Rev 47:486–495.

Bonn Convention (1979) Convention on the Conservation of Migratory Species of Wild Animals (CMS). J Int Wildl Law Policy:1–6.

Bos, O. G., Gittenberger, A., Boois, I. J. de, Asch, M. van, Wal, J. T. van der, J. Cremer, B., Hoorn, van der, Pieterse, S., Bakker, P. A. J. 2016. Soortenlijst Nederlandse Noordzee. Den Helder, Wageningen University & Research Rapport. C125/16A. http://edepot.wur.nl/401117

Broadhurst, M. & Orme C. D. L. 2014. Spatial and temporal benthic species assemblage responses with a deployed marine tidal energy device: a small scaled study. Marine Environmental Research 99: 76-84.

Brothers JR & Lohmann KJ (2015) Report Evidence for Geomagnetic Imprinting and Magnetic Navigation in the Natal Homing of Sea Turtles Evidence for Geomagnetic Imprinting and Magnetic Navigation in the Natal Homing of Sea Turtles. Curr Biol 25:392–396.

Bryden I, Couch S (2007) How much energy can be extracted from moving water with a free surface: A question of importance in the field of tidal current energy? Renew Energy 32:1961–1966

Bryden IG, Couch SJ, Owen a, Melville G (2007) Tidal current resource assessment. Proc Inst Mech Eng Part A J Power Energy 221:125–135

Burrows R, Walkington IA, Yates NC, Ing TSHE (2009) Tidal energy potential in UK waters. Proc Inst Civ Eng Marit Eng:155–164

Burrows, M. 2012. Influences of wave fetch, tidal flow and ocean colour on subtidal rocky communities. Marine Ecology Progress Series 445: 193-207. doi:10.3354/meps09422

Cada G, Ahlgrimm J, Bahleda M, Bigford T, Stavrakas SD, Hall D, Moursund R & Sale M (2007) Potential Impacts of Hydrokinetic and Wave Energy Conversion Technologies on Aquatic Environments. Fisheries 32:174–181.

Calloway 2017. Wave and Tidal Range Energy Devices Offer Environmental Opportunities as Artificial Reefs. Proceedings of the 12th European Wave and Tidal Energy Conference 27th Aug -1st Sept 2017, Cork, Ireland

Campani T, Baini M, Giannetti M, Cancelli F, Mancusi C, Serena F, Marsili L, Casini S & Fossi MC (2013) Presence of plastic debris in loggerhead turtle stranded along the Tuscany coasts of the Pelagos Sanctuary for Mediterranean Marine Mammals (Italy). Mar Pollut Bull 74:225–230.

Carman KR, Fleeger JW & Pomarico SM (1997) Response of a benthic food web to hydrocarbon contamination. Limnol Oceanogr 42:561–571.

Causon PD & Gill AB (2018) Linking ecosystem services with epibenthic biodiversity change following installation of offshore wind farms. Environ Sci Policy 89:340–347.

CEFAS (2006) Scroby Sands Offshore Wind Farm – Coastal Processes Monitoring.

Chatzirodou A, Karunarathna H, Reeve DE (2016) Investigation of deep sea shelf sandbank dynamics driven by highly energetic tidal fl ows. Mar Geol

Chimienti M, Barton KA, Scott BE and Travis JMJ (2014) Modelling foraging movements of diving predators: a theoretical study exploring the effect of heterogeneous landscapes on foraging efficiency. PeerJ 2:e544

Chimienti M, Cornulier T, Owen E, Bolton M, Davies IM, Travis JM & Scott BE (2016) The use of an unsupervised learning approach for characterizing latent behaviors in accelerometer data. Ecol Evol 6(3):727-741

Christianen, M. J. A., Lengkeek, W., Bergsma, J.H., Coolen, J. W. P., Didderen, K., Dorenbosch, M., Driessen, F. M. F., Kamermans, P., Reuchlin-Hugenholtz, E., Sas, H., Smaal, A., van den Wijngaard, K.A. & van der Have, T.M. 2018. Return of the native facilitated by the invasive? Population composition, substrate preferences and epibenthic species richness of a recently discovered shellfish reef with native European flat oysters (Ostrea edulis) in the North Sea. Marine Biological Research 0: 1–8.

CITES (1984) Convention on international trade in endangered species of wild Fauna and Flora (CITES). Environ Policy Law 13:130–130.

Clark NA (2006) Tidal barrages and birds. Ibis 148:152-157

Coolen, J., Lengkeek, W., Degraer, S., Kerckhof, F., Kirkwood, R. J. & Lindeboom, H. J. 2016. Distribution of the invasive Caprella mutica (Schurin), 1935 and native Caprella linearis (Linnaeus, 1767) on artificial hard substrates in the North Sea: Separation by habitat. Aquatic Invasions 11(4): 437–449.

Coolen, J. W. P., van der Weide, B. E., Cuperus, J., Blomberg, M., Van Moorsel, G., Faasse, M. A., Bos, O. G., Degraer, S. & Lindeboom, H. J. 2018. Benthic biodiversity on old platforms, young wind farms and rocky reefs. ICES Journal of Marine Science.

Copping A, Sather N, Hannah L, Whiting J, Zydlewski G, Staines G, Gill A, Hutchinson I, A O, Simas T, Bald J, Sparling C, Wood J & Masden E (2016) Annex IV 2016 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World.

Crain CM, Kroeker K & Halpern BS (2008) Interactive and cumulative effects of multiple human stressors in marine systems. Ecol Lett 11:1304–1315.

Cresci, A., Paris, C., Durif, C., Shema, S., Bjelland, R. Skiftesvik, A. & Browman, H. 2017. Glass eels (Anguilla anguilla) have a magnetic compass linked to the tidal cycle. Science Advances 3(6): e1602007.

Crowder L (2000) Leatherback's survival will depend on an international effort. Nature 440:881.

Daam MA, Teixeira H, Lillebø AI & Nogueira AJA (2019) Establishing causal links between aquatic biodiversity and ecosystem functioning: Status and research needs. Sci Total Environ 656:1145–1156.

Dadswell, M. J., Rulifson, R. A. & Daborn, G. R. 1986. Potential Impact of Large-Scale Tidal Power Developments in the Upper Bay of Fundy on Fisheries Resources of the Northwest Atlantic. Fisheries 11(4): 26-35.

Dannheim, J., Bergström, L., Birchenough, S.N.R., Brzana, R., Boon, A.R., Coolen, J.W.P., Dauvin, J.-C., De Mesel, I., Derweduwen, J., Gill, A.B., Hutchison, Z.L., Jackson, A.C., Janas, U., Martin, G., Raoux, A., Reubens, J., Rostin, L., Vanaverbeke, J., Wilding, T.A., Wilhelmsson, D., Degraer, S., 2019. Benthic effects of offshore renewables: identification of knowledge gaps and urgently needed research. ICES J. Mar. Sci. https://doi.org/10.1093/icesjms/fsz018

Davies IM & Thompson F (2011) Assessment of collision risk for seals and tidal stream turbines. ICES Rep CM 2011/S:11

Deflorio M, Area A, Corriero A, Santamaria N & DE METRIO G (2005) Incidental captures of sea turtles by swordfish and albacore longlines in the Ionian sea. Fish Sci 71:1010–1018.

de Groot J, Bailey I. What drives attitudes towards marine renewable energy development in island communities in the UK?Int J Mar Energy. 2016;13:80-95. doi:10.1016/J.IJOME.2016.01.007

De Mesel, I., Kerckhof, F., Norro, A., Rumes, B. & Degraer, S. 2015. Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. Hydrobiologia 756: 37–50.

Deruiter SL & Larbi Doukara K (2012) Loggerhead turtles dive in response to airgun sound exposure. Endanger Species Res 16:55–63.

Devine-Wright, P. (2011). Enhancing Local Distinctiveness Fosters Public Acceptance of Tidal Energy: A UK Case Study.Energy Policy, 39(1), 83-93.

Devine-Wright, P., 2009. Fencing in the bay? Place attachment, social representations of energy technologies and the protection of restorative environments. In Eds. Marino Bonaiuto, Mirilia Bonnes, Anna Maria Nenci and Giuseppe Carrus. Urban diversities, biosphere and well-being: Designing and managing our common environment. Hogrefe and Huber

Didrikas, T. & Wijkmark, N. 2019. Möjliga effekter på fisk vid anläggning och drift av vindkraftspark på Storgrundet.

Dierschke V, Furness RW and Garthe S (2016) Seabirds and offshore wind farms in European waters: Avoidance and attraction. Biol Cons 202:59-68

Doyle TK, Houghton JDR, O'Súilleabháin PF, Hobson VJ, Marnell F, Davenport J & Hays GC (2008) Leatherback turtles satellite-tagged in European waters. Endanger Species Res 4:23–31.

Drake, L. A., Doblin, M. A. & Dobbs, F. C. 2007. Potential microbial bioinvasions via ships' ballast water, sediment, and biofilm. Marine Pollution Bulletin 55(7): 333-341.

Dreyer SJ, Polis HJ & Jenkins LD (2017) Changing Tides: Acceptability, support, and perceptions of tidal energy in the United States. Energy Res Soc Sci 29:72–83. https://www.sciencedirect.com/science/article/pii/S221462961730107X

Duarte CM, Pitt KA, Lucas CH, Purcell JE, Uye S, Robinson K, Brotz L, Decker MB, Sutherland KR, Malej A, Madin L, Mianzan H, Gili J-M, Fuentes V, Atienza D, Pagés F, Breitburg D, Malek J, Graham WM & Condon RH (2013) Is global ocean sprawl a cause of jellyfish blooms? Front Ecol Environ 11:91–97.

Duinker PN, Burbidge EL, Boardley SR & Greig LA (2012) Scientific dimensions of cumulative effects assessment: toward improvements in guidance for practice. Environ Rev 21:40–52.

Duncan C, Thompson JR & Pettorelli N (2015) The quest for a mechanistic understanding of biodiversity–ecosystem services relationships. Proc R Soc B Biol Sci 282:20151348.

Easton MC, Woolf DK, Bowyer P a. (2012) The dynamics of an energetic tidal channel, the Pentland Firth, Scotland. Cont Shelf Res 48:50–60

Eckert SA (2006) High-use oceanic areas for Atlantic leatherback sea turtles (Dermochelys coriacea) as identified using satellite telemetered location and dive information. Mar Biol 149:1257–1267.

Eleftheriou A & McIntyre AD (2005) Methods for the study of marine benthos. Third edition. Blackwell: Oxford.

Elliott M (2011) Marine science and management means tackling exogenic unmanaged pressures and endogenic managed pressures – A numbered guide. Mar Pollut Bull 62:651–655.

Ernst, D. A. & Lohmann, K. J. 2016. Effect of magnetic pulses on Caribbean spiny lobsters: implications for magnetoreception. Journal of Experimental Biology 219: 1827-1832. doi: 10.1242/jeb.136036

European Commission (1992) Council Directive 92/43/EEC On the Conservation of Natural Habitats and of Wild Fauna and Flora. Off J Eur Union 94:40–52.

European Commission (2008) Directive 2008/56/EC of the European Parliament and of the Council, of 17 June 2008, establising a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

Fairley I, Masters I, Karunarathna H (2015) The cumulative impact of tidal stream turbine arrays on sediment transport in the Pentland Firth. Renew Energy 80:755–769

Ferreira RL, Martins HR, Da Silva AA & Bolten AB (2001) Impacts of swordfish fisheries on sea trutles in the Azores.pdf. Life Mar Sci 18A:75–79.

Firth, L. B., Browne, K. A., Knights, A. M., Hawkins, S. J. & Nash, R. 2013. Climate change and adaptational impacts in coastal systems: the case of sea defences. Environmental Science-Processes & Impacts 15(9): 1665-1670

Firth, A. (2013) Historic Environment Guidance for Wave and Tidal Energy. Published by Fjordr Ltd on behalf of English Heritage, Historic Scotland and Cadw

Fowler AM, Jørgensen A, Svendsen JC, Macreadie PI, Jones DO, Boon AR, Booth DJ, Brabant R, Callahan E, Claisse JT, Dahlgren TG, Degraer S, Dokken QR, Gill AB, Johns DG, Leewis RJ, Lindeboom HJ, Linden O, May R, Murk AJ, Ottersen G, Schroeder DM, Shastri SM, Teilmann J, Todd V, Hoey G Van, Vanaverbeke J, Coolen JWP (2018) Environmental benefits of leaving offshore infrastructure in the ocean. Front Ecol Environ 16:571–578

Fowler AM, Macreadie PI, Booth DJ (2015) Renewables-to-reefs: Participatory multicriteria decision analysis is required to optimize wind farm decommissioning. Mar Pollut Bull 98:368–371

Fox, C. J., Benjamins, S., Masden, E. A. & Miller, R. 2018. Challenges and opportunities in monitoring the impacts of tidal-stream energy devices on marine vertebrates. Renewable and Sustainable Energy Reviews 81: 1926

Frid C, Andonegi E, Depestele J, Judd A, Rihan D, Rogers SI, Kenchington E, Rogers I, Kenchington E, Rogers SI & Kenchington E (2012) The environmental interactions of tidal and wave energy generation devices. Environ Impact Assess Rev 32:133–139.

Furness RW, Wade HM & Masden EA (2013) Assessing vulnerability of marine bird populations to offshore wind farms. J Eviron Manage 119:56-66

Furness RW, Wade HM, Robbins AM & Masden EA (2012) Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. ICES J Mar Sci 69(8):1466-1479

Garrett C, Cummins P (2005) The power potential of tidal currents in channels. Proc R Soc A Math Phys Eng Sci 461:2563–2572

Garthe S & Hüppop O (2004) Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. J Appl Ecol 41(4):724-734

Gill AB (2005) Offshore renewable energy: ecological implications of generating electricity in the coastal zone. J Appl Ecol 42:605–615.

Gill, A. B., Thomsen, F., & Bartlett, M. 2012. Potential interactions between diadromous fishes of U.K. conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments. Journal of Fish Biology 81: 664-695.

Gourvenec S (2018) Shaping the offshore decommissioning agenda and next-generation design of offshore infrastructure. Proc Inst Civ Eng - Smart Infrastruct Constr 171:54–66

Grant MC, Trinder M & Harding NJ (2014) A diving bird collision risk assessment framework for tidal turbines. SNH Commissioned Rep 773

Grech M, Stagno LM, Aquilina M, Cadamuro M, Witzke U (2016) Floating photovoltaic installations in Maltese sea waters. In: European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC). Munich, p 1964–1968

Grecian WJ, Inger R, Attrill MJ, Bearhop S, Godley BJ, Witt MJ & Votier SC (2010) Potential impacts of wave-powered marine renewable energy installations on marine birds. Ibis 152(4):683-697

Grossman, G. D., Jones, G. P. & Seaman Jr., W. J. 1997. Do artificial reefs increase regional fish production? A review of existing data. Marine Renewable Energy 22: 17–23.

Hamelin KM, James MC, Ledwell W, Huntington J & Martin K (2017) Incidental capture of leatherback sea turtles in fixed fishing gear off Atlantic Canada. Aquat Conserv Mar Freshw Ecosyst 27:631–642.

Harrald, M., Hayes, P. & Hall, M. 2018. Impact of Trawling on the Benthos Around Oil and Gas Pipelines. Scottish Marine and Freshwater Science 9(13): 25.

Heather A. Morrison *,†, Frank A. P. C. Gobas ‡, Rodica Lazar † and & Haffner† GD (1996) Development and Verification of a Bioaccumulation Model for Organic Contaminants in Benthic Invertebrates.

Hooper T, Beaumont N & Hattam C (2017) The implications of energy systems for ecosystem services: A detailed case study of offshore wind. Renew Sustain Energy Rev 70:230–241.

Hutchison, Z., Sigray, P., He, H., Gill, A., King, J. & Gibson, C. 2018. Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables, University of Rhode Island, Cranfield University: 254

Jackson A (2014) Riding the waves: use of the Pelamis device by seabirds. - Proceedings of the 2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies (EIMR2014), Stornoway, Scotland, UK

Jia Z, Wang B, Song S, Fan Y (2014) Blue energy: Current technologies for sustainable power generation from water salinity gradient. Renew Sustain Energy Rev 31:91–100

Johansen S, Larsen ON, Christensen-Dalsgaard J, Seidelin L, Huulvej T, Jensen K, Lunneryd SG, Boström M & Wahlberg M (2016) In-air and underwater hearing in the Great Cormorant (Phalacrocorax carbo sinensis). In The Effects of Noise on Aquatic Life II. Springer, New York, NY.

Johnston A, Cook AS, Wright LJ, Humphreys EM & Burton NH (2014) Modelling flight heights of marine birds to more accurately assess collision risk with offshore wind turbines. J Appl Ecol 51(1):31-41

Kaiser, M. J. 2005. Are marine protected areas a red herring or fisheries panacea? Canadian Journal of Fisheries and Aquatic Sciences 62(5): 1194-1199.

Kaiser, M. J., Clark, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J. & and I. Karakassis. 2006. Global analysis and recovery of benthic biota to fishing. Marine Ecology Progress Series 311: 1–14.

Katsaprakakis DA (2016) Energy storage for offshore wind farms. In: *Offshore wind farms. Technologies, Design and Operation.* Elsevier. pp. 459–193.

Kellner, J. B., Tetreault, I., Gaines, S.D. & Nisbet, R.M. 2007. Fishing the line near marine reserves in single and multispecies fisheries. Ecological Applications 17(4): 1039–1054.

Kerckhof, F., Coolen, J.W.P., Rumes, B., Degraer, S. 2018. Recent findings of wild European flat oysters Ostrea edulis (Linnaeus, 1758) in Belgian and Dutch offshore waters: new perspectives for offshore oyster reef restoration in the southern North Sea. Belgian Journal of Zoology 148: 13–24.

Kirby, R. & Retière, C. 2009. Comparing environmental effects of Rance and Severn barrages. Proceedings of the Institution of Civil Engineers - Maritime Engineering 162(1): 11-26.

Klar R, Steidl B & Aufleger M (2018) A floating energy storage system based on fabric. Ocean Eng 165:328–335.

Klar R, Steidl B, Sant T, Aufleger M & Farrugia RN (2017) Buoyant Energy—balancing wind power and other renewables in Europe's oceans. J Energy Storage 14:246–255.

Kregting, L., Elsaesser, B., Kennedy, R., Smyth, D., O'Carroll, J., *et al*. 2016. Do Changes in Current Flow as a Result of Arrays of Tidal Turbines Have an Effect on Benthic Communities? PLOS ONE 11(8): e0161279. https://doi.org/10.1371/journal.pone.0161279

Kregting, L., *et al*. 2018. Environmental Impact Report of the H2020 project PowerKite. Northern Ireland, UK, Queen's University Belfast.

Langhamer, O., Wilhelmsson, D. & Engstrom, J. 2009. Artificial reef effect and fouling impacts on offshore wave power foundations and buoys – a pilot study. Estuarine Coastal and Shelf Science 82: 426–432.

Langhamer, O. 2010. Effects of wave energy converters on the surrounding soft-bottom macrofauna (west coast of Sweden). Marine Environmental Research 69(5): 374-381.

Langton R, Davies IM & Scott BE (2011) Seabird conservation and tidal stream and wave power generation: Information needs for predicting and managing potential impacts. Mar Policy 35(5):623-630

Lavender AL, Bartol SM & Bartol IK (2014) Ontogenetic investigation of underwater hearing capabilities in loggerhead sea turtles (Caretta caretta) using a dual testing approach. J Exp Biol 217:2580–2589.

Leopold, M & Scholl, M. (eds.) 2018. Monitoring getijdenturbines Oosterscheldekering. Jaarrapportage 2017. Wageningen Marine Research, Wageningen UR (University & Research centre), Wageningen Marine Research rapport C036/18, 49 blz.

Lohmann KJ, Putman NF & Lohmann CMF (2012) The magnetic map of hatchling loggerhead sea turtles. Curr Opin Neurobiol 22:336–342.

MacLeod, A. K., Orr, K. K., Greenhill, L., & Burrows, M. 2014. Understanding the potential effects of wave energy devices on kelp biotopes. Scottish Natural Heritage Commissioned Report. Scottish Natural Heritage.

Makabe R, Furukawa R, Takao M & Uye SI (2014) Marine artificial structures as amplifiers of Aurelia aurita s.l. blooms: A case study of a newly installed floating pier. J Oceanogr 70:447–455.

Martin KJ, Alessi SC, Gaspard JC, Tucker AD, Bauer GB & Mann DA (2012) Underwater hearing in the loggerhead turtle (Caretta caretta): a comparison of behavioral and auditory evoked potential audiograms. J Exp Biol 215:3001–3009.

Martin-Short R, Hill J, Kramer SC, Avdis A, Allison PA, Piggott MD (2015) Tidal resource extraction in the Pentland Firth, UK: Potential impacts on flow regime and sediment transport in the Inner Sound of Stroma. Renew Energy 76:596–607

MaRVEN, 2016: https://publications.europa.eu/en/publication-detail/-/publication/01443de6-effa-11e5-8529-01aa75ed71a1

Masden EA, McCluskie A, Owen E & Langston RHW (2015) Renewable energy developments in an uncertain world: The case of offshore wind and birds in the UK. Mar Policy 51:169–172.

Masden EA, Foster S & Jackson AC (2013) Diving behaviour of Black Guillemots Cepphus grylle in the Pentland Firth, UK: potential for interactions with tidal stream energy developments. Bird study 60(4):547-549

Masden EA, McCluskie A, Owen E, Langston RHW (2015) Renewable energy developments in an uncertain world: The case of offshore wind and birds in the UK. Mar Policy 51:169–172

Matthiessen P & Law RJ (2002) Contaminants and their effects on estuarine and coastal organisms in the United Kingdom in the late twentieth century. Environ Pollut 120:739–757.

Matthiessen P, Reed J & Johnson M (1999) Sources and Potential Effects of Copper and Zinc Concentrations in the Estuarine Waters of Essex and Suffolk, United Kingdom. Mar Pollut Bull 38:908–920.

Matthiessen, P., Law & R. J. 2002. Contaminants and their effects on estuarine and coastal organisms in the United Kingdom in the late twentieth century. Environ Pollut 120:739–757

Meißner, K, S. H., Bellebaum J. & Sordyl, H. 2006. Impacts of submarine cables on the marine environment: a literature review. Germany, Institute of Applied Ecology Ltd.

Menge, B. A. 1976. Organization of the New England Rocky intertidal community: role of predation, competition, and environmental heterogeneity. Ecological Monographs 46: 355–393.

MeyGen (2012) MegGen Tidal Energy Project Phase 1 Environmental Statement. Available at: https://tethys.pnnl.gov/publications/meygen-tidal-energy-project-phase-1-environmental-statement

McGregor RM, King S, Donovan CR, Caneco B & Webb A (2018) A Stochastic Collision Risk Model for Seabirds in Flight. Report to the Scottish Government. https://www2.gov.scot/Topics/marine/marineenergy/mre/current/StochasticCRM

Mcilvenny J, Tamsett D, Gillibrand P, Goddijn-murphy L (2016) On the Sediment Dynamics in a Tidally Energetic Channel : The Inner Sound , Northern Scotland.

Millar, D, Smith, H, & Reeve, D. (2007). Modelling analysis of the sensitivity of shoreline change to a wave farm. ocean engineering. 34(1):884-901

Momber A (2011) Corrosion and corrosion protection of support structures for offshore wind energy devices (OWEA). Mater Corros 62:391–404.

Montevecchi WA (2006) Influences of artificial light on marine birds. In: Rich C & Longcore T (eds) Ecological Consequences of Artificial Night Lighting. Island Press,Washington, DC

Mork, M. 1996. Wave attenuation due to bottom vegetation. Waves and nonlinear processes in hydrodynamics. Impact of tidal energy. S. P. Neill, Jordan, J. R. & Couch, S. J. Oslo, Kluwer Academic Publishing.

Morrison, H. A., Gobas, F. A. P. C., Lazar, R. & Haffner, G. D. 1996 Development and Verification of a Bioaccumulation Model for Organic Contaminants in Benthic Invertebrates.

Mrosovsky N, Ryan GD & James MC (2009) Leatherback turtles: The menace of plastic. Mar Pollut Bull 58:287–289.

National Marine Fisheries Service & US Fish and Wildlife Service (2013) Leatherback Sea Turtles (Dermochelys Coriacea) 5-Year Review: Summary and Evaluation. 93 pp.

Nall, C. R., Guerin, A. J. & Cook, E. J. 2015. Rapid assessment of marine non-native species in northern Scotland and a synthesis of existing Scottish records. Aquatic Invasions 10(1): 107-121.

Neill SP, Litt EJ, Couch SJ, Davies AG (2009) The impact of tidal stream turbines on large-scale sediment dynamics. Renew Energy

Neill, S. P., Vogler, A., Browan, G., Baston, A., Lewis, S., Gillibrand, M., Waldman, P. & Woolf, D. 2017. The wave and tidal resource of Scotland. Renewable Energy 114: 3-17.

Normandeau, E., Tricas, T. & Gill, A. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species. Pacific OCS Region, Camarillo, CA. OCS Study., U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement.

Ocean Grazer B.V. (2019) Ocean Grazer - Offshore hybrid renewable energy harvest and storage device https://oceangrazer.com/. Accessed 04-02-2019

O'Hara Murray RB, Gallego A (2017) A modelling study of the tidal stream resource of the Pentland Firth, Scotland. Renew Energy 102:326–340

Offshore Wind in Europe - Key trends and statistics 2017 (2018).

OSPAR (1992) Convention for the Protection of the Marine Environment of the North-East Atlantic. 33.

OSPAR Commission (2009a) Background Document for Leatherback turtle Dermochelys coriacea.

OSPAR Commission (2009b) Background Document for Loggerhead turtle caretta caretta.

OSPAR 2010. Quality Status Report Case Reports for the OSPAR List of threatened and/or declining species and habitats – Update. Intertidal Mytilus edulis beds on mixed and sandy sediments.

OSPAR 2017. OSPAR Intermediate Assessment, OSPAR Commission

Papaefthymiou S V., Karamanou EG, Papathanassiou SA & Papadopoulos MP (2010) A Wind-Hydro-Pumped Storage Station Leading to High RES Penetration in the Autonomous Island System of Ikaria. IEEE Trans Sustain Energy 1:163–172.

Payne JF, Andrews CA, Fancey LL, Cook AL & Christian JR (2007) Pilot Study on the Effects of Seismic Air Gun Noise on Lobster (Homarus americanus) Environmental Studies Research Funds Report No. 171. St. John's, NL.

Pederson, J. A., Gollasch, S., Laing, I., McCollin, T., Miossec, L., Occhipinti-Ambrogi, A., Wallentinus, I., & Werner, M. 2017. Status of introductions of non-indigenous marine species to the North Atlantic and adjacent waters 2003−2007. ICES Cooperative Research Report No. 334, 144.

Pichegru L, Nyengera R, McInnes AM & Pistorius P (2017) Avoidance of seismic survey activities by penguins. Sci Rep 7(1):16305

Pimm AJ, Garvey SD, Jong M de (2014) Design and testing of Energy Bags for underwater compressed air energy storage. Energy 66:496–508

Piniak WED, Eckert SA, Harms CA & Stringer EM (2012) Underwater hearing sensitivity of the leatherback sea turtle (Dermochelys coriacea ): Assessing the potential effect of anthropogenic noise. Herndon, VA.

Polagye B, Copping A, Suryan R, Kramer S, Brown-Saracino J & Smith C (2014) Instrumentation for monitoring around marine renewable energy converters: Workshop final report. - PNNL-23100 Pacific Northwest National Laboratory, Seattle, WA, USA

Popper AN, Hawkins AD, Fay RR, Mann DA, Bartol S, Carlson TJ, Coombs S, Ellison WT, Gentry RL, Halvorsen MB, Løkkeborg S, Rogers PH, Southall BL, Zeddies DG & Tavolga WN (2014) ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI.

REDstack (2019) REDstack's Afsluitdijk Project. https://www.redstack.nl/en/projects/36/afsluitdijk-project. Accessed 04-02-2019

Reilly K, O'Hagan A & Dalton G (2014) The Attitudes of Fishermen on the Island of Ireland Towards the Development of Marine Renewable Energy in their Locality - Preliminary Survey Results [Presentation]. In: *Presented at the Environmental Impact of Marine Renewables 2014, Stornoway, Scotland, UK.* .

RICORE project: http://ricore-project.eu/wp-content/uploads/2015/10/D3-2-RiCORE_Novel_Technology_Selection-encrypt.pdf

Rivier A, Bennis A, Pinon G, Magar V, Rivier A, Bennis A, Pinon G, Magar V, Parameterization MG, Gross M, Gr AB (2017) Parameterization of wind turbine impacts on hydrodynamics and sediment transport To cite this version : HAL Id : hal-01537624 Parameterization of wind turbine impacts on hydrodynamics and sediment transport. Ocean Dyn

Roc T, Conley DC, Greaves D (2013) Methodology for tidal turbine representation in ocean circulation model. Renew Energy 51:448–464

Rogan E, Breen P, Mackey M, Cañadas A, Scheidat M, Geelhoed S & Jessopp M (2018) Aerial Surveys of Cetaceans and Seabirds in Irish waters : Occurrence, distribution and abundance in 2015-2017. Dublin, Ireland.

Roleda, M. Y., & Dethleff, D. 2011. Storm-generated sediment deposition on rocky shores: Simulating burial effects on the physiology and morphology of Saccharina latissima sporophytes. Marine Biology Research 7(3): 213-223. doi: 10.1080/17451000.2010.497189

Rusu E, Guedes Soares C (2013) Coastal impact induced by a Pelamis wave farm operating in the Portuguese nearshore. Renew Energy 58:34–49

Sabine CL, Feely RA, Gruber N, Key RM, Lee K, Bullister JL, Wanninkhof R, Wong CS, Wallace DWR, Tilbrook B, Millero FJ, Peng T-H, Kozyr A, Ono T & Rios AF (2004) The Oceanic Sink for Anthropogenic CO2. Science (80- ) 305:367–371.

Sahu A, Yadav N, Sudhakar K (2016) Floating photovoltaic power plant: A review. Renew Sustain Energy Rev 66:815–824

Shckorbatov, Y., Rudneva, I., Pasiuga, V., *et al*. 2010. Electromagnetic field effects on Artemia hatching and chromatin state. Open Life Sciences 5(6):785-790. doi:10.2478/s11535-010-0063-8

Shapiro GI (2011) Effect of tidal stream power generation on the region-wide circulation in a shallow sea. Ocean Sci 7:165–174

Sheng L, Zhou Z, Charpentier JF, Benbouzid MEH (2017) Stand-alone island daily power management using a tidal turbine farm and an ocean compressed air energy storage system. Renew Energy 103:286–294

Schuyler QA, Wilcox C, Townsend KA, Wedemeyer-Strombel KR, Balazs G, van Sebille E & Hardesty BD (2016) Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. Glob Chang Biol 22:567–576.

Sheehy, D. & Vik, S. 2010. The role of constructed reefs in non-indigenous species introductions and range expansions. Ecological Engineering 36(1):1-11 doi: 10.1016/j.ecoleng.2009.09.012

Shields, M. A., Woolf, D.K., Grist, E. P. M., Kerr, S. A., Jackson, A. C., Harris, R. E., Bell, M. C., Beharie, R., Want, A., Osalusi, E., Gibb, S. W. & Side, J. 2011. Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment. Ocean & Coastal Management 54: 2-9.

Schuyler QA, Wilcox C, Townsend KA, Wedemeyer-Strombel KR, Balazs G, Sebille E van, Hardesty BD (2016) Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. Glob Chang Biol 22:567–576

Scottish Government (2016) Survey, Deploy and Monitor licensing policy guidance. Version 2. Available online: https://www2.gov.scot/Topics/marine/Licensing/marine/Applications/SDM

Segner H, Schmitt-Jansen M & Sabater S (2014) Assessing the Impact of Multiple Stressors on Aquatic Biota: The Receptor's Side Matters. Environ Sci Technol 48:7690–7696.

Shapiro GI (2011) Effect of tidal stream power generation on the region-wide circulation in a shallow sea. Ocean Sci 7:165–174

Sheng L, Zhou Z, Charpentier JF, Benbouzid MEH (2017) Stand-alone island daily power management using a tidal turbine farm and an ocean compressed air energy storage system. Renew Energy 103:286–294

Shields MA, Dillon LJ, Woolf DK, Ford AT (2009) Strategic priorities for assessing ecological impacts of marine renewable energy devices in the Pentland Firth (Scotland, UK). Mar Policy 33:635–642

Simas T, Muñoz-Arjona E, Huertas-Olivares C, De Groot J & Stokes C (2012) Understanding the role of stakeholders in the wave energy consenting process: engagement and sensitivities. 4th Int Conf Ocean Energy.

Slocum AH, Fennell GE, Dundar G, Hodder BG, Meredith JDC & Sager MA (2013) Ocean Renewable Energy Storage (ORES) System: Analysis of an Undersea Energy Storage Concept. Proc IEEE 101:906–924.

Smale, D. A., Burrows, M. T., Moore, P., O'Connor, N., & Hawkins, S. J. (2013). Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecology and Evolution 3(11): 4016-4038. https://doi.org/10.1002/ece3.774.

Smith HCM, Pearce C, Millar DL (2012) Further analysis of change in nearshore wave climate due to an offshore wave farm: An enhanced case study for the Wave Hub site. Renew Energy 40:51–64

Smyth K, Christie N, Burdon D, Atkins JP, Barnes R, Elliott M (2015) Renewables-to-reefs? - Decommissioning options for the offshore wind power industry. Mar Pollut Bull 90:247–258

Spotila JR, Reina RD, Steyermark AC, Plotkin PT & Paladino F V. (2000) Pacific leatherback turtles face

extinction. Nature 405:529–530.

Stelzenmüller V, Coll M, Mazaris AD, Giakoumi S, Katsanevakis S, Portman ME, Degen R, Mackelworth P, Gimpel A, Albano PG, Almpanidou V, Claudet J, Essl F, Evagelopoulos T, Heymans JJ, Genov T, Kark S, Micheli F, Grazia M, Rilov G & Rumes B (2018) Science of the Total Environment A risk-based approach to cumulative effect assessments for marine management. Sci Total Environ 612:1132–1140.

Stelzenmüller V, Vega Fernández T, Cronin K, Röckmann C, Pantazi M, Vanaverbeke J, Stamford T, Hostens K, Pecceu E, Degraer S, Buhl-Mortensen L, Carlström J, Galparsoro I, Johnson K, Piwowarczyk J, Vassilopoulou V, Jak R, Louise Pace M & van Hoof L (2015) Assessing uncertainty associated with the monitoring and evaluation of spatially managed areas. Mar Policy 51:151–162.

Stokes C, Beaumont E, Russell P & Greaves D (2014) Perceptions of the Inshore Wave Resource by Beach Water-Users in the lee of Wave Hub. In: *2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies (EIMR2014)At: Stornoway, Isle of Lewis, Outer Hebrides, Scotland.* p. 4.

Szostek, C. L., Davies, A. J. & Hinz, H. 2013. Effects of elevated levels of suspended particulate matter and burial on juvenile king scallops Pecten maximus. Marine Ecology Progress Series 474: 155–165.

Taormina, B., Bald, J., Want, A., Thouzeau, G., Lejart, M., Desroy, N. & Carlier, A. 2018. A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. Renewable and Sustainable Energy Reviews 96: 380-391.

Tasker ML, Jones PH, Blake BF, Dixon TJ & Wallis AW (1986) Seabirds associated with oil production platforms in the North Sea. Ringing & Migration 7(1):7-14

Thiel, M. & Gutow, L. 2005. The ecology of rafting in the marine environment. II. The rafting organisms and community. Oceanography and Marine Biology 43: 279-418.

Tillin, H., Hiddink, J., Jennings, S., Kaiser, M. 2006. Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea basin scale. Marine Ecology Progress Series 318: 31-45. doi:10.3354/meps318031.

Titah-Benbouzid H & Benbouzid M (2017) Biofouling Issue on Marine Renewable Energy Converters: a State of the Art Review on Impacts and Prevention. Int J Energy Convers 5:67.

Tyrrell, M. C. & Byers. J. E. 2007. Do artificial substrates favor nonindigenous fouling species over native species? Journal of Experimental Marine Biology and Ecology 342(1): 54-60.

Venugopal V, Nemalidinne R, Vögler A (2017) Numerical modelling of wave energy resources and assessment of wave energy extraction by large scale wave farms. Ocean Coast Manag

Vermaat JE, NSR. A, MD. F, JS U, CM D, N M, S. E & van Vierssen W (1997) The Capacity of Seagrasses to Survive Increased Turbidity and Siltation: The Significance of Growth Form and Light Use. Ambio 26:499–504.

Wade HM (2015). Investigating the potential effects of marine renewable energy developments on seabirds. PhD dissertation. University of Aberdeen. Retrieved from https://pure.uhi.ac.uk/portal/en/studentthesis/investigating-the-potential-effects-of-marine-renewable-energy-developments-on-seabirds(a13794b8-f416-4e96-8199-5fbd3af39d32).html

Wade HM, Masden EA, Jackson AC & Furness RW (2016) Incorporating data uncertainty when estimating potential vulnerability of Scottish seabirds to marine renewable energy developments. Mar Policy 70:108-113

Waggitt JJ & Scott BE (2014) Using a spatial overlap approach to estimate the risk of collisions between deep diving seabirds and tidal stream turbines: A review of potential methods and approaches. Mar Policy 44:90-97

Waggitt JJ, Cazenave PW, Torres R, Williamson BJ & Scott BE (2016) Quantifying pursuit-diving seabirds' associations with fine-scale physical features in tidal stream environments. J Appl Ecol 53(6):1653-1666

Wale, M. A., Simpson, S. D., Radford, A. N. 2013a. Noise negatively affects foraging and antipredator behaviour in shore crabs. Animal Behaviour 86: 111-118.

Wale, M. A., Simpson, S. D. & Radford, A. N. 2013b. Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. Biology Letters 9(2): 2012-1194.

Walkington I, Burrows R (2009) Modelling tidal stream power potential. Appl Ocean Res 31:239–245

West J, Bailey I & Whithead I (2009) Stakeholder Perceptions of the Wave Hub Development in Cornwall, UK. In: *Proceedings of the 8th European Wave and Tidal Energy Confernce*. pp. 1102–1111.

Whitehead, D. L., Gauthier, A. R., Cameron, R. M., Perutz, M. & Tibbetts, I. R. 2015. Ultrastructure of the ampullary organs of Plicofollis argyropleuron (Siluriformes: Ariidae). Journal of Morphology 276: 1405-1411. doi:10.1002/jmor.20428

Whitehouse RJS, Harris JM, Sutherland J, Rees J (2011) The nature of scour development and scour protection at offshore windfarm foundations. Mar Pollut Bull 62:73–88

Wiersma,B., Devine-Wright, P. (2014) Publicengagement with offshore renewable energy: a critical review-Wiley Interdisciplinary Reviews,

Wilding TA, Gill AB, Boon A, Sheehan E, Dauvin J, Pezy J-P, O'Beirn F, Janas U, Rostin L & De Mesel I (2017) Turning off the DRIP ('Data-rich, information-poor') – rationalising monitoring with a focus on marine renewable energy developments and the benthos. Renew Sustain Energy Rev 74:848–859.

Wilhelmsson, D. & Malm, T. 2008. Fouling assemblages on offshore wind power plants and adjacent substrata. Estuarine Coastal and Shelf Science 79: 459–466.

Williams R, Wright AJ, Ashe E, Blight LK, Bruintjes R, Canessa R, Clark CW, Cullis-Suzuki S, Dakin DT, Erbe C, Hammond PS, Merchant ND, O'Hara PD, Purser J, Radford AN, Simpson SD, Thomas L & Wale MA (2015) Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management. Ocean Coast Manag 115:17–24.

Willis-Norton E, Hazen EL, Fossette S, Shillinger G, Rykaczewski RR, Foley DG, Dunne JP & Bograd SJ (2015) Climate change impacts on leatherback turtle pelagic habitat in the southeast pacific. Deep Res Part II Top Stud Oceanogr 113:260–267.

Willsteed E, Gill AB, Birchenough SNR & Jude S (2017) Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground. Sci Total Environ 577:19–32.

Willsteed EA, Jude S, Gill AB & Birchenough SNR (2018) Obligations and aspirations: A critical evaluation of offshore wind farm cumulative impact assessments. Renew Sustain Energy Rev 82:2332–2345.

Wilson B, Batty RS, Daunt F & Carter C (2007) Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive, Scottish Association for Marine Science, Oban.

WindEurope (2018) Offshore Wind in Europe - Key trends and statistics 2017.

Witherington B, Kubilis P, Brost B & Meylan A (2009) Decreasing annual nest counts in a globally important loggerhead sea turtle population. Ecol Appl 19:30–54.

Witt MJ, Hawkes LA, Godfrey MH, Godley BJ & Broderick AC (2010) Predicting the impacts of climate change on a globally distributed species: the case of the loggerhead turtle. J Exp Biol 213:901–911.

Witt MJ, Sheehan E V, Bearhop S, Broderick AC, Conley DC, Cotterell SP, Crow E, Grecian WJ, Halsband C, Hodgson DJ, Hosegood P, Inger R, Miller PI, Sims DW, Thompson RC, Vanstaen K, Votier SC, Attrill MJ & Godley BJ (2012) Assessing wave energy effects on biodiversity: the wave hub experience. Philos Trans A Math Phys Eng Sci 370:502–29.

Wolf J, Walkington IA, Holt J, Burrows R (2009) Environmental impacts of tidal power schemes. Proc Inst Civ Eng Marit Eng:165–177

World Energy Council Netherlands. 2017. Bringing North Sea energy ashore efficiently, 59 pages.

Yang Z, Wang T, Copping AE (2013) Modeling tidal stream energy extraction and its effects on transport processes in a tidal channel and bay system using a three-dimensional coastal ocean model. Renew Energy 50:605–613

# 8 List of participants

This report is the result of the work of a pre-meeting at ICES headquarters in Copenhagen 15–16 January 2019 to to provide a first draft on the "*current state and knowledge of studies into the deployment and environmental impacts of the following wet renewable energies and marine energy storage (floating, coastal infrastructure), tidal stream (screws, kites), tidal flow (barrage, lagoon) and others*" requested by OSPAR. The pre-meeting at Copenhagen was attended by members of the working group on benthic renewable energy developments (WGMBRED), the working group on marine renewable energy (WGMRE) and other relevant experts.

The report was further elaborated at WGMBRED 11–15 February and WGMRE 26–28 February. A list of contributors is presented below.

| Name | E-mail | Affiliation |
|---|---|---|
| Jan Vanaverbeke | jvanaverbeke@naturalsciences.be | Royal Belgian Institute of Natural Sciences, Belgium |
| Joop W.P. Coolen | joop.coolen@wur.nl | Wageningen University & Research, The Netherlands |
| Marion Harrald | Marion.Harrald@gov.scot | Marine Laboratory, Aberdeen, Scotland |
| Ross Culloch | Ross.Culloch@gov.scot | Marine Laboratory, Aberdeen, Scotland |
| Adrian Tait | Adrian.Tait@gov.scot | Marine Laboratory, Aberdeen, Scotland |
| Bob Rumes | bob.rumes@naturalsciences.be | Royal Belgian Institute of Natural Sciences, Belgium |
| Carol Sparling | Carol.Sparling@gov.scot | Marine Scotland Science, Aberdeen |
| Kirsty Wright | Kirsty.Wright@gov.scot | Marine Scotland Science, Aberdeen |
| Rory O'Hara Murray | R.Murray@marlab.ac.uk | Marine Scotland Science, Aberdeen |
| Tom Evans | Tom.Evans@gov.scot | Marine Scotland Science, Aberdeen |
| William Hunt | william.hunt@ucc.ie | University College Cork, Ireland |
| Andrew B. Gill | andrewbgill0510@gmail.com | Cranfield University, UK |
| Zoe Hutchison | zoe.hutchison@outlook.com | Cranfield University, UK |

| Name | E-mail | Affiliation |
|---|---|---|
| Jolien Buyse | jolien.buyse@ilvo.vlaanderen.be | The Flanders Research Institute for agriculture, fisheries and food (ILVO) |
| Robin Brabant | robin.brabant@naturalsciences.be | Royal Belgian Institute of Natural Sciences, Belgium |
| Juan Bald | jbald@azti.es | AZTI Tecnalia, Spain |
| Daniel Wood | Daniel.Wood@cefas.co.uk | Centre for Environment, Fisheries and Aquaculture Science (CEFAS), UK |
| Marijke Warnas | marijke.warnas@rws.nl | Directorate-General for Public Works and Water Management<br>Governing body of protected sites, The Netherlands |
| Lara Salvany | Lara.salvany@ices.dk | ICES, Denmark |

# Annex 1: Reviewers reports

## Reviewer num. 1

**Background**

OSPAR requested a report for advice on the current state and knowledge of studies into the deployment and environmental impacts of wet renewable technologies and energy storage systems. The aim of this review of the report was to: "evaluate the response from the experts and to comment on the completeness of the advice and to state clearly whether the work is sufficient for ICES to base its advice to OSPAR".

Below a summary of the main findings of my review is followed by chapter specific comments.

**Summary**

The report is generally well written and comprehensive and covers the topics listed in the request. The structure of the report is generally good, starting with a useful description of the different wet renewables (current situation and future prospects) and energy storage systems and continuing with receptor specific chapters, cumulative impacts, further work needed, emerging technologies and conclusions. The report provide a thorough assessment of existing knowledge (with more than 220 references) on wet renewables, energy storage systems and potential impacts. The report will therefore be useful and important as a compilation of references dealing with wet renewables. The report also define important future research requirements, i.e. which issues needs to be investigated in more detail and also a pledge for an ecosystem-based research approach which is indeed needed. The report can therefore be said to be useful as a basis for further discussion and for ICES to base its advice to OSPAR, depending on what type of advice OSPAR is expecting.

That said, I think the report could be made even more useful. As it stands it can be difficult to extract valuable information from the report as, for example, the executive summary is not very useful for this purpose. It would also be useful to clearly list the most sensitive species/species groups or habitats (although in many cases based on sparse information), as well as a list of most important research needs, for example upfront in the executive summary.

Further, the spatial aspect is largely missing from the report. It would potentially be useful with a map with operational and planned wet renewable devices. This would help to assess potential overlap of wet energy devices with species distributions. The need of spatial planning could at least be highlighted (more than currently) in the text as an important next step. Before potential impacts are well understood the best thing to do is to avoid overlap of sensitive species/receptors with wet renewables, i.e. spatial planning. A good example from the OWF case is the red-throated diver, which has been shown to be highly sensitive to anthropogenic pressures. Although we do not now the potential consequences on the population level due to displacement, the information on displacement can be used to avoid building windfarms in high density areas of red-throated divers.

## Chapter specific Comments:

### Executive summary

The summary is a description of the evolution of the project more than a summary of the findings. The summary would be more helpful and useful for advice if the main findings would be listed, this could include the main (potential) environmental impacts (changes to the environment) or most sensitive species as well as the most urgent research needs.

### Chapters 1, 2 & 3 Introduction, overview of wet renewable and future prospects

Good, not much to comment. These chapters provide a good background for the coming chapters dealing with potential impacts.

End of Page 16 reference missing,

Page 28 chapter 3.2.2 planned sites named as XXX, YYY and ZZZ

### Chapter 4. Potential changes to the environment

The summary table of changes to the environment is useful as it gives an overview. However, in terms of advice it would be useful to summarize which receptors are potentially most prone or most sensitive to changes (negative or positive). This could potentially be done by adding a colour scale to the table.

The table is not consistently reflecting what is written in the chapters below on the different receptors. Some aspects are highlighted for some receptors but not for other although it clearly could be important for both. For example, artificial reefs, could also be important for fish. Also, in the energy removal column it is stated for birds the "Ecosystem impacts may change prey species abundance…" Why is this not the case for marine mammals in the table? In other words the table could be improved and be more consistent to what has been written in the chapters below.

### 4.3 Landscape

Is this an error and should it be merged with seascape? Or what is the difference? Confusing.

### 4.4 Benthos

Static vs dynamic components it is a bit confusing and unclear in the case of benthos, for example, non-native species is included under static in the text and dynamic in the summary table? Why is changes in hydrological regime under static component and not dynamic? Could be a good idea to remove unnecessary text, make it clearer and streamline the table against the text.

In chapter 4.4.1.4 it is stated that wind and tidal energy structures have not been designed to be artificial reefs. Would it be a good idea to suggest that they could be designed in such a way that they can function better as artificial reefs at least in some suitable locations?

As for other receptors it would be valuable to get an idea about which species, species groups or particular habitats that are most sensitive. This would aid spatial planning.

4.4.1 and 4.4.1.3 [ CITATION NEEDED] in three locations

### 4.5 Fish

Could the "aggregation" chapter be called artificial reefs to be more consistent with the previous chapter? What about changes in hydrological regimes? It is not included, but was included for benthos? Are the different chapter consistent enough?

**4.6 Marine mammals**

There are no static chapter? In the summary table several static components are listed? In the second chapter on page 57, the authors indicate that it is important to study and understand the distribution of the species to be able to predict future risk and potential consequences of displacement. I think this is a key issue that is important for all receptors and should get more attention throughout the report. At the end of the marine mammal chapter there is also a cumulative impact chapter which is not numbered, cumulative impacts are not discussed on this level for other receptors. Why only for mammals? Perhaps merge with the chapter on cumulative effects below.

In chapter 4.6.5.2. a reference to a section is missing.

**4.6 Seascape/public perception**

Should be merged with landscape or more likely the other way around?

**4.7 Birds**

On page 63 the sensitivity scoring by Furness *et al.* 2012 is presented. It would be useful for the report to also list most sensitive species, because the focus should be on these species. It would be important to do a similar approach for other receptors and add a spatial component as well. In which areas do these species occur? An ecosystem approach is discussed later in the report which is good but this would not exclude the value of looking into the most vulnerable species and habitats. Both approaches are useful and complementary.

In the last chapter on page 65, it is indicated that CRMs look into mortality etc., while mechanistic models (read IBMs/ABMs) describes behavior. Individual based models or agent based models (IBMs/ABMs) can also be considered to be CRMs. I suggest to reformulate, something in line with that there is a lot of potential in using IBMs/ABMs for more realistic collision risk modelling in the future.

**4.8 Others**

Why are Otters and Polar bears not in the marine mammal chapter? Is it relevant to include polar bears at all in this report?

**4.9 Cumulative impacts**

To assess the cumulative effect "with receptors as a basis" it would be useful to look into the sensitivity of species and focus on the most sensitive and add a spatial component as pointed out above. Further, to be able to assess actual consequences of displacement, population modelling is needed, in line with for example: Warwick-Evans, V., Atkinson, P.W., Walkington, I., Green, J.A., 2018. Predicting the impacts of wind farms on seabirds: An individual-based model. J. Appl. Ecol. 55, 503-515.

**5. What to do next**

The holistic ecosystem approach as described in this chapter is good advice, however, it will be challenging and require a lot of effort. In the meantime it would also be important, to as already mentioned many times, to focus on sensitive receptors and conduct spatial planning to avoid overlap and potential population or ecosystem consequences which are difficult to estimate currently.

**6. Conclusions**

The last sentence is the starting point of the way forward, would be nice to see a summary of the most urgent research needs, which were described in the different chapters of the report, if not here see the comment regarding the Executive Summary.

## Reviewer num.2

I have read through the advice collated by the ICES workgroups and want to organize my remarks into three parts:

- The focus and comprehensiveness of the topics addressed in the advice document, with an emphasis on the descriptions and stressors from devices;
- The content and balance of the material presented about effects on receptors; and
- My recommendations and suggestions for improvement.

**Focus and Comprehensiveness of the Advice, with Emphasis on Stressors**

The advice document includes descriptions of many tidal devices and wave energy converters. For the most part, the landscape is covered well. However, there are some errors and odd omissions; I spend some space here on the specifics of the tidal and wave devices as the evidence to date shows that the potential risk to marine receptors is dependent to a large degree on the specifics of placement in the water column/seabed, as well as the design and operation of particular devices. For this reason, I believe that the specifics of environmental stressors in the marine system matter.

The present trend in tidal devices is away from heavy bottom mounted devices and more towards floating tidal as these devices have considerable advantages: deployment and maintenance is much easier and enormously cheaper than bottom mounted devices; the mid water column location of the devices taps into faster tidal flows; and the amount of steel and concrete used is much less (and therefore less expensive) than for bottom-mounted devices. The only reference to mid water column devices is in the section on vertical-axis turbines (page 8), stating that the devices are floating and hanging in the water column with no seabed contact (which is not right….an anchor is still needed). In fact, vertical-axis devices may be bottom-mounted or floating. Other errors in tidal devices descriptions include: oscillating hydrofoils (page 9), which may oscillate upwards and downwards or side to side; enclosed tip devices (venturis) on page 10, in fact describe ducted turbines which may or may not include venturis to speed the flow of water; the description of tidal kites (page 11) misses the very important point that these devices can travel in the water column much faster than the speed of the tidal current. The description of moorings (page 12) describes a flexible mooring; I think this is referring to a caternary mooring, but I am not sure. Caternary mooring have been the most common type of mooring, although that thinking is changing among tidal developers.

Tables 1 and 2 describe the number of devices and their status in the OSPAR countries. I have trouble understanding the purpose of these tables as there is no commentary. Is the point to imply there are few operational devices but interest among the countries? Some commentary would help, including the source of the numbers. Also, it is important to note that these figures will become obsolete very quickly and may not provide the best idea of the status of the industry; perhaps a link to live estimates somewhere (OES perhaps….?) would be preferable.

The descriptions of wave energy converters is not particularly up to date; the description of the linear attenuator (called "attenuator") is the special case of Pelamis (page 17), and does not account for other linear attenuators, some of which sit perpendicular to the wave fronts. It would be best not to refer to surge converter as "oscillating" (page 18) as this confuses the reader with an oscillating water column. The oscillating water column (page 18) described is similar to the Limpet; however most OWCs are actually floating and located away from shore on an anchoring system, rather than shorebased. The two extant devices of which I am aware that operate on the submerged pressure differential principle (page 19 -20) are actually an amalgam of the descriptions of the submerged pressure differential and the bulge wave: notably Bombora and M3 that use similar physics to the bulge wave describes, moving water back and forth in a bag on the seafloor.

Similar to the tidal tables, table 3 needs some explanation as to the purpose and origin of the data. Better figures may be available from OES.

The energy storage systems reported on are, for the most part, notional and not in operation. I see the value of alerting the OSPAR officials to the potential future installations, however, the amount of space devoted to certain ideas like buoyant energy would lead the reader to believe this is an existing and widely used concept, which it is not. It might be worth noting that, other than pumped storage (which is in use), that hydrogen derived from wet renewables is being pioneered at EMEC already. Also, the most likely and immediate storage of energy from wet renewables is the charging of battery banks, generally lithium ion, and should be mentioned.

A forward look at prospects for the industry is hard to capture and the brief look at the markets given here is dated but not wrong. You might note that the Dutch have had tidal turbines operating in flood control barriers for some years.

In terms of opportunities (page 30), I applaud the recognition of significant opportunities in the non-grid market; this represents the likely path forward for many of the main industrial players. For barriers to development (page 30) the two leading issues should be (according to developers) survivability at sea, and financing (which is obviously tied up with many other factors); reliability and efficiency come later.

**Content and Balance of the Material on Receptor Potential Effects**

The material on potential environmental effects is copious but not well balanced, and key references are missing. For many specific comments, please see my notations in the advice report text. I will address the most common issues:

Table 4 sums up the material but provides a view that is swayed by the amount of text in each of the following sections. For example, the reader might assume that the top issues of concern are: changes to the benthic environment and biota; changes in physical systems such as circulation and sediment transport; effects on marine mammals; and effects on birds. The literature and consensus among scientists and practitioners at test sites and commercial developments around the world would differ from these priorities. Taking the assumption that devices will be properly sited to avoid particularly sensitive areas, the following is more likely:

Changes in benthic environments are likely to result only in the limited footprint of a foundation or anchor; these changes are no different that those for other industries and shipping. The focus in this report on benthic environments for wet renewables wants the reader to have greater cause for concern.

Change in the physical environment have been investigated through numerical models a great deal. While virtually none of the models have been validated, the fidelity of properly applied hydrodynamic models is so high (based on highly accurate bathymetry), that the inability to detect changes against the background of natural variability for small to fairly large numbers of turbines or WECs, indicates that changes in circulation, water quality, sediment transport, and other ecosystem processes, will occur only with very large numbers of operating devices. The important aspects of the stressor are: 1) for very large proposed numbers of devices, modelling and monitoring will be needed; and 2) that proper siting of turbines must be assured such that shallow locations (<40 m depth) with mobile sediments be avoided or carefully monitored.

Risks to marine mammals, fish, and sea turtles from tidal turbine blades is a legitimate concern, one for which there are few useful data, and no appropriate analogue on which to depend. The emphasis on marine mammals in the advice is appropriate (although very confusing), while much less emphasis is placed on fish and sea turtles, which may be equally or in fact more at risk than marine mammals as neither group of animals has the same ability to detect and avoid underwater hazards. Effects on diving birds is presented as equally of concern as for marine mammals (and more so than for fish or sea turtles); however, seabirds dive periodically for food, and may have some probability of encountering an operating turbine, but their habitat is in air, not in water as the other denizens at risk. Assuming that seabirds will be at equal risk to animals living around the turbines asks the reader to stretch credibility.

Other concerns over Table 4 include:

- Fish are limited to large and migratory species, while in fact resident species may be at even more risk as they are likely to congregate around a turbine or base;
- Effects of EMF on fish are stated as barrier effects, not allowing for shielding of cables, or taking into account several studies in the US that contradict this finding;
- Fish hearing may be affected by underwater sound (PTS, TTS) just like that of marine mammals;
- Barrier effects for marine mammals are listed as a concern, however it is important to note that this will require large numbers of devices;
- Ecosystem impacts are listed for birds as an important effect, which is stretching everything we know about changes due to tidal and wave devices, particularly at small to medium sized commercial arrays;
- Public perception of wet renewables lists the concerns that surfers have raised, however this has been thoroughly debunked – perhaps a better example could be listed (overall environmental concerns, exclusion zones from recreational fishing and boating….);
- Otters in North America are never seen far enough from shore to interact with wet renewables – are European otters so different?
- And finally, why bats? What is the mechanism of potential harm?

**Recommendations**

It is clear that this report was prepared in haste; I suggest that the next iteration consider some reorganization:

If the environmental issues were organized around stressors rather than receptors, there would be a better chance that the treatment for each animal group or habitat would be even. Equally, there would be less repetition in subsequent sections.

Many of the factual issues around tidal and wave devices would benefit from asking a device leader in the field to review the write ups. I work closely with developers in several countries but am not myself a developer. The industry is changing and it behooves the advice to OSPAR to be as accurate as possible for the timeframe of the advice.

There was little attention paid to work in countries not represented on the panel; I have indicated some work in my comments, but there is much more – fish collision work out of Japan, the US, and Sweden, etc.

While the desire is understandable to extrapolate findings from offshore wind (where more work has been done) to wet renewables, it is important to be judicious and ensure that the mechanisms of potential harm are the same before making assumptions.

## Reviewer num. 3

Review of report

**Advice on the current state and knowledge of studies into the deployment and environmental impacts of wet renewable technologies and energy storage**

March 19, 2019

**General**

The report constitutes an impressive review. Most parts of the report can be considered complete with respect to catching and demonstrating the literature of the field. The report is very well written.

The term "wet renewables", which might have been defined in the request from OSPAR, is misleading for a wider audience and should have been exchanged. For instance, wet renewables would per definition include hydropower. For the technologies covered here, marine renewables would be a more apt name.

The report do not cover the impact of energy storage systems very well. This is not surprising since there has been few or none specific studies on wet energy storage systems and what is known from similar constructions can probably be imposed. However, given the title and request, perhaps this should be stated or discussed.

A general criticism to the report as it is written would be that hypothetical speculations of possible impacts are mixed with empirical or well-founded conclusions, without clear distinction. Readers outside the field may have difficulties to see the difference. This is important for understanding risk and priorities. I suggest that the text gives clear information on which impacts or risks are established, well founded, uncertain and speculative, respectively.

One example of above is the many references to MacLeod *et al.* (2014) which of several seems speculative. MacLeod *et al.* (2014) is in itself an extensive review. It is not possible for the reader to distinguish between different levels of uncertainty and speculation from this reference. I suggest the references are cited directly in case data are underpinning statements; otherwise, it is made clear that the impact is hypothetical.

The report covers a good review of different technology types, but rarely distinguish among these when impacts are discussed in later sections. This is explained by the wide variety of technologies and the few empirical data. Nevertheless, some differences should be covered. For instance, the kite technology involves a 100 m long wire whispering cross the pelagic at 10 m/s while other tidal devices reaches no more than 5 meter and wave energy devices never moves fast at all. These differences could be discussed in section about collisions, for instance.

The thematic sections are generally good but vary in quality. I consider sections on marine mammals and birds to be particularly well covered, as well as sections on cables and electromagnetic fields. Sections on fish (4.5.1.3 aggregation) and (4.5.2.1 fish strike) could be more developed. Particularly the section on fish strike is surprisingly limited given the risk involved and uncertainties. Here, I suggest also adding more on differences between different fish behaviour in strong currents, swimming speed capacity and size.

There are two different sections on cumulative impacts, both with the same name. The later section (4.9) is to my opinion the most correct interpretation of the concept. This section is good, although it would merit from a small additional section on spatial cumulative impact assessment

(CIA). The former section on cumulative impacts (comes after 4.6.5.3) has a different interpretation of the concept. Perhaps this section should be renamed something like population effects or up-scaling of effects. Here, discussion of impacts from the point of population dynamics would be interesting, is there a maximum allowable catch, by these technologies?

References are plenty and cover most areas well. I will give a few more suggestions. Some references are missing in the text (marked but not inserted) and some references are mentioned in the text but not listed.

The section numbering is currently incomplete.

**Specifics**

**Page 6.** The term “abiotic receptors” is not straightforward. Underwater sound, for instance, is a product or emission rather than a receptor. Consider simply calling abiotic receptors “physical changes”.

**Page 7.** There are some examples of high tidal resources outside Europe. I think Canada and perhaps US should be added.

**Page 8-26.** The technical descriptions are very brief, which might be OK given that the core of the review is their ecological impacts. But some information of dimensioning would be necessary for the reader to understand the possible interaction with environment. For instance, what is the typical width of rotor blades and length of circling tether? How fast will rotors and buoys move?

**Page 16.** The wave distribution map should be changed for a map with more information and including areas with lower wave energy. For instance, areas like the Baltic Sea may have waves with less energy content and lower maximums, but also with less stress on buoys and therefore still making an economical case.

**Page 31.** Before moving into section 4 it would be valuable for OSPAR to have a restrained assessment of the likelihood for the different technology-types to actually become viable and deployed over the next couple of decades. It may be difficult to make precise predictions but some rating is probably possible – either as a qualitative ‘voting-round’ by the expert panel or based on literature. Certainly, all technical concepts are not equally likely to develop into real industries in the near future.

**Page 34.** Bats are mentioned here, but I do not find bats elsewhere in the text. Probably bats can be removed.

**Section 4.1.** The section is informative and good. It would be valuable to add some references to knowledge from existing constructions known to affect hydrodynamics, such as bridges and heave trafficked ship lanes. This would give an understanding of the magnitude of possible effect.

**Section 4.4.1.1.** It is mentioned that the benthic footprint of a WEC can be 1 km2, with reference to MacLeod 2014. This sounds dramatic and would be alarming for OSPAR and any concerned institution. Please look into this reference and explain how these calculations are derived.
The impact of resuspended sediments on kelp at tidal sites also sounds exaggerated to me(page 39-40). Are MacLeod speculating or can we establish this as a risk, given the typical coarse sediments of tidal sites (which is stated elsewhere in the report).

**Section 4.4.1.2.** This section is interesting and could be developed. Both regarding the outlook for fishing inside these areas with moving devices and with the respect to the ecological effects. The statement that such fishing remains a threat to benthic habitats need to be developed or removed.

**Section 4.4.1.3.** The reference to the Swansea tidal lagoon potential for seagrass growth sounds promising. However, given that the hypothesis comes from the developer, can you give a notion on this from a generic standpoint. May tidal lagoons help to restore some of Europe's many silted estuaries in the future?

**Section 4.4.1.4.** This section would benefit from including some of the many studies that have been done on offshore wind power, fouling and reef effect. There may be much to learn from this partly equivalent technology.

**Section 4.4.1.5.** This section should preferably develop further. Arguments are given both for believing that the role of MRED in terms of vectors for alien species are exaggerated (Coolen 2018) and for this to be a serious problem (De Mesel 2015, Sheehy & Vik 2010). What is based on observations, models and speculations, respectively?

Part of the text is difficult to interpret "…may have created networks of…which act like stepping stones". Does this mean that the stepping stone theory has been confirmed by this reference, and if so please explain more about the magnitude and details. This topic is probably very important to have clarified as much as possible from the viewpoint of OSPAR.

Consider adding discussion on the role of natural bottom habitat and variability to this section.

**Section 4.4.3.2.** End of this section has another possibly speculative argument from MacLeod, on hard bottom substrate recovery. Are these environments at risk from nearby/distant wet renewables construction works? If so this is important, otherwise the level of speculation may be noted.

**Section 4.4.3.5.** About cable heat emission. A good coverage of a sparsely researched topic. Would be interesting with a sentence or two on how such effects on environment transplant when the area of exposure are so elongated and narrow as above a cable trace.

**Section 4.4.4** In the last section, a reference from seismic sound is given as example that noise may increase the risk of predation and cause more oxygen consumption. While such responses are possible also from lower continuous noise exposure, which has been shown for fish (eel) when it comes to predation, this reference about seismic noise says little about effects from tidal and wave energy operational noise. The statement may be confounding for the audience.

**Section 4.5.1.2.** The review about fish aggregation in wet renewable arrays seems to be based on the 2008 assessment, which is not the most updated reference in this discussion. More have been done on source/sink ecology within the field of offshore wind farms. This section, which otherwise include many relevant references, would benefit from an updated/extended discussion.

**Section 4.5.2.1.** This section on fish strike is surprisingly limited given the potential risk rotor-blades/kites may or may not pose to fish (and other nekton). There are few observations, but more than shown here. The section would benefit from more in-depth review of which fish that may be at risk and – importantly – from which kind of turbines. Here different wet renewables differs a lot. Fish size and behavior with respect to current speed and direction, influences the collision risk. Although this is a limited review a bit more could be added in this section.

**Sections on sound and EMF on fish** are very well covered. Possibly, a notion on "the risk of attractive noise" could be added.

**Sections on marine mammals** are also very well covered, although a few important references could be added regarding the knowledge on seals and porpoises behavior in operational offshore wind farms (see below: Vellejo 2017, Russel 2014).

I have little expertise on bird impacts from wet renewables and therefore cannot contribute to this part of the review. However, this part is extensive and seem to cover a lot of literature.

**4.8.2 and 3.** The sections on otters and polar bears are good complements. I think that they could be expanded slightly, with more information on these animal's specific behavioural traits, in relation to man-made objects in general. That would make these sections less generic and more informative.

**Cumulative impacts.** As mentioned in the generic comments the two sections with same title are in my view dealing with different aspects, population level impacts and cumulative impacts, both of which are important. For the latter (section 4.9) spatial analyses such as Cumulative Impact Assessments (CIA), could be mentioned given their increasing importance within marine spatial planning and status assessments. If so, the initial work by Halpern *et al*. 2008 and the subsequent Helcom HOLAS should be referenced. It may be of interest that Sweden has applied the CIA method to assess the contribution of impact from different sectors within the Swedish development of marine spatial plans. These analyses indicate that, given a significant increase of energy development (offshore wind) in Swedish waters, this sector would contribute with 0.05 – 0.3% of the cumulative impact, depending on region. This information does not relate directly to wet renewables but gives a hint of orders of magnitude when energy developments are compared to other concurring stressors from a strategic and spatial viewpoint with all limitations of such perspective.

**Suggested additional references**


Halpern *et al.* 2008 A Global Map of Human Impact on Marine Ecosystems. Science vol 319

Hammar *et al.* 2017 Introducing ocean energy industries to a busy marine environment. Renewable and Sustainable Energy Reviews 74 (2017) 178–185

Hammar *et al.* 2015 A Probabilistic model for Hydrokinetic turbine collision risks: Exploring impacts on fish. PLoS One 2015:10 e0117756

Raoux *et al.* 2017 Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning? Ecological Indicators 72 (2017) 33–46

Russel *et al.* 2014 Marine mammals trace anthropogenic structures at sea. Current Biology Vol 24 No 14

Vallejo *et al.* 2017 Responses of two marine top predators to an offshore wind farm. Ecology and Evolution. 2017;7:8698–8708