WETFEET

D7.4 – EIA of the proposed breakthroughs for large scale deployment

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EXECUTIVE SUMMARY

This document presents Deliverable 7.4 of the WETFEET H2020 project – Report with characterization of EIA-relevant issues related to the breakthroughs implementation for large scale deployment.

LIST OF ACCRONYMS

AEP	Annual Energy Production
DE	Dielectric Elastomers
DEG	Dielectric Elastomer Generator (to refer to the whole generator)
EIA	Environmental Impact Assessment
EAM	Enhanced Added-Mass
CAPEX	Capital Expenditures
LCOE	Levelized Cost of Electricity
NS	Negative Spring
OPEX	Operational Expenditures
OWC	Oscillating Water Column
PTO	Power Take-Off
TRL	Technology Readiness Level
TPL	Technology Performance Level
WEC	Wave Energy Converter

1. Introduction

Within the framework of the WETFEET H2020 EU funded project, a set of breakthroughs have been identified to address the obstacles that have been delaying the path towards commercialization of the wave energy sector, including:

1) Survivability breakthrough via device submergence under storm conditions;
2) Operation and maintenance continuously submerged device and adaptation of components and strategies;
3) Power take-off via the analysis and development of innovative PTO alternatives including polymeric membranes;
4) Performance optimization via the practical implementation and functionality of a negative spring for an OWC;
5) Array breakthrough via sharing of mooring and electrical connections between nearby devices.

While these breakthrough features are expected to positively impact the wave energy sector as a whole, the work is focused on their development and integration into two different wave energy converters (WECs), namely (i) the OWC (Oscillating Water Column), both with structures undertaking significant and limited heaving motions, and (ii) the Symphony, a variable volume submerged buoy.

This deliverable will address the environmental aspects of the breakthroughs addressed during the WETFEET project.

1.1. Wave energy concepts

1.1.1. The Oscillating Water Column Spar-buoy

The OWC spar buoy type is considered the lower risk and most economic buoy by the British Department of Trade & Industry but still several pathways for cost-reductions were identified.

The operating principle of an OWC resides in the cycle of compression-decompression of trapped air to flow through a turbine couples to a generator (Figure 2). Power extraction efficiency could be optimized with a proper structural design and control system, as for example achieving minimal interference between the generator and the air flow exiting the system.

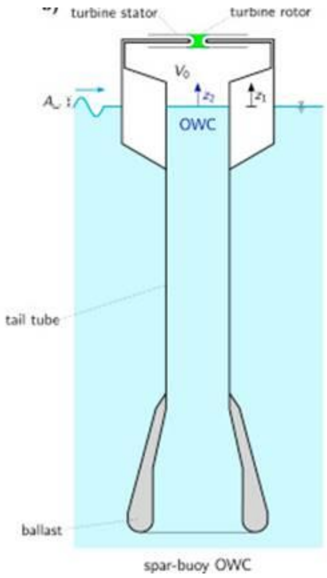


FIGURE 2- SPAR-BUOY OWC DESIGN (HENRIQUES, ET AL., 2016).

A high-level energy conversion model begins with the incoming mechanical wave power interacting with the OWC spar-buoy and inducing a vertical motion in the water column which is converted into pneumatic power. The time-varying pressure then drives a mechanical air turbine connected to the exterior atmosphere part of the power can be converted into electricity by a generator and ultimately feed the grid.

1.1.1. The Symphony

The Symphony consists of an inner cylinder vertically fixed in the water column, via mooring lines, and an outer cylinder (floater) that is moving up and down in relation to the inner cylinder (Figure 1.1), driven by the alternating wave forces. The two cylinders are connected through two membranes, each with different effective surface area, thus making a pressurized internal fluid (most likely water) move within an enclosed volume. The pressurized water volume stabilizes the floater position and makes the enclosed air volume act as a spring. The water movement can also be used directly to drive a turbine as PTO. Air/water compensation tanks located in the inner cylinder are connected to the spring chamber to allow for spring adjustments. All the components that are subject to maintenance, as well as the vital controls are located inside a cocoon that is removable under water, while leaving the Symphony on site.

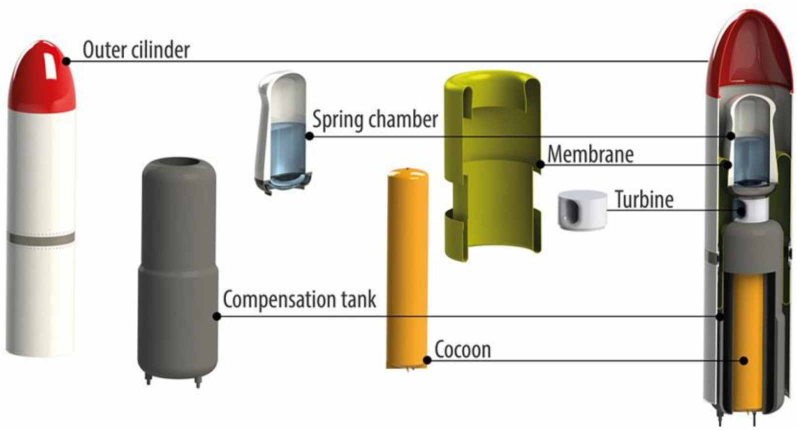


FIGURE 1.1- SCHEMATIC VIEW OF THE SYMPHONY MAIN COMPONENTS AND THEIR LOCATION.

The following sequence sketches the Symphony operation during a wave cycle (Deliverable 2.2):

1) The system is anchored to the ground, wave starts passing over the device, water pushes the outer cylinder down, making it accelerate downwards. The water in the roll-membrane is being pushed through the turbine, which extracts energy from the water flow. Air compresses when water flows in the spring chamber, generating a force on the water inside the spring room;
2) When the wave crest is directly above the top of the floater, the force applied on the outer cylinder is at its maximum. At this point the outer cylinder is moving downward at its maximum speed with zero acceleration;
3) As the outer cylinder is being pushed down, the increasing resulting force due to the compressed air becomes greater that the force generated by the wave, making the velocity from the movement of the outer cylinder decrease;
4) The system is at its lowest point. The compressed air reaches its highest pressure of the cycle. At this moment the outer cylinder speed is zero and the upwards acceleration is maximum;
5) The compressed air in the spring chamber creates a force on the water inside the spring room pushing it back to the turbine which extracts energy from the water flow into the roll-membrane;
6) The outer cylinder keeps accelerating upwards until the force of the wave pushing the outer cylinder down and the force of the compressed air pushing the outer cylinder upwards become balanced again. Once this balance is reached, the velocity of the outer cylinder moving upwards reaches its maximum;
7) The outer cylinder slows down as the force generated by the water becomes greater than the for of the compressed air;
8) The acceleration keeps on increasing downwards until it reaches its maximum. At this point the velocity of the outer cylinder is zero.

As a new crest passes, the outer cylinder starts moving downwards again, repeating the cycle.

1.2. Environmental Impact Assessment

In general, Environmental Impact Assessment (EIA) is a procedure that ensures that the environmental implications of decisions are considered before the decisions are made for individual projects. Its application is nowadays incorporated in numerous national regulations for licensing human activities, including wave energy harnessing. The main steps of the EIA approach are presented in Figure 1.2.

The Scoping process is an essential step of the EIA, which aims to identify, at an early stage of the project development, the key environmental issues that will need most attention. Environmental key issues are e.g. environmental receptors significantly affected, effects or potential impacts of the project on the environment, environmental issues that need detailed study (both desk study and or baseline survey), methodologies to use, possible mitigation measures, constraints that may pose problems and whom to consult with. During this process, many potential environmental and socio-economic potential impacts can be avoided through amendments to the e.g. choice of location, technology and materials (Simas, et al., 2010).

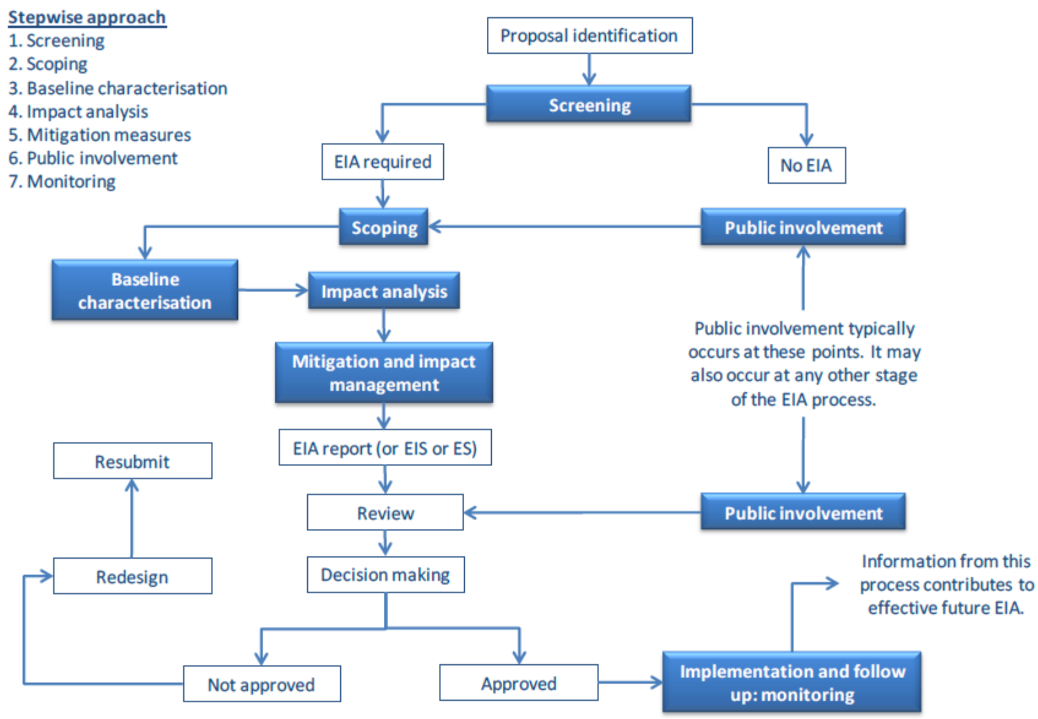


FIGURE 1.2- THE ENVIRONMENTAL IMPACT ASSESSMENT STEPWISE APPROACH: THEORETICAL STEPS.

Since the main objective of the task related with this deliverable is to anticipate relevant impacts of the selected breakthroughs and to propose mitigation measures, the process was adapted, and the following step-by-step was followed:

1. The main characteristics of the breakthroughs are described and when it is relevant the negative and the positive aspects from an environmental point of view compared to the reference case are pointed out;
2. The main environmental stressors regarding each breakthrough are identified as well as the main environmental receptors and the potential impacts. These are evaluated based on the criteria presented in Table 1.1.
3. When different scenarios are available for the same breakthrough specific criteria is defined to help understanding how the different configurations could impact the main receptors;
4. When significant negative impacts are identified, mitigation measures are proposed;
5. A simplified risk analysis considering two scenarios for large-scale deployment: in Scotland and Portugal is carried out.

TABLE 1.1- CRITERIA FOR ENVIRONMENTAL IMPACT EVALUATION.

Criteria	Qualitative grade
Nature of impact	Direct, indirect
Signal	Positive, neutral, negative
Magnitude (Severity)	Maximal, moderate, minimal
Probability of occurrence	High, medium, low
Duration	Temporal, intermittent, permanent

Frequency	Continuous, discontinuous, periodic, regular, rare
Temporal extension	Immediate, short-term, medium-term, long-term
Spatial extension	Local, adjacent, regional, national, global
Recoverability	Irrecoverable, irreversible, reversible, recoverable, fugal
Inter-relations between actions and effects	Simple, cumulative, synergetic
Need for mitigation	Critical, severe, moderate, partial, no-mitigation
Significance	High significance, significant, low significance, irrelevant

2. Improved power conversion

The breakthroughs addressing an improvement of power conversion are related with:

a) A tetra-radial turbine; and
b) The use of dielectric elastomer generators.

Regarding the tetra-radial turbine one of the main anticipated stressors is the underwater noise radiated in the marine environment. Underwater soundscape results from the combination of several natural and anthropogenic sources. For marine species sound plays a very important role in a variety of their lives, such as for communication, predator-prey behaviors, orientation, navigation, mate selection, among other.

Comparing with other sources of noise marine renewable energy devices may produce lower noise levels but have the potential to cause long-term exposure to several marine organisms (Gill, 2005). The behavioral responses of fish, seabirds and marine mammals may be significantly different while facing changes in soundscape. Responses may either be avoiding areas with intense sound or become acclimated to the added noise.

Since the breakthroughs are being addressed from an early stage, there are some mitigation measures that could be studied in further studies as for example, considering silent designs (e.g. an air layer isolating the chamber where the turbine is located). Other mitigation measure could be to avoid sensitive areas, particularly for those species relying on sound to survive (e.g. breeding areas for cetacean species).

The analysis of this parameter was not considered at this stage of development and therefore no measurements were made regarding the noise features generated by the breakthroughs to support impact assessment.

2.1. Dielectric elastomer generators (DEG)

Dielectric Elastomer Generator is being studied as an alternative to traditional Power Take-Off (PTO) systems, which utilise air turbines in oscillating water column devices (Têtu, 2017). The operating principle of a Dielectric Elastomer Generator (DEG) is based on a solid-state deformable transducer made of elastic polymers that can convert mechanical energy into direct electricity via the variable capacitance electrostatic generation.

The main advantages of this technology over traditional PTO systems are: direct drive cyclical operation with good energetic efficiency that is almost independent of wave period; easier installation and

maintenance and lower costs. The overall feasibility of DGE-PTO has been demonstrated in the Future Emerging Technologies EU FP7 Project PolyWEC. The environmental impacts of this technology were also addressed. Considering the review carried out the main concerns were identified:

- **Material degradation and dispersion**

Degradation refers to the process leading to the deterioration of polymer properties and can occur through mechanical and chemical weathering processes. The effects of chemical leaching on marine animals and habitats highly depend on the quantity and toxicity of the material and on the duration of the leaching event. The increasing concern about environmental impacts of materials and their applications in marine devices has been moving innovation towards bio-sourced and recyclable matrix polymers, which can be reinforced by natural fibres. Dielectric membranes could be manufactured from different materials: rubber, silicones, acrylic and polyurethanes. From the evaluation performed under the PolyWEC project, material degradation and dispersion effects were considered to be unlikely and due to the slow degradation process of these materials, effects are expected to have a low magnitude in the surrounding environment.

- **Collision and injury risk**

One of the main concerns regarding WEC devices is related with moving parts and the risk of collision or injury of marine animals. The potential for collision, and the main receptors affected will depend on the integration of the DEG membrane on top or in the bottom of the device.

- **Electromagnetic fields**

During the operation the dielectric layer of the DEG is subject to a high electric field and therefore it is important to consider if they can be detected by sensitive species and if they are of biological relevance. This topic has been addressed in the context of submarine cables, and it is recognised that many electro-sensitive species potentially respond to the electric fields but it is not clear whether such interaction results in any response or consequence for the organisms (Gill *et al*., 2005). There is also evidence that the benthic species, elasmobranch and turtles can respond to and be affected by EMF associated with sub-sea cables (Gill *et al*., 2009). EMF from the DEG were not measured and thus it is not possible to assess the level of impact. Magnetic fields decay rapidly near the source, and therefore it is expected that the worst-case scenarios from an environmental point of view are those where DEG membranes are in direct contact with the marine environment.

- **Electric shock hazard**

DEG membranes are electrically charged and electric shock can result from two situations: malfunction or an unexpected rupture. In this situation, the resulting electric discharge can reach MJ of energy released into the water column. The propagation distance will depend on the intensity and voltage level. Due to the high conductivity of the water in the marine environment, the electric current propagation is expected to occur fast and to dissipate rapidly and therefore an impact at local level is expected. Several studies identified physiological and behavioural reactions to electric fields such as shrimps, bony fish and elasmobranchs (Murray *et al*,. 2014; Soetaert *et al*., 2014; Poleo *et al*., 2001; Gill *et al*., 2009).

Comparing the use of DEG on the OWC Spar-buoy and the Symphony, the impact can be higher for the first type of device, for the bottom configuration, since the membrane has direct contact with seawater. For device types like Symphony electric hazards are expected to be minimised since the membrane is enclosed in a chamber. Potential mitigation measures can be the use of an insulation layer covering the di-electric membrane to avoid current propagation. Considering the existing uncertainty about the electric voltage leaked into the marine environment, another mitigation measure would be to avoid environmentally sensitive areas regarding deployment locations (e.g. nursery or breeding areas).

2.1.1. The OWC Spar-buoy

Two solutions for the integration of DEG into the OWC Spar-buoy architecture were analysed, considering the location of the DEG on top or in the lower part of the device (Figure 2.1). The potential environmental impact risks are much dependant on the selected configuration.

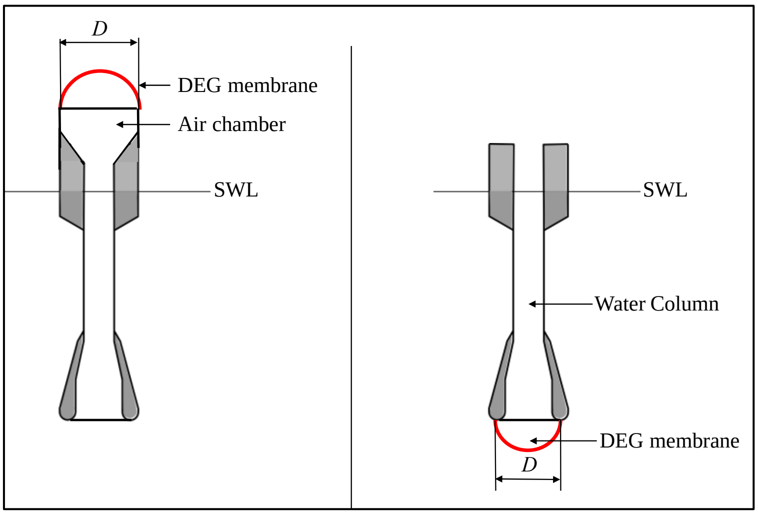


FIGURE 2.1- DIFFERENT INTEGRATION STRATEGIES FOR THE DEG (RED LINE) INTO THE SPAR BUOY OWC CONCEPT.

Regarding collision, due to its properties and operation the structure will deform in accordance with the prevailing wave regime. Depending on their movement size and speed, dynamic components may exert a minor or a greater force that may lead to injury if the animal's reaction and size cannot cope with that.

One of the consequences of the presence of WECs in the marine environment is the potential to affect biodiversity by functioning as artificial reefs and by attracting different animals, such as fish, seabirds and marine mammals (Langhamer *et al.*, 2009; Copping *et al.*, 2016). Depending on the integration architecture, different receptors can be affected. On one hand, if the top configuration is selected it is expected that the DEG presents higher risk for seabirds, since it is suggested that they can use the floating parts above the waterline as roosting platforms (Cooping *et al.*, 2016). On the other hand, if the bottom configuration is selected the main receptors are marine mammals since the membrane can pose a physical obstacle to the animal crossing the device area e.g. for feeding purposes.

Considering large scale deployment, the selection of one of the two configurations should account on the main environmental receptors present around the deployment site to mitigate the potential impact on important species. For example, if the site for deployment is close to shore or near of an important seabird area (e.g. nesting sites) the top configuration should be avoided. At the same time, if the device is going to be deployed in an important area for marine mammals (e.g. feeding, breeding) the site should be avoided. Another mitigation that can be considered when the device/park is located in migration sites, is to consider to shut-down the device, but this is only reasonable when migration routes and seasons are very well established.

2.1.2. The Symphony

Different solutions for the integration of DEG into the Symphony architecture are presented in Figure 2.2. Considering the design of the Symphony, the DEG will not be in direct contact with the marine environment since it will be enclosed in the cocoon. Therefore, the described impacts are unlikely to occur for this device. However, if a general submerged pressure differential WEC is considered, the DEG will be in contact with seawater and the same impacts as describe above for the OWC Spar-buoy may apply (Figure 2.3). Also, as for the OWC Spar-buoy, if the membrane stretches out of the physical structures of the device it may pose a risk for collision or injury of marine animals swimming near the device.

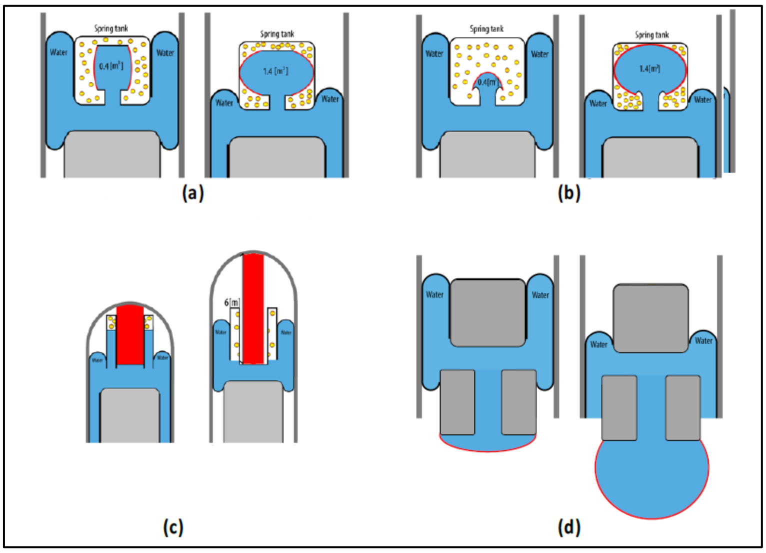


FIGURE 2.2- DIFFERENT INTEGRATION STRATEGIES FOR THE DEG (RED LINE) INTO THE SYMPHONY CONCEPT.

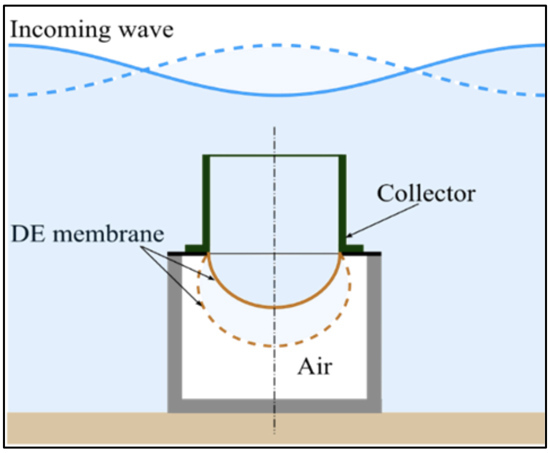


FIGURE 2.3- INTEGRATION OF DEG IN A SUBMERGED PRESSURE DIFFERENTIAL WEC.

TABLE 2.1- EVALUATION OF THE ENVIRONMENTAL IMPACTS REGARDING THE USE OF DEG.

Impact	Main receptors	Impact evaluation			Mitigation measures
		OWC Spar-buoy		Symphony	
		Top configuration (Without contact with seawater)	Bottom configuration (In contact with seawater)		
Material degradation and dispersion	Seabed communities	Indirect, negative, minimal, low, temporal, continuous, long-term, local, reversible, simple, partial, irrelevant to low significance	Indirect, negative, minimal, low, temporal, continuous, long-term, local, reversible, simple, partial, irrelevant to low significance	Indirect, negative, minimal, low, temporal, continuous, long-term, local, reversible, simple, partial, irrelevant to low significance	To avoid sensitive areas (e.g.: breeding and feeding areas)
Collision	Marine mammals Sea turtles Fish Seabirds	Direct, negative, moderate, low, temporal, regular, long-term, local, irreversible, simple, partial, low significance	Direct, negative, moderate, low, temporal, regular, long-term, local, irreversible, simple, partial, low significance	Direct, negative, moderate, low, temporal, regular, long-term, local, irreversible, simple, partial, low significance	To avoid sensitive areas Shut-down procedures when located in sensitive areas
Electromagnetic fields and electric shock hazard	Elasmobranchs	Indirect, neutral, minimal, low, temporal, rare, immediate, local, irreversible to reversible, simple, partial, low significance to significant	Indirect, neutral, minimal, low, temporal, rare, immediate, local, irreversible to reversible, simple, partial, low significance to significant	Indirect, neutral, minimal, low, temporal, rare, immediate, local, irreversible to reversible, simple, partial, low significance to significant	To avoid sensitive areas

3. Optimised structural design and device profile

3.1. Negative spring

The Negative Spring mechanism was analysed for the OWC Spar-buoy which can be considered as a heaving point absorber. Therefore, a way of achieving optimal power absorption conditions from a hydrodynamic standpoint is to have it in resonance with the typical incoming waves which is achieved using a Negative Spring mechanism. If this breakthrough is effective, this will reflect into practical modifications regarding the reference case, i.e. an OWC Spar-buoy without the negative spring mechanism:

- The device will have a higher oscillation amplitude.
- It will allow to have smaller devices for a specific wave regime;

Considering this, expected environmental concerns regarding this breakthrough are the risk of collision and the disturbance of marine life due to the noise radiated by the device.

As mentioned on the previous section the risk of collision will depend on the size or the speed at which the device moves and the velocity of the animals' reaction.

Since the size of the devices can be reduced, there is a reduction on the footprint of the park at a large-scale deployment. Therefore, the area of habitat exclusion is reduced, and this effect minimised, in particular for marine mammals.

In the OWC Spar-buoy the noise is derived from the turbines and the air flow through the turbine duct. In the OWC Spar Buoy using the negative spring mechanism the higher oscillation amplitude leads to a bigger difference on the air pressure inside the air chamber and peaks on the flux through the turbine result in higher noise levels. Information about underwater noise levels radiated by wave energy converters is scarce. From the measurements carried out so far, mainly for point absorbers devices, indicate that low levels of underwater noise are radiated (Tougaard *et al.*, 2015).

In the studies carried out in the context of the WETFEET Project higher oscillation amplitudes as well as variations on the air pressure inside the chamber were not verified and therefore it is assumed that the environmental impacts comparing with the reference case are kept the same.

Table 3.1 presents the evaluation for these impacts. However, the proper assessment for large-scale deployment should fall under the conditions of the real scenarios using predictive models for collision and underwater noise propagation. Regarding mitigation measures, noise reduction measures might be considered at the design phase, considering e.g. the use of insulation materials.

TABLE 3.1- EVALUATION OF THE ENVIRONMENTAL IMPACTS FOR THE NEGATIVE SPRING MECHANISM.

Impacts	Main receptors	Impact evaluation	Mitigation measures
		OWC Spar Buoy	
Collision	Marine mammals Fish	Direct, negative, moderate, low, permanent (during the operation of the device), rare, immediate, local, irreversible, simple, no-mitigation, low significance to average significance	To avoid sensitive areas (e.g. feeding and breeding areas);
Underwater noise disturbance	Marine mammals Fish Benthic communities	Direct, negative, minimal, low, permanent, continuous, long-term (during the operation of the device), local to adjacent (depends on sound propagation), reversible, cumulative (with other activities generating noise e.g. maritime traffic), partial, irrelevant to significant	Application of noise reduction measures at the design phase
Habitat disturbance	Marine mammals	Direct, positive, minimal, low, permanent (during the operation of the device), continuous (during the operation of the device), long-term, local to adjacent, reversible, simple, no mitigation, low significant to significant	-

3.2. Survivability submergence

Survivability submergence breakthrough was addressed for both type of devices. However, survivability submergence for the Symphony is based on changes on the control system and therefore the same environmental impacts described above are expected with its application.

3.2.1. The OWC Spar-buoy

The reference case corresponds to the device operating on the surface of the ocean. To improve survivability when exposed to storms, submergence is proposed as a breakthrough. Two strategies were addressed (Deliverable 3.2): a) reducing the length of 4 of the mooring lines by means of winches, while the other 2 are let loose; b) introducing extra masses representing additional water ballast; b) introducing extra masses representing additional water ballast. In large-scale deployments this means several devices submerged, being an obstacle to the free movement of the animals. Therefore, anticipated concerns are related with: risk for collision and entanglement in mooring lines. Another concern, not directly related is the risk for navigation and fishing and the potential to miss the obstacle.

The assessment of the risk of entanglement is dependent on the configuration that is selected. According to Harnois et al. (2015), the overall risk of entanglement is low. However, for the different configurations analysed, catenary moorings and moorings using accessory buoys present higher risk of entanglement. Regarding collision, it is anticipated that marine mammals are the main group being affected due to the presence of devices underwater. However, most of these animals can use echolocation to identify obstacles and avoid them (Au, 1993). Avoidance behaviour can result in exclusion of the animals from the site. The cost of this impact can be mitigated avoiding the location of the device/park in sensitive sites for marine species (e.g. migration routes, breeding areas). Other solution that may be studied is laying down the device on the seabed. In this case an additional impact is anticipated on the seabed communities (Table 3.2).

TABLE 3.2- EVALUATION OF THE ENVIRONMENTAL IMPACTS FOR SUBMERGENCE OF THE OWC SPAR-BUOY UNDER HARSH ENVIRONMENTAL CONDITIONS.

Impact	Receptors	Impact evaluation OWC Spar-buoy	Mitigation measures
Collision	Marine mammals	Direct, negative, moderate, low, temporal, rare, short-term, local, irreversible, simple, no mitigation, significant to low significance	To avoid sensitive areas(e.g. feeding and breeding areas);
Entanglement	Marine mammals	Direct, negative, moderate, low, temporal, rare, short-term, local, reversible, simple, partial, irrelevant to low significance	To avoid sensitive areas To avoid the moorings to be loosen
Seabed disturbance	Benthic communities	Direct, negative, minimal, low, temporal, rare, short-term, local, recoverable, simple, no mitigation, low significance	To avoid sensitive areas

4. Array optimization

In the WETFEET Project array optimisation was addressed based on shared moorings with rigid connections and with non-rigid connections with the main objective of reducing costs through mooring component sharing.

4.1. The Symphony

Regarding the Symphony device, the mooring system for future devices is out of WETFEET scope. However, a preliminary mooring system has been designed, consisting of a tension leg for keeping the device vertically in the water column and a slack mooring for station keeping (Figure 4.1). The array optimisation based on shared mooring and cables was not addressed for this type of devices and therefore the environmental impact assessment was not considered as well.

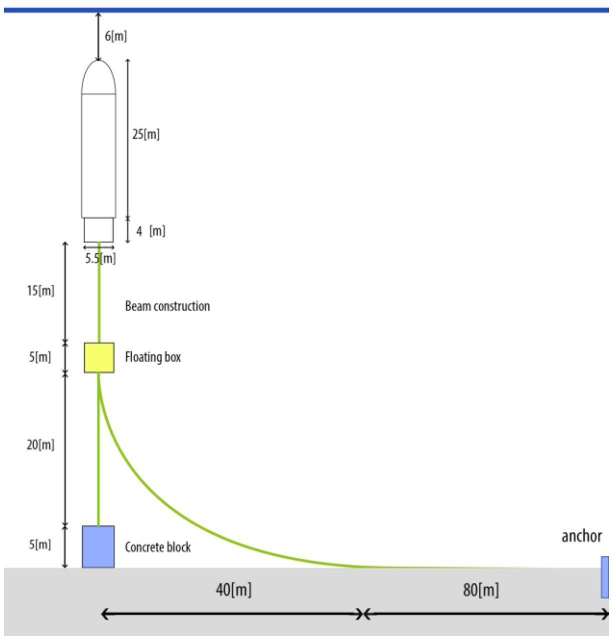
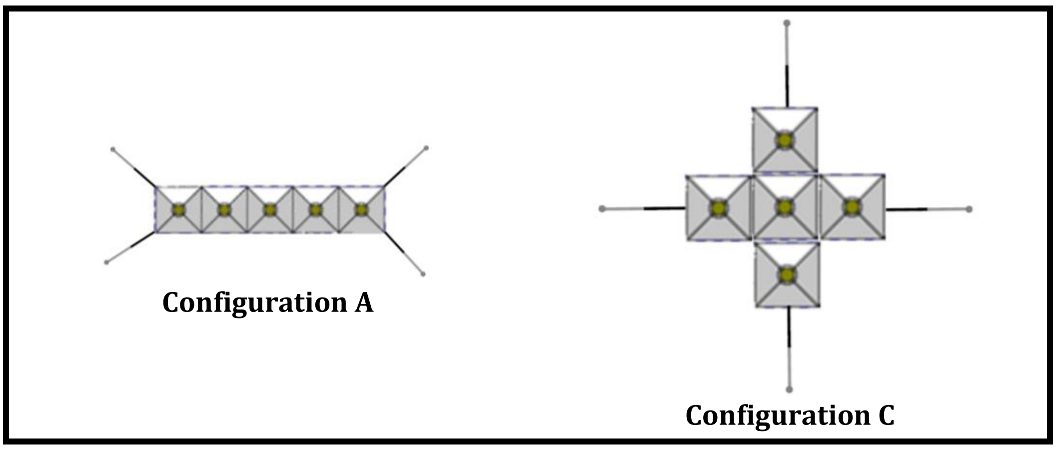


FIGURE 4.1- INDICATIVE MOORING LAYOUT FOR A 6 M SYMPHONY IN 80 M DEPTH.

4.2. The OWC Spar Buoy

4.2.1. Shared moored with rigid connections

In Deliverable 6.2, environmental criteria were considered to select the configurations to be tested for rigid connections. The configurations selected are presented in Figure 4.2. Configuration A was selected since it is easily scalable for a higher number of devices. Configuration C was selected because it is a way to reduce the footprint area. Configuration E was selected because it represents a good compromise between costs and reduced risk of failure. To quantify the impact, the number of mooring lines, anchors and footprint area were quantified to rank the three configuration types from an environmental point of view. Considering the worst-case scenario, from the best environmental friendly to the worst, the following rank was obtained for the mooring configurations: C, followed by E and finally A.



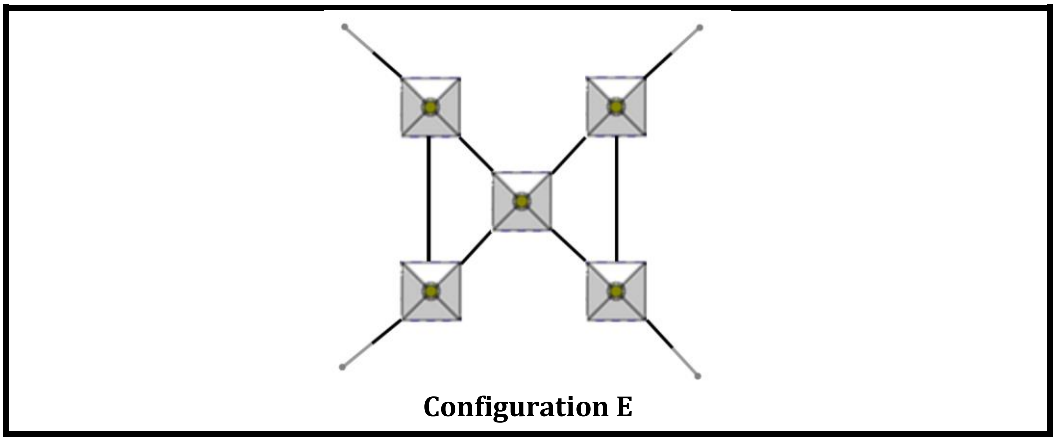


FIGURE 4.2- SELECTED CONFIGURATION FOR SHARED MOORINGS WITH RIGID CONNECTIONS.

The main anticipated impacts for a large-scale deployment are related with seabed disturbance due to the anchoring system. In the shared mooring system with non-rigid connections, the risk for collision or entanglement is reduced.

4.2.2. Shared moorings with non-rigid connections

In the context of the WETFEET Project an arrangement of five OWC Spar-buoy devices was chosen to be arranged in a die format (Figure 4.3), and three mooring schemes were analysed (Table 4.1). For the environmental impact assessment, the reference case will be an isolated device with a three-point mooring as presented in Figure 4.4. The moorings for the OWC Spar-buoy devices were either bottom-lines, connecting each device to the floor, or interconnecting lines; connecting two devices together. Each mooring line consists of three synthetic fibre and two chain sections as shown by Figure 4.5. Interconnecting lines are assumed to be made of synthetic line and a clump weight was attached to the middle of each line.

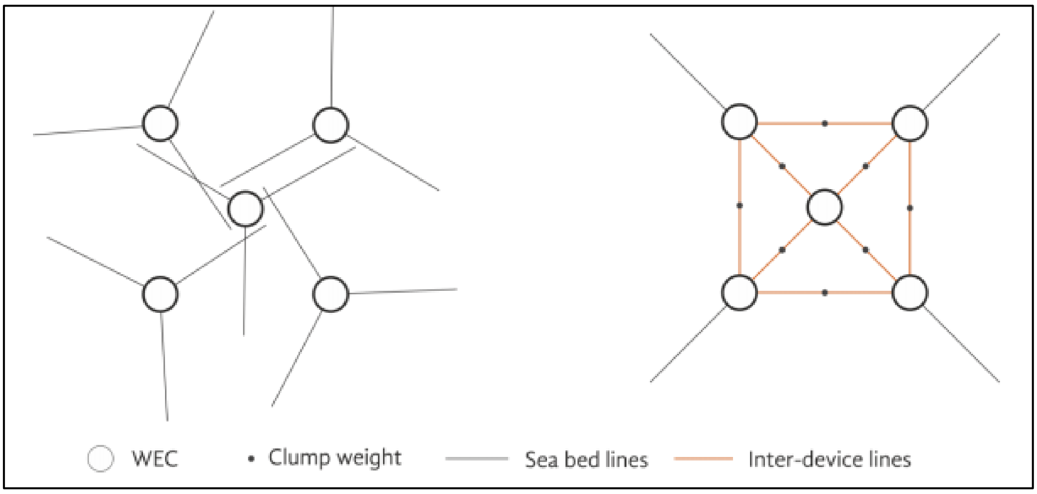


FIGURE 4.3- PROPOSED CONFIGURATION IN THE INDIVIDUALLY MOORED (REFERENCE CASE) (LEFT) AND MOST INTERCONNECTED ARRANGEMENT (RIGHT).

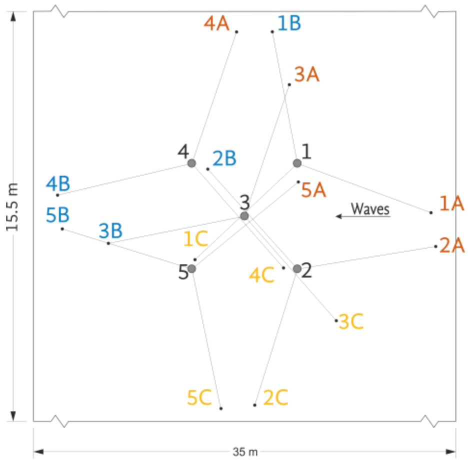
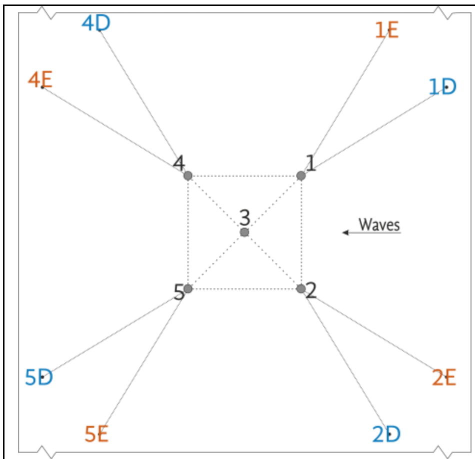
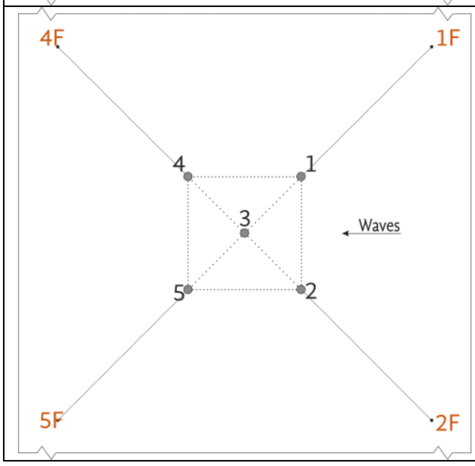
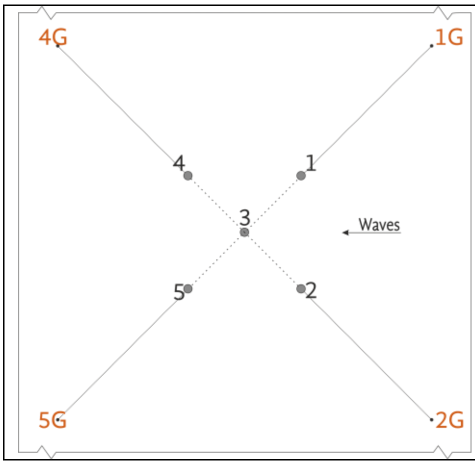
	**Configuration A (reference case)** Each device is isolated with a three-point mooring. Details: - 15 anchors - 15 mooring lines - 15 touching-down points

FIGURE 4.4- REFERENCE CONFIGURATION FOR ENVIRONMENTAL IMPACT ASSESSMENT OF SHARED MOORING BREAKTHROUGH.

TABLE 4.1- ARRAY CONFIGURATIONS OF THE OWC SPAR BUOY TESTED UNDER WETFEET.

	**Configuration B** Devices 1, 2, 4 and 5 are sharing floating lines with the central device. With redundancy on mooring in devices 1, 2, 4 and 5. Details: - 8 anchors - 12 Seabed lines - 4 inter-device-lines - 8 touching-down points
	**Configuration C** Devices 1, 2, 4 and 5 are sharing floating lines with the central device. Without redundancy on mooring in devices 1, 2, 4 and 5. Details: - 4 anchors - 8 mooring lines - 4 inter-device-lines - 4 touching-down points

	**Configuration D** Devices 1, 2, 4 and 5 are sharing floating lines with the central device. Without redundancy on mooring in devices 1, 2, 4 and 5, and without mooring lines between 1 and 2; 2and 5; 5 and 4 and 4 and 1. Details: - 4 anchors - 4 mooring lines - 4 touching-down points

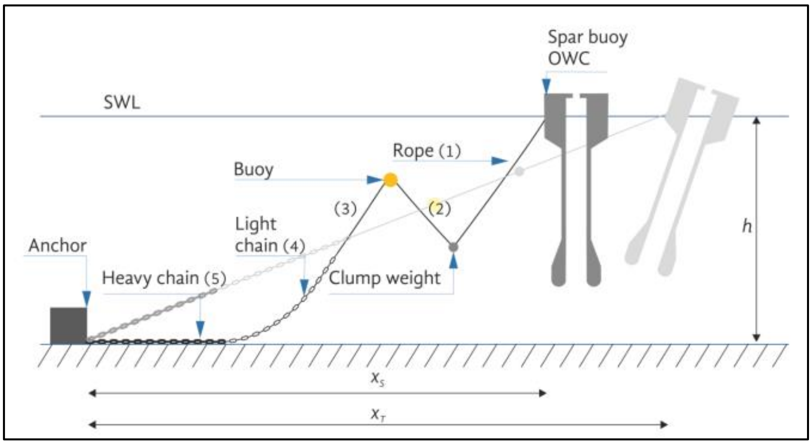


FIGURE 4.5- THE SEABED MOORING SYSTEM, AND THE SYSTEM IN A FULLY LIFTED SCENARIO.

Anticipated impacts for the reference case in a large-scale deployment are the risk of collision or entanglement for moving animals, seabed disturbance, underwater noise and the artificial reef effect. The evaluation of these impacts is presented Table 4.2. The same impacts are expected for the different configurations analysed. However, due to the reduction of mooring lines when shared configurations are used the impact intensity is reduced.

The risk for collision exists either when the device is submerged and not visible to the other marine users, or in case of a line failure. However, collision risk is reduced by the existence of a safety exclusion zone for the farm.

Regarding seabed disturbance, it is expected that benthic communities are mainly affected during the installation of the anchors and during the operation phase of the park due to the chain touching the seabed at the touch-down point (TDP). Comparing with the reference case, less anchors will be needed to fix the system (15 vs. 8 or 4), and therefore there is also an environmental advantage in considering shared moorings. Of all the different configurations analysed, Configuration C represents the more environmentally friendly solution. Seabed disturbance can be considered local and limited to the devices' footprint on the seabed (Greaves et al., 2016). Therefore, another parameter that can be considered for large-scale impact assessment is the footprint of the farm.

Another environmental impact related with large-scale parks is the cumulative underwater noise provoked by the mooring metal chains plus the devices operation noise in the acoustic environment (Beharie and Side, 2012). On the one hand, it could work as an acoustic cue for the animals to detect the presence of the park and on the other this continuous noise may introduce long-term impacts on the animals. There is a lack of available data about the contribution of the mooring chain noise to the ambient noise and therefore the assessment in real conditions is required of this impact is required.

Mooring lines will also provide hard substrate for marine organisms to colonise, acting as an artificial reef. If on the one hand it can generate an enhanced habitat, on the other it can work as a stepping-stone for invasive species (Langhamer, 2012). The signal of the impact will depend on the site where the device is to be installed.

TABLE 4.2- EVALUATION OF THE ENVIRONMENTAL IMPACTS FOR NON-RIGID SHARED MOORINGS.

Impact	Receptors	Impact evaluation	Mitigation measures
		OWC Spar-buoy	
Collision and entanglement	Marine mammals	Direct, negative, moderate, low, temporal, rare, short-term, local, reversible, simple, partial, low significance to significant	Selection of the design with less mooring lines in the water column; To avoid sensitive areas during site selection process (e.g. feeding and breeding areas);
Seabed disturbance	Benthic communities	Direct, negative, moderate, high, temporal (during the installation) or permanent (during operation in the touch-down point), continuous (during operation phase), short-term (installation)/ long-term (operation), local, recoverable, simple, partial, low significance	Selection of the design and configuration with less mooring points; Selection of the configuration with less footprint; To avoid sensitive areas during site selection process;
Underwater noise	Marine mammals Fish	Direct, positive (if it works as a cue for marine animals for the presence of the park,)/ negative (if it results in acoustic disturbance), minimal, low, permanent (during operation), regular, long-term (during operation phase), local/ adjacent (depends on sound propagation), recoverable, simple, partial, irrelevant to low significance	To avoid as much as possible the use of chain; To avoid sensitive areas during site selection process;
Artificial reef effect	Marine life	Direct, positive (habitat enhancement)/negative (due to the potential for invasive species to grow), moderate, high, permanent (while the park is operational), continuous (during the operation phase), long-term, adjacent, reversible, simple, no-mitigation	-

5. Final remarks

Environmental Impact Assessment processes and the understanding of the devices interaction with the marine environment are important aspects hampering siting and consenting/permitting of devices. This report focused on the environmental impacts of the proposed breakthroughs to understand the obstacles that may be posed towards the commercialisation of the wave energy sector. The analysis allows understanding how these breakthroughs may support and promote the development of more environmentally friendly solutions either from an engineering or operational point of view.

As the analysis addressed device components, the environmental impact analysis was focused on the comparison of the environmental impact of the large-scale deployment considering a reference case versus the large-scale deployment if the project integrates the breakthroughs. Anticipating environmental impacts at an early stage is a major advantage as environmentally friendly solutions may be discussed promoting the development of projects with less or minimised environmental impacts.

In general, the anticipated impacts from the breakthroughs are aligned with general concerns about the interactions between devices and the marine environment, however, it was possible to understand that some of them are clearly advantageous from an environmental point of view, in particular for shared moorings and cables. Table 5.1~~Table 5.1~~ presents a summary of the environmental impacts for the different breakthroughs indicating if they will have a positive, negative or neutral effect comparing to the reference case.

TABLE 5.1- SUMMARY OF THE ENVIRONMENTAL IMPACTS FOR THE BREAKTHROUGHS ANALYSED. THE SIGNS: (+) INDICATES A POSITIVE CONTRIBUTION TO THE ENVIRONMENTAL IMPACTS, (-) INDICATES A NEGATIVE CONTRIBUTION TO THE ENVIRONMENTAL IMPACT AND (O) INDICATES A NEUTRAL CONTRIBUTION TO THE ENVIRONMENTAL IMPACTS FOR LARGE-SCALE DEPLOYMENT IN COMPARISON TO THE REFERENCE CASE.

			OWC	Symphony
Improved power conversion	**Dielectric elastomer generator**	Material degradation and dispersion	o	o
		Collision and injury risk	-	o
		Electromagnetic fields	o	o
		Electric shock hazard	-	-
Optimized structural design and device profile	**Negative spring**	Collision risk	o	
		Acoustic disturbance	o	
		Habitat disturbance	+	
	Survivability submergence	Collision	-	o
		Entanglement	o	o

		Seabed disturbance	-	-
Array optimization	**Shared moorings and cables**	Collision and entanglement	+	
		Seabed disturbance	+	
		Acoustic disturbance	+	
		Artificial reef effect	+/-	

References

Au, W. W. L. 1993. The Sonar of Dolphins. New York NY: Springer Verlag.

Beharie, R. and Side, J., (2012). *Acoustic Environmental Monitoring – Wello Penguin Cooling System Noise Study.* A report commissioned by Aquatera Limited. International Centre for Island Technology, Report No. 2012/01/AQ

Copping, N. Sather, L. Hanna, J. Whiting, G. Zydlewsk, G. Staines, A. Gill, I. Hutchison, A. M. O'hagan, and T. Simas, "Annex IV 2016 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World," Pacific Northwest Natl. Lab. behalf US Dep. Energy (the Annex IV Oper. Agent), 2016.

Gill, A.; Huang, Y.; Gloyne-Philips, I.; Metcalfe, J.; Quayle, V.; Spencer, J.; Wearmouth, V. (2009). *COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2: EMF Sensitive Fish Response to EM Emissions from Sub-sea Electricity Cables of the Type used by the Offshore Renewable Energy Industry*. Report by Centre for Environment Fisheries and Aquaculture Science (CEFAS), Centre for Intelligent Monitoring Systems (CIMS), Centre for Marine and Coastal Studies Ltd (CMACS), Cranfield University, and University of Liverpool. pp 128.

Gill, A.; Gloyne-Philips, I.; Neal, K.; Kimber, J. (2005). *COWRIE 1.5 The Potential Effects of Electromagnetic Fields Generated by Sub-Sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms - A Review*. Report by Centre for Marine and Coastal Studies Ltd (CMACS) and Cranfield University. pp 128.

Greaves D., Conley D., Magagna D., Aires E., Leitão J.C., Witt M., Embling C. B., Godley B. J., B. A. W.J., Saulnier J., Simas T., O'Hagan A. M., O'Callaghan J., Holmes B., Sundberg J., Torre-Enciso Y., Marina D., (2016). Environmental Impact Assessment: Gathering experiences from wave energy test centres in Europe, *International Journal of Marine Energy*, 14: 68-79.

Harnois V., Smith H.C.M., Benjamins S., and Johanning L. (2015). Assessment of entanglement risk to marine megafauna due to offshore renewable energy mooring systems. *International Journal of Marine Energy*, 11:27–49.

Langhamer O. (2012). Artificial Reef Effect in relation to Offshore Renewable Energy Conversion: State of the Art. *The Scientific World Journal*, vol. 2012, Article ID 386713, 8 pages. doi:10.1100/2012/386713

Langhamer, O., Wilhelmsson, D., & Engström, J. (2009). Artificial reef effect and fouling impacts on offshore wave power foundations and buoys: a pilot study. *Estuarine, Coastal and Shelf Science*, 82(3), 426–432. https://doi.org/10.1016/j.ecss.2009.02.009

Murray P. C. B., Robertson P., M., & Bailey, N., F, "Electrofishing for Razor Clams (*Ensis siliqua* and *E. arquatus*): Effects on Survival and Recovery of Target and Non-Target Species," Scottish Mar. Freshw. Sci., vol. 5(14), no. 1– 44

Poleo, A. B. S. H., Johannessen, F. and Harboe Jr, M. (2001). *High Voltage Direct Current (HVDC) Sea Electrodes: Effects on Marine Life*. Department of Biology, University of Oslo.,

Soetaert, M., Chiers K., Duchateau L., Polet H., Verschueren B., and Decostere A. (2014) Determining the safety range of electrical pulses for two benthic invertebrates: brown shrimp (*Crangon crangon* L.) and ragworm (*Alitta virens S*.). *ICES Journal of Marine Science.*

Tougaard J (2015) Underwater Noise from a Wave Energy Converter Is Unlikely to Affect Marine Mammals. *PLoS ONE* 10 (7): e0132391. https://doi.org/10.1371/journal.pone.0132391

WavEC, "D6.3 – Methodology for monitoring electromagnetic fields underwater.," 2014.