SAFE WAVE

STREAMLIING THE ASSESSMENT OF ENVIRONMENTAL EFFECTS OF WAVE ENERGY

DELIVERABLE 2.1
Development of environmental monitoring plans

Co-funded by the EMFF programme of the European Union

WP 2

Deliverable 2.1 Development of environmental monitoring plans

WavEC

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1. SafeWAVE project synopsis

The Atlantic seaboard offers a vast marine renewable energy (MRE) resource which is still far from being exploited. These resources include offshore wind, wave and tidal. This industrial activity holds considerable potential for enhancing the diversity of energy sources, reducing greenhouse gas emissions, and stimulating and diversifying the economies of coastal communities. As stated by the European Commissioner of Energy, Kadri Simson, during the Energy Day in the framework of the climate conference (COP25) held in Madrid (2-13 December 2019), "the European experience shows that the benefits of clean energy go beyond reduced greenhouse gas emissions and a healthier environment. Clean energy transition boosts the economy and creates jobs. The European Green Deal is also a growth strategy". In the same framework of COP25 and during the Oceans Day, the European Commissioner for environment, oceans, and fisheries, Virginijus Sinkevičius explained that "fighting climate change and protecting marine life biodiversity is a centrepiece of the EU's ocean policy. Due to climate change, our oceans are facing serious challenges, which require an urgent and comprehensive response. But oceans are also a part of the solution". Therefore, ocean energy is one of the pillars of the EU's Blue Growth strategy. Ocean energy could provide clean, predictable, indigenous, and reliable energy and contribute to the EU's objective of reaching a share of renewables of at least 32% of the EU's gross final consumption by 2030. As it was underlined by Virginijus Sinkevičius, "Marine renewable energy has an incredible potential. The offshore wind sector is growing strongly enough to compete with traditional energy sources. The emerging technologies such as wave and tidal energy will take the same pathway".

The nascent status of the Marine Renewable Energy (MRE) sector and Wave Energy (WE) in particular, yields many unknowns about its potential environmental pressures and impacts, some of them still far from being completely understood. Wave Energy Converters' (WECs) operation in the marine environment is still perceived by regulators and stakeholders as a risky activity, particularly for some groups of species and habitats.

The complexity of MRE licensing processes is also indicated as one of the main barriers to the sector development. The lack of clarity of procedures (arising from the lack of specific laws for this type of projects), the varied number of authorities to be consulted and the early stage of Marine Spatial Planning (MSP) implementation are examples of the issues identified to delay projects' permitting.

Finally, there is also a need to provide more information on the sector not only to regulators, developers, and other stakeholders but also to the general public. Information should be provided focusing on the ocean energy sector technical aspects, effects on the marine environment, role on local and regional socio-economic aspects and effects in a global scale as a sector producing clean energy and thus having a role in contributing to decarbonize human activities. Only with an informed society would be possible to carry out fruitful public debates on MRE implementation at the local level.

These non-technological barriers that could hinder the future development of WE in EU, are being addressed by the WESE project funded by EMFF in 2018. The present project builds on the results of the WESE project and aims to move forward through the following specific objectives:

1. Development of an **Environmental Research Demonstration Strategy** based on the collection, processing, modelling, analysis and sharing of environmental data collected in WE sites from different European countries where WECs are currently operating (Mutriku power plant and BiMEP in Spain, Aguçadoura in Portugal, and SEM-REV in France); the SafeWAVE project aims to enhance the understanding of the negative, positive, and negligible effects of WE projects. The SafeWAVE project will continue previous work, carried out under the WESE project, to increase the knowledge on priority research areas, enlarging the analysis to other types of sites, technologies, and countries. This will increase information robustness to better inform decision-makers and managers on real environmental risks, broad the engagement with relevant stakeholders, related sectors and the public at large and reduce environmental uncertainties in consenting of WE deployments across Europe;

2. Development of a **Consenting and Planning Strategy** through providing guidance to ocean energy developers and to public authorities tasked with consenting and licensing of WE projects in France and Ireland; this strategy will build on country-specific licensing guidance and on the application of the MSP decision support tool developed for Spain and Portugal in the framework of the WESE project; the results

will complete guidance to ocean energy developers and public authorities for most of the EU countries in the Atlantic Arch;

3. Development of a **Public Education and Engagement Strategy** to work collaboratively with coastal communities in France, Ireland, Portugal, and Spain, to co-develop and demonstrate a framework for education and public engagement (EPE) of MRE enhancing ocean literacy and improving the quality of public debates.

2. Glossary

°C Degree(s) Celsius

μT Microtesla

μV/m Microvolt per metre

A Ampere

AC Alternating current

AEMet Agencia Estatal de Meteorologia

ASV Autonomous Superficial Vehicle

AUV Autonomous Underwater Vehicle

BiMEP Biscay Marine Energy Platform

CEREMA Centre d'Etudes et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement

cm Centimetre(s)

CPO CorPower Ocean

CTD Conductivity, Temperature, Depth

CTN Centro Tecnológico Naval y del Mar

dB Decibel

DC Direct current

ECN École Centrale Nantes

EMF Electromagnetic fields

EMFF European Maritime and Fisheries Fund

EMODnet European Marine Observation and Data Network

EPE Education and Public Engagement

EVE Ente Vasco de la Energía

fps Frames per second

FWT Floating Wind Turbines

GB Gigabyte(s)

GPS	Global Positioning System
HD	Habitats Directive
Hz	Hertz
ICNF	Instituto da Conservação da Natureza e das Florestas
IPMA	Instituto Português do Mar e da Atmosfera
kg	Kilogram(s)
kHz	Kilohertz
Km	Kilometre(s)
kS/s	Kilosamples per second
kv	Kilovolt
kW	Kilowatt
LED	Light-emitting diode
LHEEA	Laboratoire de recherche en Hydrodynamique, Énergétique et Environnement Atmosphérique
m	Metre(s)
m/s	Metre(s) per second
mm	Millimetre(s)
MRE	Marine Renewable Energy
MRED	Marine Renewable Energy Device
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
mV/ μT	Millivolt per microtesla
mV/Pa	Millivolt per pascal
MVA	Megavolt-ampere
MW	Megawatt
N	North
NE	Northeast

nm	Nautical mile(s)
NOAA	National Oceanic and Atmospheric Administration
nT	Nanotesla
p	Pixel(s)
PNLN	Parque Natural do Litoral Norte
ROV	Remotely Operated Vehicle
S	South
SafeWAVE	Streamlining the assessment of environmental effects of Wave Energy
SCADA	Supervisory Control And Data Acquisition
SCI	Site of Community Importance
SONAR	Sound Navigation and Ranging
t	Tonne(s)
USBL	Ultra-short baseline
UTC	Coordinated Universal Time
V/m	Volt per metre
W	West
WavEC	WavEC Offshore Renewables
WE	Wave Energy
WEC	Wave Energy Converter
WESE	Wave Energy in Southern Europe
WGS	World Geodetic System
µPa	Micropascal

3. Executive summary

The ocean energy development is one of the main pillars of the EU Blue Growth strategy. However, while the technological development of devices is growing fast, their potential environmental effects are not well-known.

The SafeWAVE project aims to improve the knowledge on the potential environmental impacts from Wave Energy projects. In the project scope, Work Package 2 aims to collect, process, analyse, and share environmental data related to four priority areas of research: i) Electromagnetic Fields, ii) Acoustics (noise), iii) Seafloor integrity, and iv) Fish communities. Four sites where Wave Energy Converters are operating in Portuguese, Spanish and French coastal waters will be monitored, representing different types of technology, different types of locations (onshore, nearshore, and offshore), and different types of project scales (single devices and arrays of devices), hence, different types and/or magnitudes of environmental impacts.

The aim of Task 2.1 and the present report (Deliverable) 2.1 is to present the specific monitoring plans to undertake for each technology at each site.

4. Objective

The objective of this Deliverable is to present the methodology of the environmental monitoring activities to undertake for Electromagnetic fields (EMF; Section 6), underwater acoustics (Section 7), seafloor integrity (Section 8), and fish communities (Section 9) around four different types of technology of Wave Energy Converters (WEC) in four different sites and, therefore, types of marine environment: onshore – Mutriku Wave Power Plant (Mutriku, Spain), and offshore – CorPower Ocean (CPO) HiWave (CPO test site, Portugal), Wello Penguin II (BiMEP test site, Spain) and GEPS Techno WAVEGEM (SEM-REV test site, France)(Figure 1; Table 1).

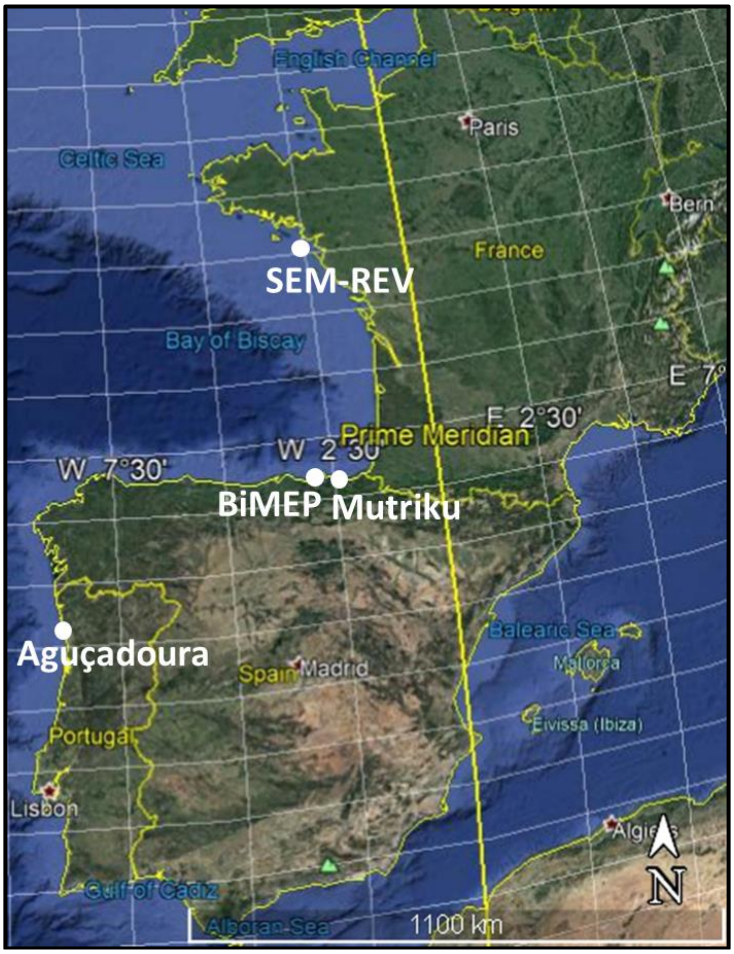

Figure 1. Test sites location in Portugal, Spain, and France (Source: Google Earth).

Table 1. Wave Energy devices under study and related monitoring parameters.

Device	Technology	Site	Location	Monitoring
Mutriku Wave Power Plant	Oscillating Water Column	Mutriku, Spain	Onshore	• Acoustics
HiWave (CPO)	Point absorber	Aguçadoura, Portugal	Offshore	• EMF • Acoustics • Seafloor integrity
Penguin II (Wello)	"Point absorber" – Rotational Mass Resonator	BiMEP, Spain	Offshore	• EMF • Acoustics • Seafloor integrity • Fish communities
WAVEGEM (GEPS Techno)	Energy autonomous platform	SEM-REV, France	Offshore	• EMF (FLOATGEN device) • Acoustics • Seafloor integrity • Fish communities

The monitoring plans will be delineated considering the project objectives, equipment to be used for data collection, parameters to record, sampling duration, frequency and methods, number, and spatial distribution of sampling points, as well as data storage, processing, analysis, and reporting, considering the specificities of each type of technology and site.

The results of these monitoring plans are the subject of subsequent Deliverables (D2.2, D2.3, D2.4 and D2.5) within Work Package 2.

5. Description of test sites and devices under study

5.1 Mutriku test site (Spain) – Mutriku Wave Power Plant

The Wave Energy Plant of Mutriku is in the Basque Country, in the Northern Coast of Spain (43°18.745'N, 2°22. 636'W) (Figure 2). This wave power plant was inaugurated in 2011 by the Basque Energy Agency (EVE) and has been successfully operating since then. Until June 2018 the plant has supplied to the grid over 1.6 GWh of electricity.

The power plant is a grid-connected plant, integrated within an existing breakwater at Mutriku harbour (Figure 2). It consists of 16 air chambers that are 4.5 m wide, 3.1 m depth, and 10 m high (above Maximum Equinoctial Spring Tide Low Water). A hole of 0.75 m diameter leads to a Wells turbine (Figure 3) and electrical generator of 18.5 kW for each air chamber, yielding total 296 kW.

This facility is now available as a test site providing developers with a unique opportunity to test new concepts in air turbines, generators, control strategies and auxiliary equipment.

Figure 2. Mutriku Wave Power Plant.

Figure 3. Mutriku Wave Power Plant turbines inside the plant.

5.2 CPO test site (Portugal) – CPO HiWave

5.2.1 CPO test site

The CPO test site (Figure 4, Table 2) is within the Aguçadoura test site in the north, west coast of Portugal.

The Aguçadoura test site was first used for the testing of PELAMIS device from July-November 2008 and after for the pilot project WindFloat from October 2011 to July 2016. The test site allows the use of a submarine cable with a 3.85 MVA capacity, with connection to an onshore substation connected to the National electricity grid. The substation comprises of a high voltage step-up transformer from 6.6kV to 15kV which is the grid connection voltage and a high voltage 6.6 kV switchgear connected to the subsea cable.

At the implementation area for MRE projects (which includes the CPO HiWave), the seafloor is mostly sandy and with a relatively flat inclination. Depth varies between 43-55 m depth. In regular conditions wave height reaches 2.5 m, rarely it reaches 7-10 m. Current speed ranges between <0.1 m/s to 1 m/s.

Concerning to areas of conservation interest, the closest one is a National Protected Area designated as Parque Natural do Litoral Norte (PNLN), which overlaps with the Site of Community Importance Litoral Norte (Habitats Directive (HD, 1992), Natura 2000 site code PTCON0017). This protected area is located at 2.8 km North to the onshore substation previously used for the WindFloat device and at 800 m East of the CPO HiWave device (Figure 4).

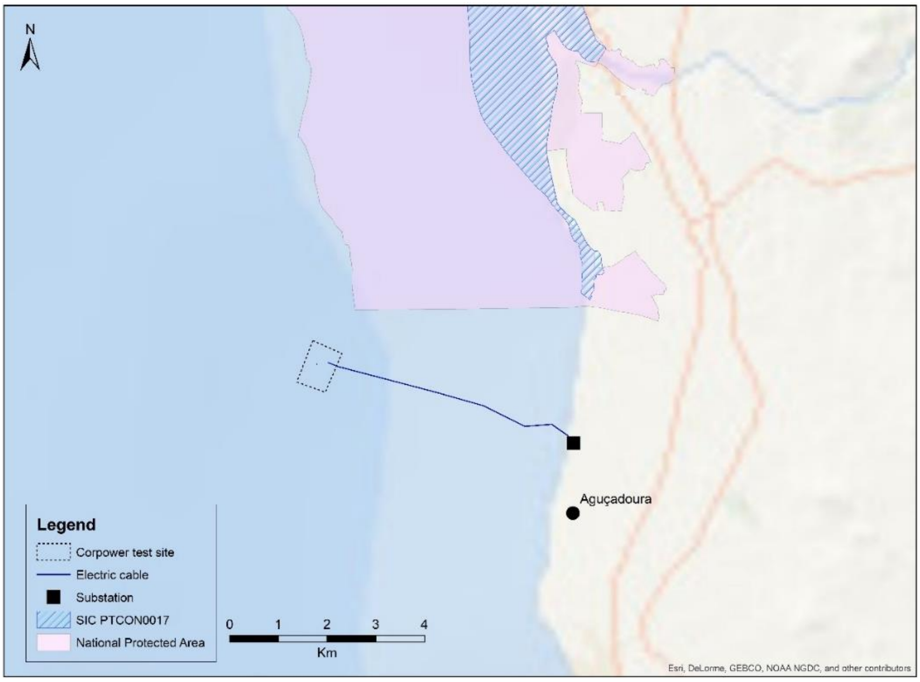

Figure 4. Location of CPO test site and the closest conservation protected area (Parque Natural do Litoral Norte and SCI PTCON0017) (Source: ICNF).

Table 2. CPO test site coordinates (WGS 84; Degrees, Decimal Minutes) (Source: CPO).

CPO test site	Longitude	Latitude
North	41° 27.770'N	8° 50.541'W
East	41° 27.310'N	8° 50.770'W
South	41° 27.200'N	8° 50.350'W
West	41° 27.630'N	8° 50.111'W

5.2.2 CPO HiWave

The CPO HiWave (Figure 5) is of point absorber type and has a 300-kW power capacity. It measures about 65 m high, with a heaving buoy on the surface which absorbs energy from ocean waves. The buoy is connected to the seafloor using a tensioned mooring system. Novel phase control technology (WaveSpring) makes the compact devices oscillate in resonance with the incoming waves, strongly amplifying the motion and power capture. The system has improved survivability in storms, thanks to its inherent transparency to incoming wave energy in long storm waves.

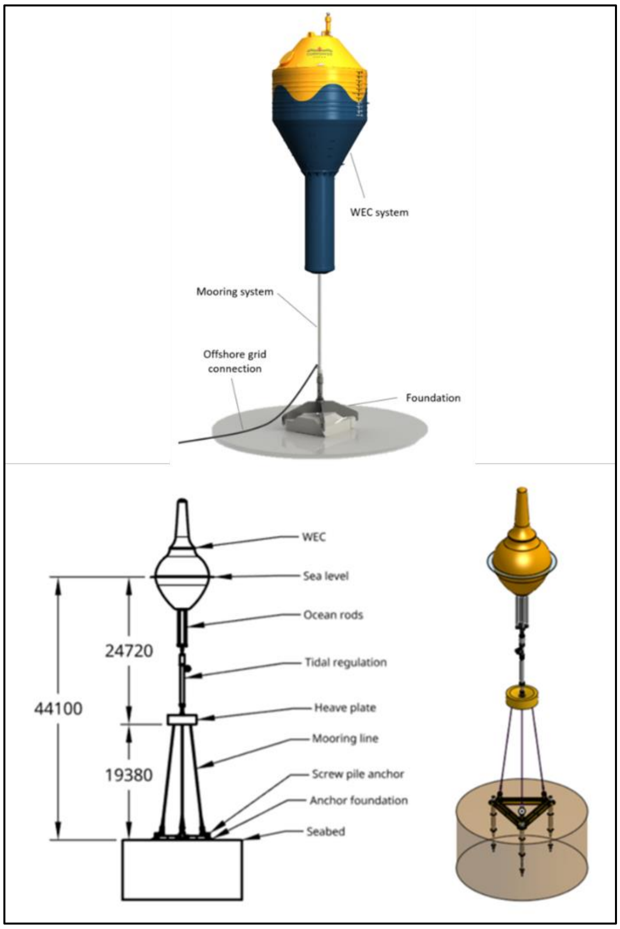

Figure 5. The HiWave WEC configuration (numbers in mm) (Source: CPO).

The wave energy converter includes the following sub-systems: buoy hull, pre-tension, WaveSpring, gearbox, control system, SCADA (Supervisory Control And Data Acquisition) system, communication system, power conversion system (generators, drives, energy storage), auxiliary systems, tidal regulation, moorings, foundation, anchors, umbilical, connectors, empty-hull-frame, and Operations & Maintenance methods.

The foundation links the mooring lines to the anchors and is envisaged to take the form of a relatively small (side dimension < 9 m) steel frame that sits on the seafloor with three anchoring points

The HiWave project will include the installation of four devices at about 5 km offshore the Aguçadoura in two phases:

- The first phase is expected to take place during August-October 2021. The C4 WEC pile, a small cable anchor (close to the pile), the cable quadrant, four navigation marks (at the corners of the site), and the C4 WEC and its mooring system, will be installed. The export cable will be directly connected to C4.
- In the second phase, about one year after, the hub and the remaining devices (C5.1, C5.2 and C5.3) will be deployed. The export cable will be disconnected from the C4 and will be connected to the hub. The C4 will also be connected to the hub.

The planned positioning of the HiWave equipment is illustrated in Figure 6 and 7 (coordinates listed in Table 3).

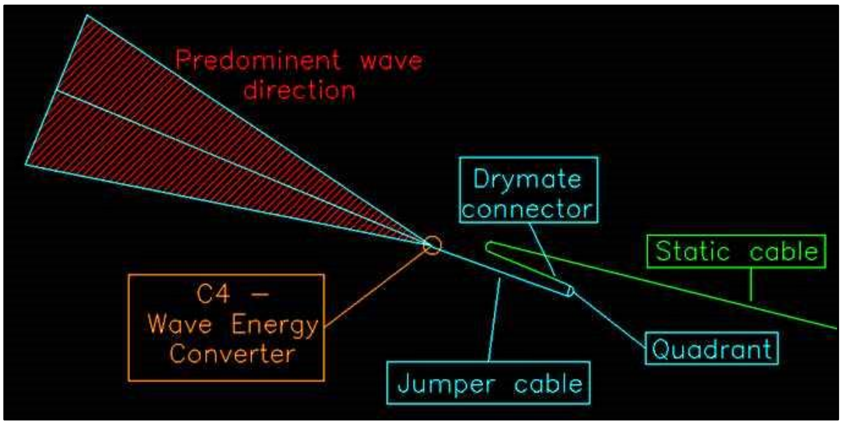

Figure 6. Planned installation layout of HiWave C4 device connected directly to the export cable (Source: CPO).

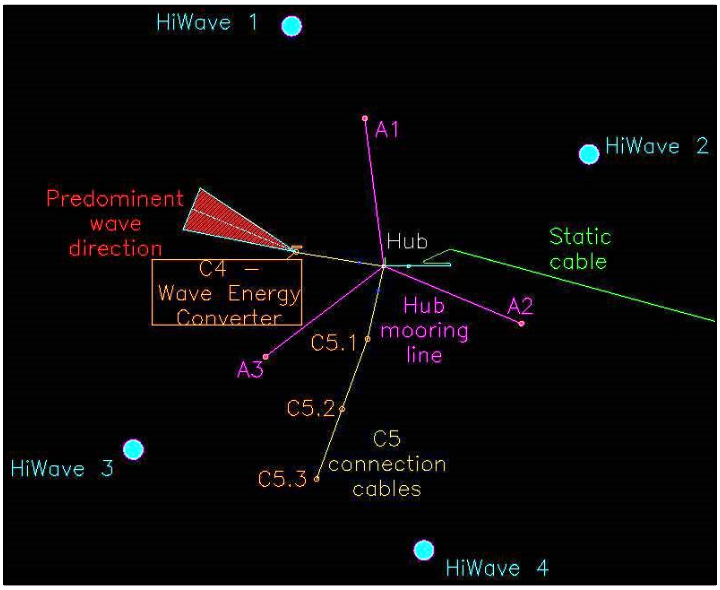

Figure 7. Complete layout of the HiWave project.

Table 3. Planned location of the HiWave equipment (WGS 84; Degrees, Decimal Minutes) (Source: CPO).

Description	Latitude	Longitude
WEC Equipment		
C4	41° 27.525'N	8° 50.534'W
C5.1	41° 27.429'N	8° 50.431'W
C5.2	41° 27.353'N	8° 50.468'W
C5.3	41° 27.277'N	8° 50.505'W
Collection Hub Equipment		
Anchor – A1	41° 27.770'N	8° 50.541'W
Anchor – A2	41° 27.446'N	8° 50.209'W
Anchor – A3	41° 27.411'N	8° 50.579'W
Hub	41° 27.509'N	8° 50.408'W
Electrical equipment		
Export cable anchor	41° 27.509'N	8° 50.372'W
C4 cable anchor	41° 27.513'N	8° 50.444'W
C5 cable anchor	41° 27.482'N	8° 50.416'W
Export cable quadrant	41° 27.510'N	8° 50.313'W
Signalling/Boundaries		
HiWave 1	41° 27.770'N	8° 50.541'W
HiWave 2	41° 27.630'N	8° 50.111'W
HiWave 3	41° 27.310'N	8° 50.770'W
HiWave 4	41° 27.200'N	8° 50.350'W

5.3 BiMEP test site (Spain) – Wello Penguin II

5.3.1 BiMEP test site

The Biscay Marine Energy Platform (BiMEP; https://www.bimep.com) is in the Basque Country, in the Northern Coast of Spain (Figure 8, Table 4). BiMEP is an open-sea facility to support research, technical testing and commercial demonstration of pre-commercial prototype utility-scale floating Marine Renewable Energy Devices (MREDs). BiMEP provides manufacturers of such devices with ready-to-use facilities to validate their designs and to test their technical and economic feasibility.

BiMEP occupies a 5.3 km^2 marked area excluded for navigation and maritime traffic and located at a minimum distance of 1,700 m from shore, close enough for fast access to deployed devices. The water depth in this area ranges from 50 m to 90 m.

The total power of 20 MW is distributed over four offshore connection points of 5 MW each (Figure 8).

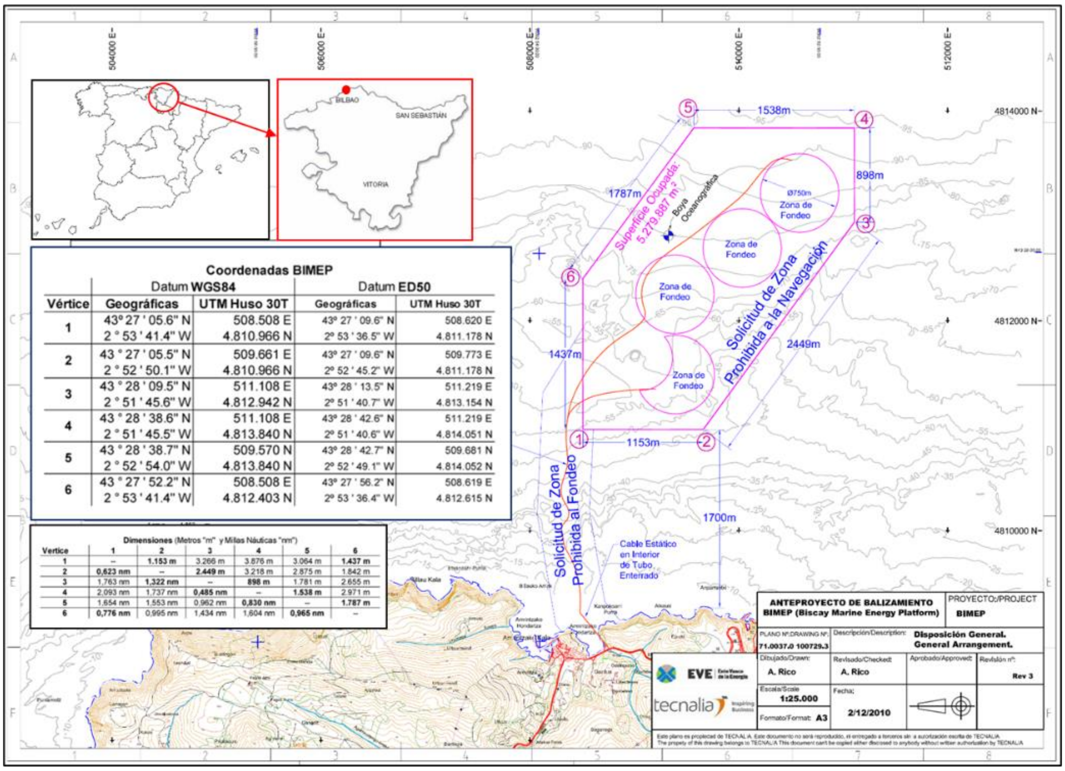

Figure 8. General arrangement of BiMEP (Source: AZTI).

Table 4. BiMEP test site coordinates (WGS 84; Degrees, Decimal Minutes) (Source: CPO).

BiMEP	Longitude	Latitude
1	43° 27.093'N	2° 53.690'W
2	43° 27.092'N	2° 52.835'W
3	43° 28.158'N	2° 51.760'W
4	43° 28.643'N	2° 51.758'W
5	43° 28.645'N	2° 52.900'W
6	43° 27.870'N	2° 53.690'W

Each berth is connected to the onshore substation via a dedicated three-phase submarine cable in series with a land three-phase line, both at 13.2 kV. The onshore electricity substation houses electrical protection systems, measurement systems and transformer, allowing the berths to be connected to the national power grid. The berths are fitted with commercial power and fibre optic connectors to enable swift connection and disconnection of MREDs.

5.3.2 Wello Penguin II

The Wello Penguin II consists of a vessel shaped attenuator device with 43.3 m length, 10.6 m depth, 6.8 m draught, 21.8 m beam and 2.2 t of weight (Figure 9). The installation of the Penguin II mooring cables is planned to be undertaken during May 2021, and the device itself in June 2021 in BiMEP (Figure 10).

Figure 9. Wello Penguin II WEC (Source: Wello).

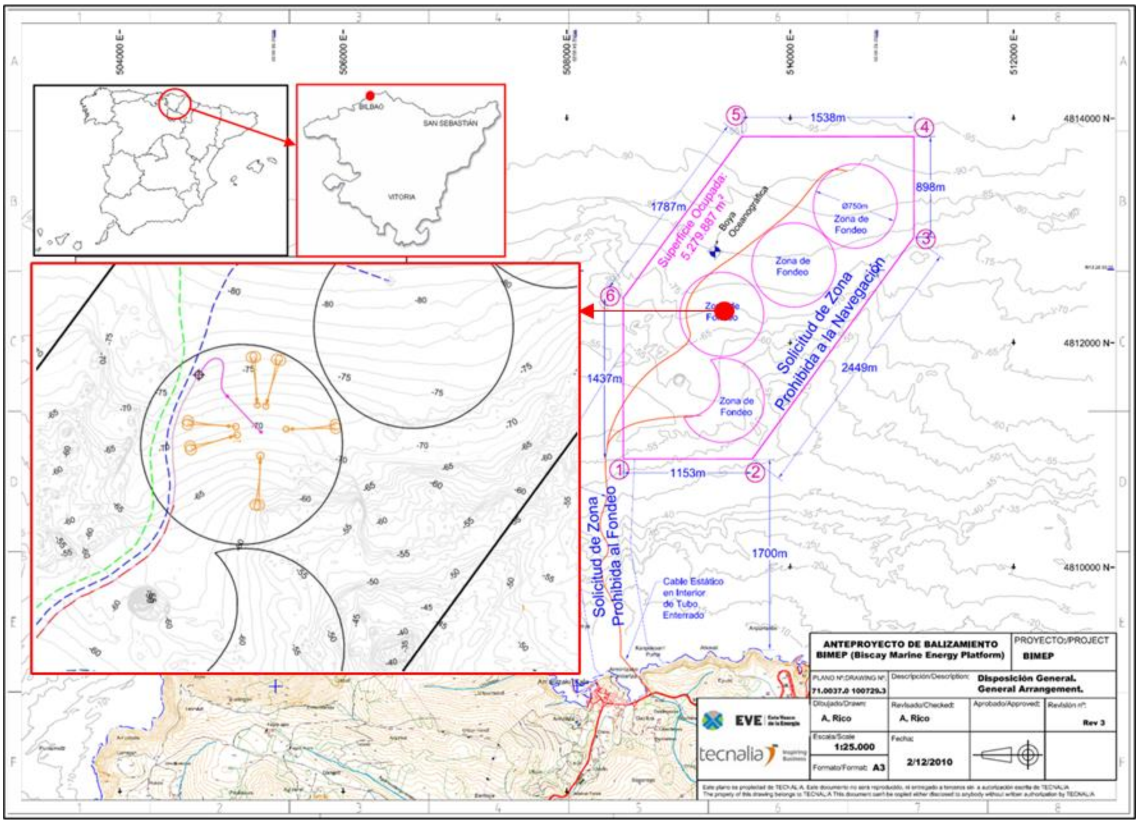

Figure 10. Wello Penguin II position in BIMEP.

The Penguin II uses a 6-legged mooring system (Figure 11). Each leg develops a catenary ending with two chain clump anchors (coordinates presented in Table 5). Each mooring leg (319 m as straight) can be divided into four main sections:

- Anchor – From the seafloor
- Lower catenary – From the anchor to the buoy
- Buoy – Junction between the upper and lower catenary
- Upper catenary – From the buoy to Penguin

The Penguin II umbilical design is a Lazy-S with a mid-water arch, which consists of buoy and two cable bend stiffeners in length of 2.1 m each (DETAIL 2 in Figure 12). Total length of the cable is 563 m, and the mid-water arc is located approximately 45 m from the seafloor and approximately 55 m horizontally from the cable outlet at the Penguin.

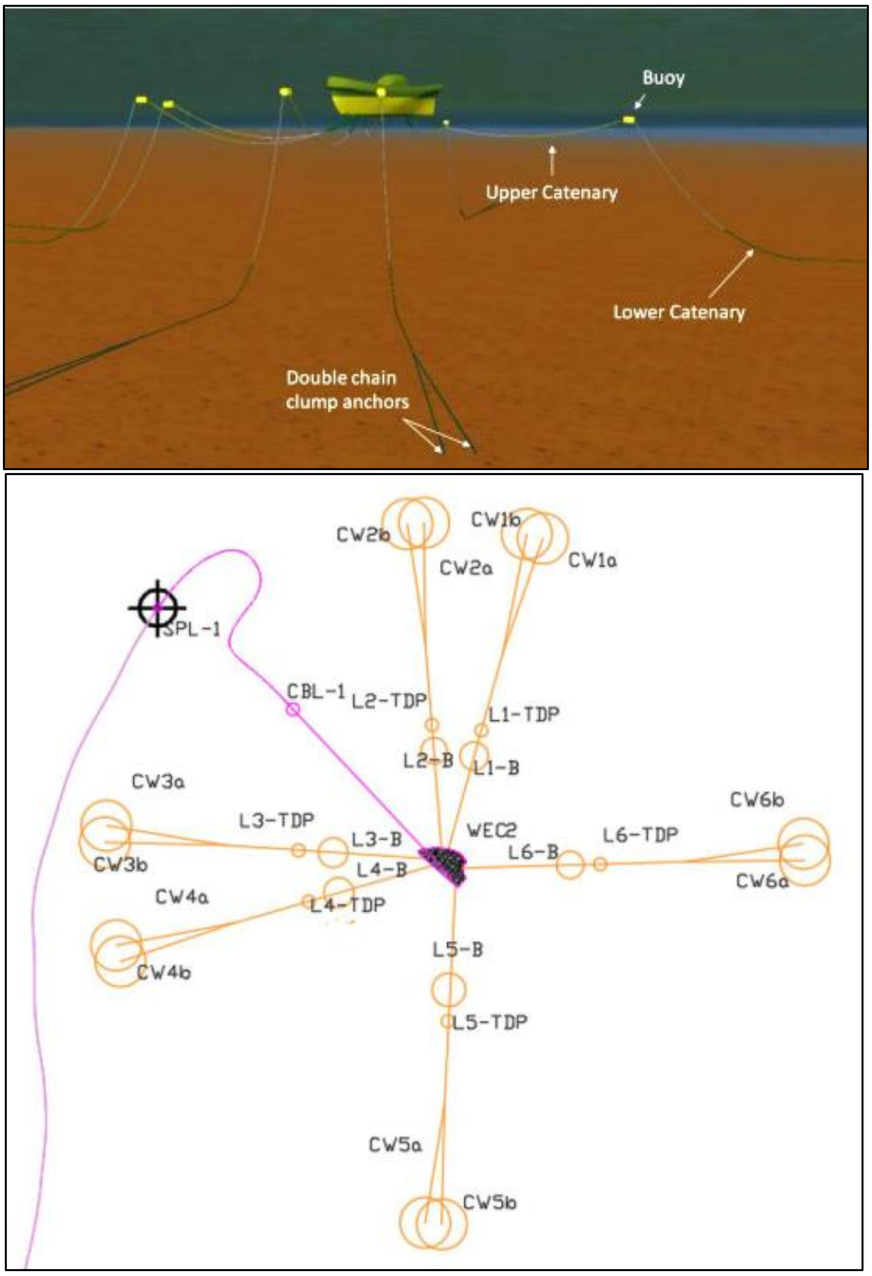

Figure 11. Schematic view of Penguin II mooring components (top) and positioning of the mooring system (bottom) (Source: Wello).

Table 5. Penguin II mooring and cable coordinates (WGS 84; Degrees, Decimal Minutes) (Source: Wello).

	Code	Description	Latitude	Longitude
	WEC2	Centre of Penguin II	43° 27.820'N	2° 52.990'W
Mooring Leg 1	CW1a	Clump Weight 1a	43° 27.960'N	2° 52.930'W
	CW1b	Clump Weight 1b	43° 27.960'N	2° 52.940'W
Mooring Leg 2	CW2a	Clump Weight 2a	43° 27.970'N	2° 53.000'W
	CW2b	Clump Weight 2b	43° 27.970'N	2° 53.010'W
Mooring Leg 3	CW3a	Clump Weight 3a	43° 27.840'N	2° 53.190'W
	CW3b	Clump Weight 3b	43° 27.830'N	2° 53.190'W
Mooring Leg 4	CW4a	Clump Weight 4a	43° 27.790'N	2° 53.190'W
	CW4b	Clump Weight 4b	43° 27.780'N	2° 53.180'W
Mooring Leg 5	CW5a	Clump Weight 5a	43° 27.670'N	2° 53.000'W
	CW5b	Clump Weight 5b	43° 27.670'N	2° 52.990'W
Mooring Leg 6	CW6a	Clump Weight 6a	43° 27.82'N	2° 52.780'W
	CW6b	Clump Weight 6b	43° 27.83'N	2° 52.780'W
Cable	SPL-1	BiMEP to WE Splice	43° 27.930'N	2° 53.160'W
	CBL-1	Cable Point 1	43° 27.890'N	2° 53.080'W

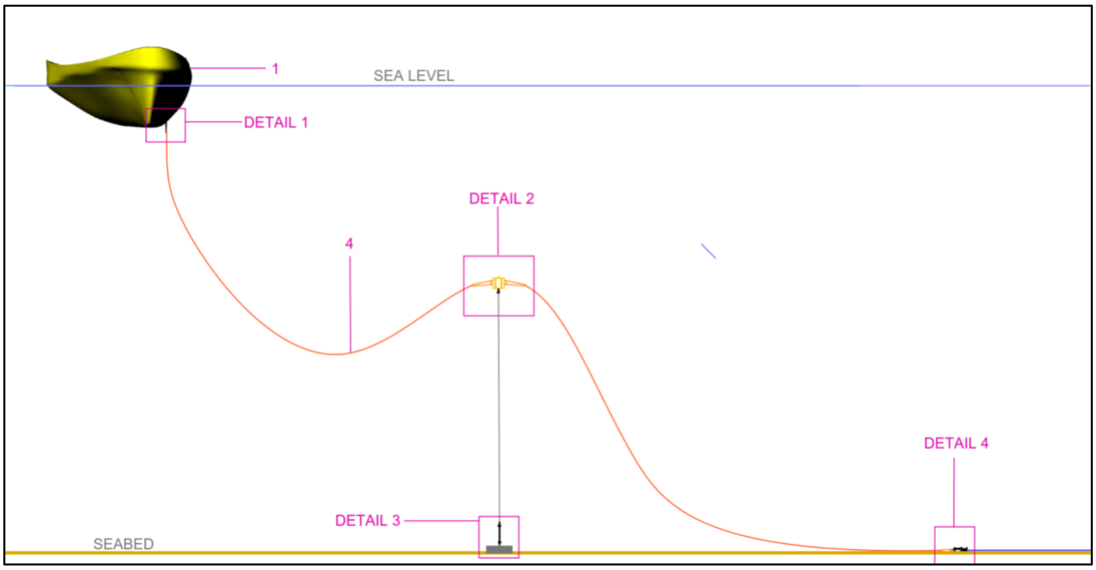

Figure 12. Penguin II umbilical system overview (Source: Wello).

5.4 SEM-REV test site (France) – GEPS Techno WAVEGEM

5.4.1 SEM-REV test site

The SEM-REV test site (https://sem-rev.ec-nantes.fr) is in the west coast of France at 20 nm from St-Nazaire harbour and approximately 10 nm from the town of Le Croisic (Figure 13, Table 6).

The site is operated by LHEEA laboratory (UMR CNRS 6598) of Centrale Nantes, and acquired all regulatory authorizations requested to allow MRE technologies reception (Arrêté n°2014-BPUP-001 of January 13, 2014).

The test site occupies approximately a 1 km^2 test zone area and is fully instrumented and monitored. The test site infrastructure includes an 8 MVA power cable connected to the national distribution grid through a 20kV onshore substation. The SEM-REV is a fully fitted wave and wind energy test facility intended to test and improve the efficiency of WECs and Floating Wind Turbines (FWT) at a prototype stage of development. The software and hardware architecture for monitoring and controlling the systems is operational at the site. Optical fibres are included in the export cable for data transmission and for control of MRE.

The test site facilities include several parts:

- An onshore research centre, located in Penn Avel park, which belongs to Coastal Conservatory and managed by Le Croisic municipality (Figure 13A);
- An onshore electrical substation connected to the national grid (Figure 13B);
- A subsea medium voltage export cable (Figure 13C);
- A connecting system at sea, called connection hub, allowing to connect devices, up to 3 simultaneously, to export cable;
- A restricted offshore area about 1 km^2 (Figure 13E).

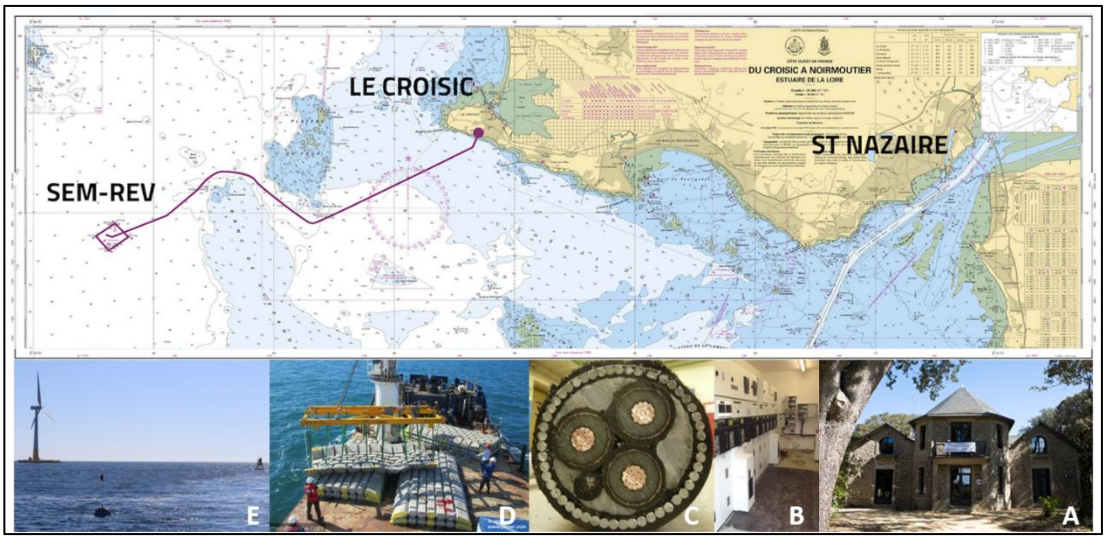

Figure 13. SEM-REV test site location and facilities (Source: ECN).

Table 6. SEM-REV test site coordinates (WGS 84; Degrees, Decimal Minutes) (Source: ECN).

SEM-REV	Latitude	Longitude
North	47° 14.700'N	2° 46.580'W
East	47° 14.340'N	2° 46.080'W
South	47° 13.940'N	2° 46.880'W
West	47° 14.340'N	2° 47.380'W

In its current configuration, SEM-REV allows to test wave technologies (up to 4 at the same time) and offshore floating wind turbines (up to 2 simultaneously, less than 3.5 MW), for short- and medium-term (6 months to 2 years) periods. SEM-REV activities involve also testing hybrid technologies (wave and floating offshore wind turbine) and enabling technological (electrical connection, anchoring, environmental monitoring, and marine safety).

The test site has been operational since the approval of two successive consenting phases in July of 2011 for WEC and in January of 2014 for FWT. The electrical grid connection was finalized in October of 2012, whereas the subsea hub connection system was deployed in August 2015. SEM-REV is currently hosting two prototypes, the FWT FLOATGEN and the WEC WAVEGEM under study in the SafeWAVE project (IHES in Figure 14; IHES is the name of the project including WAVEGEM).

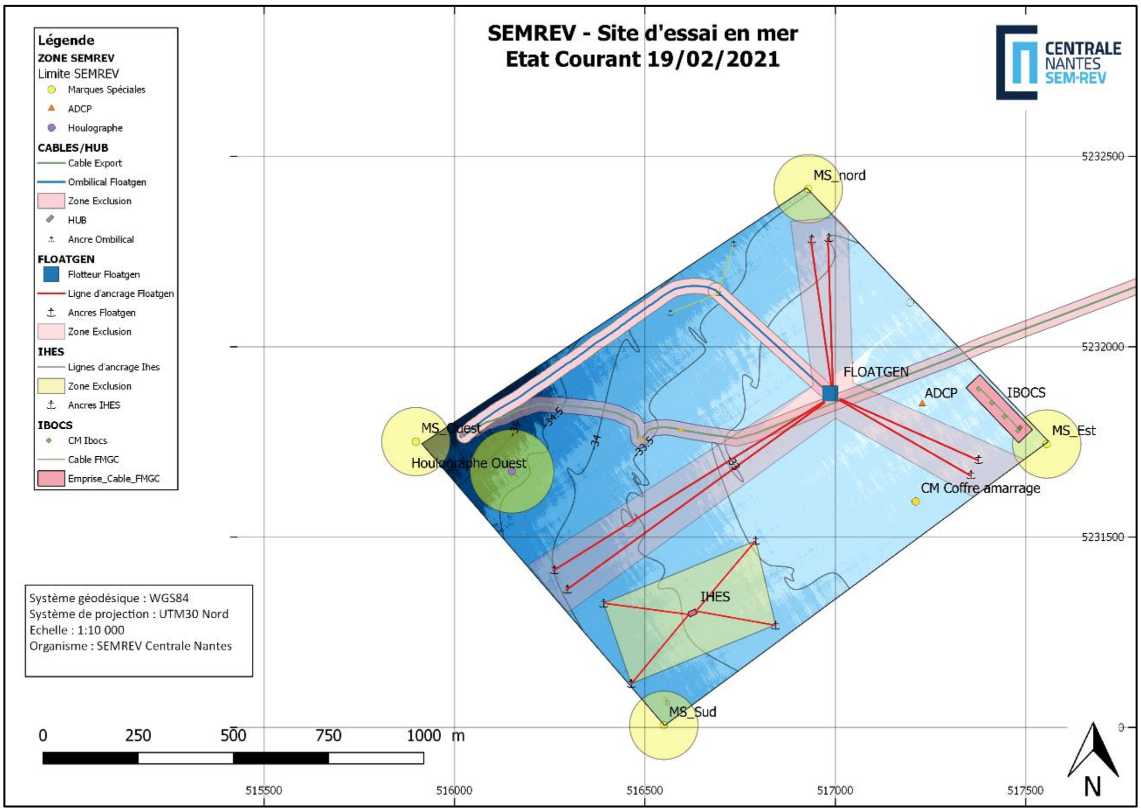

Figure 14. SEM-REV designated maritime zone (Source: ECN).

In the SEM-REV area the seafloor is sandy (medium sand to fine sand; 0.2-0.5 mm) and water depth ranges between 32-36 m. The superficial layer thickness is relatively homogeneous, and the sediment transport levels are low.

The main direction of currents is S-W and NE to a lesser extent. The velocities range from 0 m/s to 0.4 m/s. The strongest currents are coming from S-W (270°) with a maximum tidal current (10 years) of 0.7 m/s.

The highest waves come from the SW sector. The significant wave heights range from 0.5 m to 3.5 m. The extreme wave height (10 years) is 8.3 m.

The main direction of the wind is W and NE to a lesser extent. The mean velocity is 7 m/s with values essentially ranging from 2.5 to 14 m/s. The strongest winds are coming from W (270°).

5.4.2 GEPS Techno WAVEGEM

GEPS Techno WAVEGEM (Figure 15) is a hybrid autonomous energy production platform designed to supply marine or island installations without access to the electricity grid. It generates its own energy from the swell (as the main source) and the sun (photovoltaic solar panels as an additional source). The platform is flexible to accommodate energy storage and embedded applications or to export the energy produced to external submarine or surface consumers.

Figure 15. GEPS Techno WAVEGEM (Source: GEPS Techno).

The platform converts float motions into electrical energy through the circulation of seawater in closed loop and the transformation of that energy via a low-speed turbine. The power capacity is about 150 kw and the produced energy is dissipated in sea (i.e., not grid connected). Its characteristics are presented in Table 7.

WAVEGEM has a 4-point mooring system (from 30 m to 2,000 m depth). At the SEM-REV test site, each mooring line comprises (Figure 16):

- 1 anchor
- 76 m of steel bottom chain (DN76)
- 143 m of nylon
- 15 m of steel top chain (DN56)

These components are connected to each other's with special connectors.

The four anchors (MK6) are sand anchors (no gravity), each weighing 4 t (Figure 17).

Table 7. WAVEGEM device characteristics (Source: ECN).

Characteristics	Values
Height	10 m
Length	22 m
Width	14 m
Moving unloaded	204 t
Moving in operation	245 t
Draught (unloaded)	2.55 m
Draught (in operation)	2.95 m
Air draft (unloaded)	7.45 m
Air draft (in operation)	7.05 m

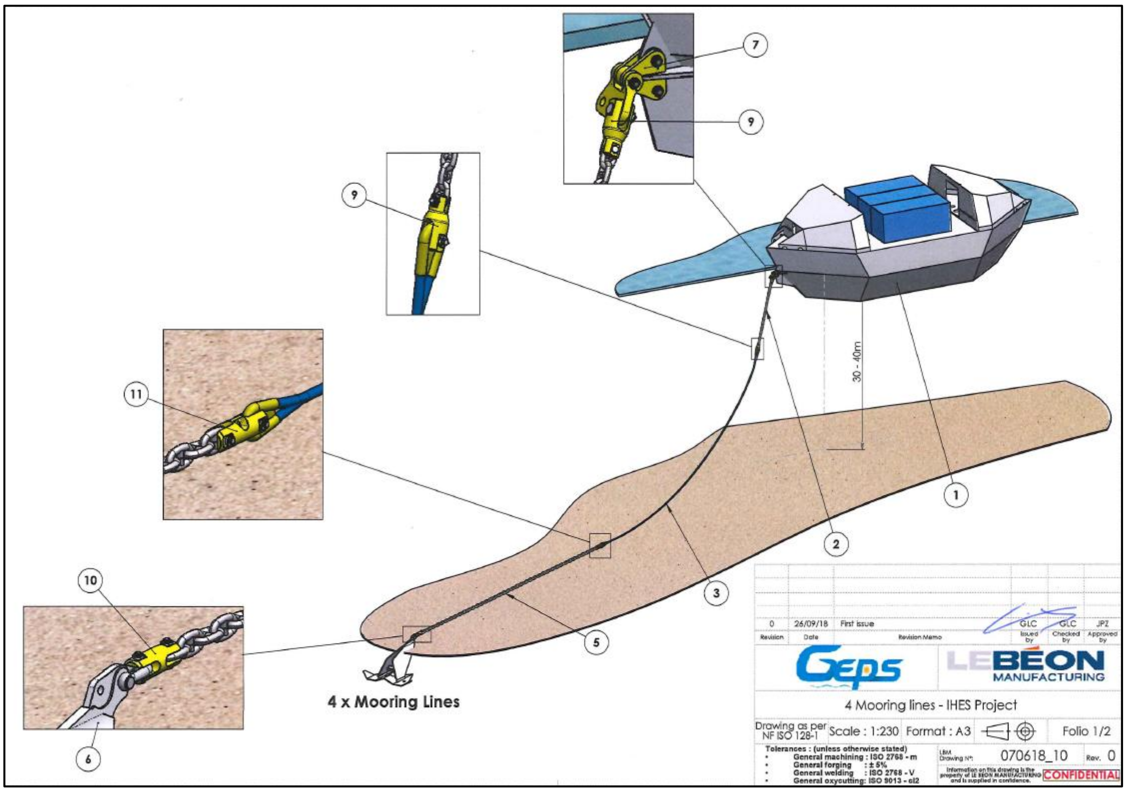

Figure 16. Simplified specification layout of the WAVEGEM mooring lines (Source: GEPS techno).

Figure 17. Sand anchor of the WAVEGEM mooring lines (Source: GEPS techno).

WAVEGEM was deployed in SEM-REV in August 2019 for a first testing period, being removed and reinstalled in August 2020 for a second testing period until August 2021. The moorings remained on the seafloor since the first installation. Table 8 presents the coordinates of the device and the anchors.

Table 8. WAVEGEM equipment coordinates (WGS 84; Degrees, Decimal Minutes) (Source: ECN).

Point	Latitude	Longitude
WAVEGEM	47°14.099'N	2°46.820'W
Anchor 1	47°14.081'N	2°46.649'W
Anchor 2	47°13.999´N	2°46.949'W
Anchor 3	47°14.113'N	2°47.006'W
Anchor 4	47°14.201'N	2°46.690'W

6. Electromagnetic fields monitoring plan

6.1 Introduction

The electromagnetic field (EMF) can be described as a physically significant field generated by an electric charge. As the name suggests, EMF can be viewed as a combination of two individual fields, the electric field $(\vec{E})$ and the magnetic field $(\vec{B})$, which are mutually dependent.

There are two different types of electric fields, the one produced by stationary electric charges, called electrostatic field, and the one produced by a changing magnetic field, called induced electric field. Both are vector units with direction and magnitude, measured in V/m, with the net value at any point being the vector sum of all the electric fields present at that point.

The magnetic fields can be generated by electric charges in motion (electric current), by varying electric fields and by the intrinsic magnetic moments of a magnetic material (e.g., permanent magnets). Similarly to the electric field, the magnetic field is a vector unit with direction and magnitude, measured in Tesla, with the net value at any point being the vector sum of all the magnetic fields present at that point.

Some marine species have specialized sensory organs or mechanisms that allow them to detect and process EMF coming from natural sources and, therefore, they may also respond to EMF resulting from energized offshore renewable components (e.g., devices, submarine power cables). However, there are significant gaps in knowledge for a proper understanding of the impact. According to the MaRVEN report (Thomsen et al., 2015), several steps can be taken to fill in the gaps, one of them being the development of techniques for measuring EMF and its measurement at different sites and for different devices and cables.

The characterization of EMF emitted by submarine power cables (the component with largest footprint) is the first step to understand how it may affect the marine environment.

The EMF emission levels from a power-carrying cable decays significantly with distance. The electric field depends on the potential across the cable and increases with it, while magnetic field depends on the flow of current through the cable and increases with the magnitude of the current.

Nowadays, it is a common practice to block the direct electric field from the external environment by using conductive sheathing. Thus, only the magnetic field and the resultant induced electric field are emitted into the marine environment.

Induced electric fields can occur from water current movement, from an organism swimming through the field or from the asymmetric rotation of the AC field within the industry standard 3-phase cable.

As it is shown in Table 9, AC cables appear to generate lower magnetic field strengths than DC cables for about the same voltage (because of the field cancelling effect between individual phases in AC cables). Higher voltage cables produce lower magnetic fields than lower voltage cables for the same power delivered (because higher voltages allow for lower cable currents for the same power).

Table 9. Characteristics of the fields (magnetic and electric) produced by AC and DC cables.

Type of current	Factors influencing the fields
AC	The magnetic fields are directly influenced by: • The cable current amplitude and frequency • The internal separation between conductors • The vertical and horizontal distance from the cable • The burial depth influence field strength at seafloor (mostly due to dielectric and magnetic properties of soil) The electrostatic fields are mostly contained within the cable, and the induced electric fields are influenced by all previous factors
DC	The magnetic fields are directly influenced by: • The cable current amplitude and frequency • The internal separation between conductors • The vertical and horizontal distance from the cable • The burial depth influence field strength at seafloor (mostly due to dielectric and magnetic properties of soil) The electrostatic fields are mostly contained within the cable, and the induced electric fields are non-existent in DC cables

6.2 Objectives

This monitoring plan provides the guidelines for the EMF monitoring of the WECs under study, particularly for underwater and onshore EMF measurements. The monitoring plan will be implemented in Task 2.2 and resulting records will be used for validation and calibration of EMF models in Task 3.1.

The main objective is to collect EMF data, with focus on magnetic field data, radiated by the electrical cable connecting the devices to shore in Aguçadoura (Portugal), BiMEP (Spain) and SEM-REV (France) test sites. This will address one of the knowledge gaps identified in the MaRVEN report (Thomsen et al., 2015) related with the need to understand EMF emitted from the MREDs cables.

6.3 Electromagnetic fields desk-based assessment

To propose a monitoring plan, the EMF characteristics must be estimated for each site. This is of most importance, as the sensors must have sensitivity and frequency span capable to characterize the expected EMF at the site.

To this work, two main types of EMF can be distinguished:

- The ambient EMF
- The EMF generated by the submarine power cables

The characterization of these will establish the noise floor and dynamic range requirements of the instrumentation.

6.3.1 Ambient electromagnetic fields

The ambient EMFs are mostly linked with the boundless presence of the geomagnetic field, a non-oscillating value (0 Hz) with an amplitude ranging between 25 and 65 μT (Finlay et al., 2010) depending on the site location and specific geophysical characteristics.

The geomagnetic field is not directly affected by the presence of seawater, because the relative magnetic permeability of air and seawater mediums have similar value ($\sim$1). However, this is different for electric fields. As enunciated by Faraday Law of induction, an electric field is induced into a conductive medium when moving through a magnetic field and, since seawater is a conductive medium, an electric field is always present in flowing seawater. This relation is given by the equation $\vec{E} = \vec{v} \times \vec{B}$ (Slater et al.,2010) where $\vec{E}$ is the induced electric field potential, $\vec{v}$ is the water velocity vector and $\vec{B}$ is the magnetic field vector (in this case, earth's magnetic field). Reciprocally, the varying electric fields induce a magnetic field as predicted by the Ampere-Maxwell law. However, these are extremely weak (bellow nano unit for our scenario) and will not be considered.

Despite the existence of other sources (such as geo- and solar-related phenomena), the movement of electrically conductive seawater through the earth's magnetic field is responsible for most of nearshore ambient EMF. The origin of the motions varies with the site, but nearshore motions are generally caused by a complex interaction between waves, costal currents, tide, and bathymetry.

Regarding the oscillation period of these motions, they can vary between seconds, minutes, hours, or days depending on the origin (e.g., the time scale of the wave period is seconds, while for tides is hours). However, looking to the wave motions, which is a significant contributor for the ambient electric field, the periods expected are from 1 to 30 seconds (1 Hz to 0.033 Hz).

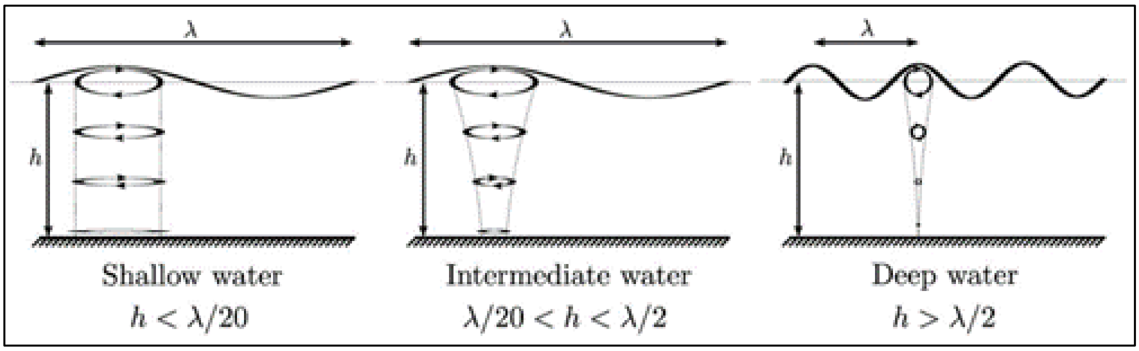

Figure 18. Representation of the motion of water particles for different depths.

To estimate the electric fields generated by the wave motion, the water particles velocity must be computed. These particles motion is a result of the interdependency of both wave and site local characteristics. As depicted in Figure 18, in deep waters the wave shape at the surface is closer to a sinusoid, resulting in a circular motion of the water particles beneath, with the orbit diameter decreasing with distance from the surface. As the wave moves into shallower waters, the wave orbits begin to interfere with the seabed, which alters the wave height (H_s) and wavelength (λ), this interaction results in more elliptical wave orbits, with the vertical component decreasing with depth.

Resorting to linear wave theory (Krogstad and Arntsen, 2000), it is possible to estimate the particles velocity as function of the wave and site characteristics. The depth of interest is close to the sea bottom where the power cable is laid. For deep water locations (Figure 18), the orbit diameter decays to near zero at the sea bottom, hence the particle velocity is negligible for these depths. For shallow and intermediate water locations, the motion of water particles at the sea bottom is close to a flat ellipse, hence, only the horizontal component will be considered.

As presented in (Krogstad et all., 2000), the equations expressing the maximum value of the horizontal particle velocity are $\hat{u}_x = \frac{w.a}{k.d}$ for shallow waters and $\hat{u}_x = w.a\frac{\cosh k(z+d)}{\sinh k.d}$ for intermediate waters, where $w = 2\pi(1/T)$ is the angular frequency, d is the water depth, z is the depth of interest (negative number), $k = 2\pi/\lambda$ is the wave number and $a = H_s/2$ is the wave amplitude. Table 10 summarizes the estimates of what is believed to be the most important ambient EMF sources, for 3 different water depths.

Table 10. Expected range for ambient EMF in Aguçadoura, BiMEP and SEM-REV test sites.

	Water Depth	Aguçadoura		BiMEP		SEM-REV	
		Amp.	Freq.	Amp.	Freq.	Amp.	Freq.
Magnetic Fields (Geomagnetic[1])	N/A	45.1 μT	0 Hz	46.2 μT	0 Hz	47.5 μT	0 Hz
Electric Fields (Motion Induced[2])	10 m	6 μV/m - 67 μV/m	0.14 Hz - 0.08 Hz	6 μV/m - 69 μV/m	0.14 Hz - 0.08 Hz	6 μV/m - 71 μV/m	0.14 Hz - 0.08 Hz
	20 m	2 μV/m - 40 μV/m	0.14 Hz - 0.08 Hz	2 μV/m - 41 μV/m	0.14 Hz - 0.08 Hz	2 μV/m - 42 μV/m	0.14 Hz - 0.08 Hz
	30 m	NA - 32 μV/m	0.14 Hz - 0.08 Hz	NA - 33 μV/m	00.14 Hz - 0.08 Hz	NA - 34 μV/m	0.14 Hz - 0.08 Hz

[1] Obtained using NOAA magnetic field calculator (https://www.ngdc.noaa.gov/geomag).

[2] For motion induced calculations, the velocity of water for both smooth (*Hs* = 0.5 m, *Tp* = 7 s) and rough (*Hs* = 4 m, *Tp* = 12 s) wave conditions were computed.

6.3.2 Subsea power cable electromagnetic fields

Energized subsea power cables are known sources of EMF. These have significantly different characteristics from the ones discussed in the previous section, both in amplitude and frequency.

As previously mentioned, magnetic fields can be generated by electric charges in motion (electric current), while electric fields are both produced by stationary electric charges (electric potential), called electrostatic fields, and by time-varying magnetic fields, called induced electric fields. All these phenomena is present in energized subsea power cables.

Regarding the electrostatic field, subsea cable conductors have a metallic shield covering the insulation which is generally grounded (zero potential). This guarantees the electrostatic field is solely contained within the insulation. On the other hand, energized cables produce a magnetic field proportional to cable current which is attracted by the ferromagnetic materials present in the cable (such as the cable armouring), however despite this 'attenuation', the magnetic field lines are not fully contained within the cable. Since the cables in study have AC profiles, a time varying-magnetic field is expected externally to the cable, which induces electric fields as predicted by Faraday's law.

Knowing the general characteristics of the subsea power cables in study (both 3-phase AC cables with external armouring) and the power capacity of both wave energy technologies, it is possible to estimate the maximum electric current expected in the cable conductors which allows to compute an approximated value of both the generated magnetic fields and induced electric field.

Considering the following equation $P = \sqrt{3}.V_{LL}.I.pf$, where P is the power rating of each device, V_{LL} is the line-to-line voltage of the 3-phase transmission system, I is the phase current (variable of interest) and pf is the power factor, it is possible to compute the phase current. Assuming the devices are producing at the rated power and the power factor is equal to one, the phase currents expected at each site are shown in Table 11.

Table 11. Phase currents expected in CorPower (HiWave), BiMEP (Penguin II) and SEM-REV (WAVEGEM) test sites.

	P Device Rated Power	VLL Transmission Voltage	I Phase Current
CorPower (HiWave)	300 kW	6 kV	28.9 A
BIMEP (Penguin II)	600 kW	13.2 kV	26.3 A
SEM-REV (WAVEGEM)	150 kW	N/A[3]	-

For this desk-based assessment, the $|E|$ and $|B|$ normalized curves from Slater et al. (2010) will be used (Figure 19). These were computed using a generic 3-phase subsea power cable with a typical cross-section layout. Although not accurate (e.g., cable dimensions are not the same), this approach allows for a quick assessment of the order of the order of magnitude of the EMF expected from both subsea cables (Table 12).

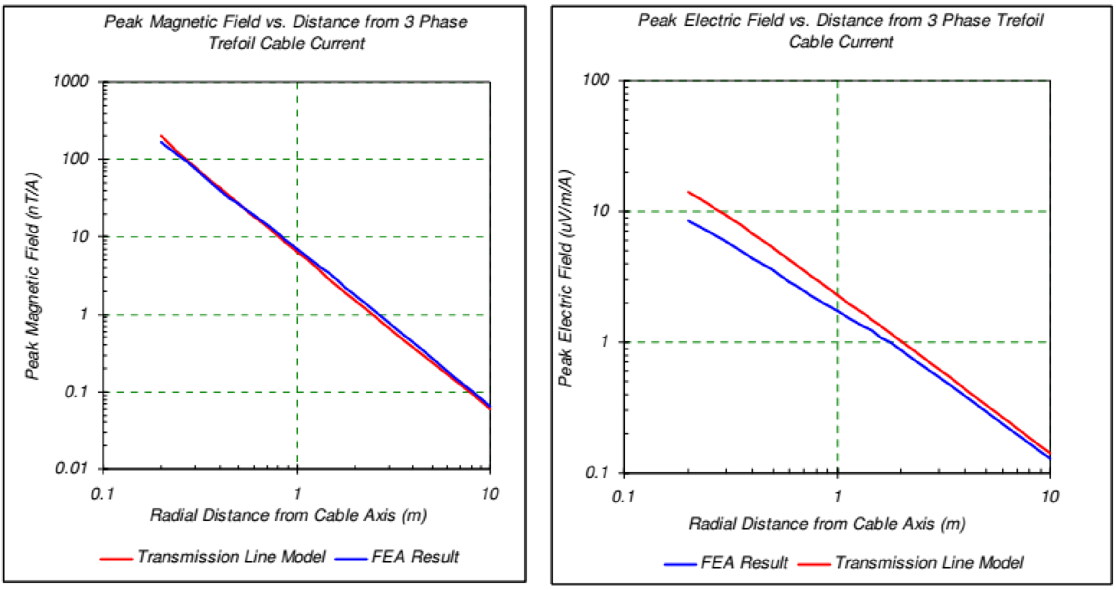

Figure 19. Normalized Magnetic (left) and Electric (right) fields generated by a 3-phase power cable as shown in Slater et al. (2010).

[3] The device is not grid connected.

Table 12. Expected EMF generated around submarine cables of the HiWave, Penguin II and WAVEGEM technologies.

	HiWave			Penguin II			WAVEGEM		
	Amplitude		Freq.	Amplitude		Freq.	Amplitude		Freq.
	0.2 m	10 m		0.2 m	10 m		0.2 m	10 m	
Magnetic Fields	$5.8\ \mu T$	$1.7\ nT$	$50\ Hz$	$5.2\ \mu T$	$1.5\ nT$	$50\ Hz$	-	-	-
Electric Fields	$290\ \mu V/m$	$4.35\ \mu V/m$	$50\ Hz$	$263\ \mu V/m$	$3.95\ \mu V/m$	$50\ Hz$	-	-	-

6.4 Sampling design and methods

The sampling campaign will last one day and will be as much as possible aligned with the schedule for acoustic, seafloor integrity, or fish communities monitoring. Measurements shall be coordinated with the WEC developers to guarantee (to the extent possible) the device is operating during the campaigns.

When no data exists to characterize baseline conditions (before device deployment), proper sites with the same characteristics of the devices site will be selected for sampling. This will allow to understand how the EMF environment could be modified by the installation of an electrical cable.

The EMF will be measured both onshore, along the shore cable route (at the CPO test site) and underwater along the subsea cable route (at all test sites).

6.4.1 Onshore measurements

The onshore measurements can provide a representative assessment of the magnetic fields generated subsea, since the relative magnetic permeability of air and seawater mediums have similar value (~1). These have several advantages over the offshore campaigns. Because they can be conducted safely from shore, measurement campaigns can target higher metocean conditions which typically generate higher magnetic fields, at a fraction of the cost of an offshore campaign. On the downside, onshore campaigns are limited to the measurement of magnetic fields, since electric fields onshore are not representative of the subsea environment, as the relative electric permittivity's of air and seawater mediums are different.

Thus, for the onshore measurements at the CPO test site, only magnetic fields will be accessed. For this, a fluxgate type sensor model Bartington Mag690 magnetometer will be used, with the specifications presented in Table 13. The magnetometer produces three independent analogue output voltages in response to the magnitude and direction of the orthogonal components of a magnetic field. The sensor will be connected to a NI USB-6009 DAQ system, with resolution (14 bits) and sampling rate (48 kS/s) capable to capture both the signal frequency and noise floor required.

Table 13. Technical specifications of the magnetometer to be used in CorPower onshore EMF measurements.

Characteristics	Bartington Mag690	Minimum requirements
Frequency Span	DC to 100Hz, maximum flat response (±5%)	DC to 50Hz
Dynamic Range	≈ 160 dB	100 dB
Noise Floor (sensitivity)	>10 to ≤ 20 pTrms/√Hz at 1Hz	1 nTrms$\sqrt{Hz}$ @ 1Hz
Number of axis	Three (right hand XYZ coordinate system)	
Measuring range	+-1000 µT	
Scaling	10mV/μT	

Measurements (5 replicate samples) will take place along the shore cable route, starting near the connecting point of the cable in the substation until the landfall location at the shore. Each measurement will last 10 minutes, correlated as far as possible with the cable current instant values.

6.4.2 Underwater measurements

For underwater EMF measurements, the Autonomous Underwater Vehicle (AUV) COMET-300 developed by RTSYS (Figure 20) equipped with an EMF sensor will be used. Measurements will be done around the umbilical cables in the water column and around cables laid in the seafloor. The sensor is a three-axis fluxgate gradiometer Bartington Grad-13-1000CS (Table 14). It will either be mounted on the hull of the COMET-300 or dragged by it. In one hand, mounting the sensor on the hull will offer more flexibility in terms of navigation as the immersion will remain constant. In the other hand, dragging the sensor would be better in terms of measurement quality (the gradiometer is further away from the COMET-300 own noise), but harder to stabilize and to manage while turning. Hence, the first solution would be privileged. The Grad-13-1000CS cannot be used beyond 200 meters water depth.

Table 14. Technical specifications of the gradiometer to be installed on COMET-300 for EMF measurements.

Characteristics	Bartington Grad-13
Bandwidth (at –3dB)	200 Hz
Data conversion	24 bits oversampled
Gradient Measurement Noise Floor	≤ 20 pTrms/√Hz/m at 1Hz
Number of axis	Three (for each of two sensing elements)
Measuring range	+-100 µT
Offset error	<10 nT in zero field

For the measurements around cables laid on the seafloor (5 replicate samples), these will take place along the pathway of the submarine cables in at least 5 sampling stations. At each sampling station, perpendicular measurements will be made both at 10 m, 7 m, and 5 m distance from the cables.

For the measurements around umbilical cables, these will be done in a single sampling station on which the AUV COMET-300 device will pass at 10 m, 7m and 5m distance from the umbilical cable.

Because the WAVEGEM device does not have an export cable to land, at the SEM-REV test site the monitoring will be performed around the FLOATGEN device.

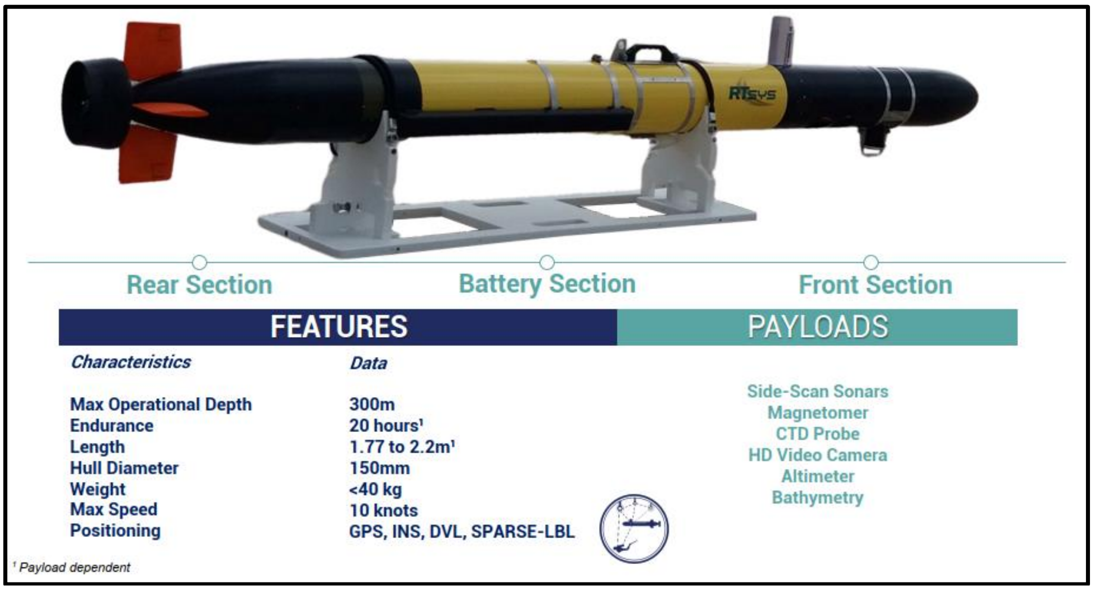

Figure 20. The AUV COMET-300 details (source: RTSYS).

6.5 Data processing

To increase the sensitivity of the recording system, it may be necessary to back off the earth's field and amplify only the changes in the field from the current value. This requires a high-pass filter, which could be a simple capacitively coupled arrangement or a multi-pole filter to provide a steep roll off characteristic.

The output from all fluxgate sensors will contain noise from the driving electronics. Where low noise operation is required, a filter should always be provided to reject the noise which lies outside the band of interest.

When the sensor output is digitized, it may be necessary to include an analogue low-pass anti-alias filter to prevent the creation of in-band noise by beating the 15 kHz excitation with the sampling clock of the digitizer.

The level of unwanted breakthrough at 15 kHz has been minimized in the Mag690 but may still cause an apparently raised noise level when sampled at low sampling frequencies without further analogue filtering.

In applications such as magnetic signature monitoring, it may be required to remove both the DC standing field and all AC noise and pick-up above a set frequency. The band of interest will be around the fundamental frequency of the cable current, 50 Hz, although higher harmonics should be considered. Thus a band pass filter can be used to provide the required signal.

6.6 Reports

The results from the EMF monitoring campaigns will be presented in Deliverable 2.2, together with a review of all monitoring work performed (including information about the campaigns, and deviations to the plan and its mitigation).

7. Acoustics monitoring plan

7.1 Introduction

According to the Marine Strategy Framework Directive (MSFD), "noise" is defined as an "anthropogenic sound that has the potential to cause negative impacts on the marine environment, including component biota but not necessarily the whole environment" (MSFD, 2008).

Operational noise of MREDs is of concern to several regulators and stakeholders by the potential impact on marine life. Noise monitoring is a key procedure to characterize the noise emitted by a source and to verify its acoustic propagation.

Information about the sources of noise expected from wave energy devices can be gathered from works done in air for their individual components. The main expected sources of noise are bearings, gearbox, pumps, and ropes. However, depending on their location in the device the noise would not propagate underwater or if it happens their frequency and sound pressure level might not be the same (Walsh et al., 2017).

This section presents the monitoring plan for "noise" that will guide the monitoring work to carry out in Task 2.3 (Acoustic monitoring). This plan will consider underwater noise and aerial noise generated by the wave energy devices under study.

7.2 Objectives

This monitoring plan provides the guidelines for the acoustic monitoring of the WE devices under study, particularly for underwater noise and airborne noise measurements. The monitoring plan will be implemented in Task 2.3 and resulting records will be used for validation and calibration of underwater noise propagation modelling models in Task 3.2.

The main objective is to collect acoustic data (underwater and airborne noise) from all devices under study. Also, empirical propagation loss and directivity assessment will be considered. This will address one of the knowledge gaps identified in the MaRVEN report (Thomsen et al., 2015) and the OES-Environmental 2020 state of the science report (Copping and Hemery, 2020) related with the need to characterize sound levels of different MRE technologies.

7.3 Monitoring parameters and equipment

The parameters to monitor can be divided into three groups: a) acoustic parameters, b) auxiliary parameters, and c) complementary parameters.

It should be noted that while the acoustic monitoring will be done both for underwater and aerial noise, greater emphasis will be given to underwater noise, due to its greater impact on the marine environment.

7.3.1 Acoustic parameters

7.3.1.1 Background noise

The background noise (sometimes referred as 'ambient noise') may be distinguished from radiated noise (sound radiated by a specific source under study), and self-noise (the noise generated by the recording equipment and its deployment/platform).

The exact meaning depends on the context, with the differences in meaning depending on whether local sources of anthropogenic sound are excluded. In the context of this project, background noise would exclude radiated noise from the specific device under study. Thus, the background noise would be measured when the source was silent (or absent). In any case, the background noise will not include self-noise of the recording system nor platform noise from the deployment, operation, and recovery of the instrumentation.

In the case that background noise of any of the equipment under study have been already measured, it may be susceptible to be used as background. For this, it will be verified if the site, duration, and quality of the measurements are correct for such consideration.

7.3.1.2 Underwater radiated noise

Radiated noise is the sound radiated by a specific source. This is distinct from background noise, which is the noise received from many indistinguishable sources. Thus, the noise of interest is the noise radiated during operation.

To characterize radiated noise (Robinson et al., 2014) by the source, it is necessary to consider the following factors:

- **Frequency content:** radiated noise for each metrics (see section 7.4.1) as a spectrum in 1/3 octave frequency bands. A narrowband frequency analysis may be desirable if tonal noises are detected from any device under study.
- **Temporal variation:** due to the acoustic output varies with time (both by variations of operation of the device and by environmental variations), then the measurements must sample the range of variations. This may require the measurements to be undertaken for an extended period rather than a short snapshot.
- **Spatial variation (directivity):** many sources may radiate noise asymmetrically both in horizontal and vertical planes. The source directivity patterns may also vary with acoustic frequency. Because detailed assessment of complex directivity patterns may not be cost-effective, or may be impractical, the underwater noise should be measured at several point within concentric circles around the source.
- **Near-field and far-field:** the acoustic near-field is the region close to the source where the field exhibits considerable interference between sound waves emanating from different parts of the source structure. On the other hand, the acoustic far-field is the region far enough away from the source so that the sound pressure and particle velocity are substantially in phase, and all sound waves appear to be emerging from a point (usually termed the acoustic centre of the source). Detailed study of the near-field of the devices is not required and the frequency range under study is relatively low, hence, accurate measurements in the near-field are not required. Nevertheless, the measurement points will be closer together as they are closer to the source.

The measurements for the devices noise characterization, empirical propagation loss and directivity of sound will be made following specific considerations for each device.

Underwater measurements will be carried out using hydrophones model SoundTrap ST300 HF (manufactured by Ocean InstrumentsNZ) sound recorder (Table 15).

7.3.1.3 Airborne noise

In addition to the underwater noise measurements, airborne noise measurements will be made in the vicinity of every device using a microphone. Likewise, measurements will be made of both the background and radiated noise.

These airborne measurements will be carried out using a microphone model Behringer ECM8000 (Table 16) integrated in a technical recording solution assembled by CTN.

Table 15. Characteristics of the SoundTrap ST300 HF hydrophones.

Feature	SoundTrap ST300 HF
Sample rate	576, 288, 192, 96, 72 & 48 kHz
Bit depth	16-Bit SAR
Self-noise	Less than 37 dB re 1 μPa above 2 kHz
Sensitivity	-204 dB re 1μPa
Bandwidth	20 Hz to 150 KHz ± 3dB
Dynamic Range	96 dB
Autonomy	Up to 13 days continuous operation
Memory	256 GB
Calibration	Factory OCR calibration certificate
Ancillary Sensors	Temperature – 0.1 °C precision, 1 °C uncalibrated accuracy in water Acceleration – To detect orientation or cable strum / platform vibration. Tri-axial accelerometer, +/- 8 g, Sampling up to 1 Hz

Table 16. Characteristics of the Behringer ECM8000 microphone.

Feature	Behringer
Sample rate	96 kHz
Bit depth	24-Bit SAR
Self-noise	Less than 30 dB re 20 μPa above 1 kHz
Sensitivity	13 mV/Pa
Bandwidth	1 to 15 kHz ± 3 dB
Dynamic Range	90 dB
Autonomy	Up to 10 days continuous operation
Memory	256 GB
Calibration	Factory OCR calibration certificate

The different propagation speed and absorption of acoustic waves in the air with respect to the water have implications that will affect the monitoring strategy:

- The speed of propagation of acoustic waves in air (~343 m/s) is ~ 1/4 that of seawater (~1480 m/s). Therefore, for the same frequency of excitation, the air waves are shorter than in the sea. Thus, the effects of the source shape are more prominent, that is, the near-field becomes larger and the directivity can be more variable than those measured underwater.
- The absorption of acoustic waves in air is much greater than in seawater (by two orders of magnitude, in dB/m). For this reason, monitoring must be carried out in the vicinity of the devices to obtain measurements that are adequate.

7.3.2 Auxiliary parameters

Auxiliary parameters may be relevant to complement the measured noise levels during analysis. The following parameters will be monitored:

- **Time:** the clock synchronization of each sensor and a control clock should be checked. Time should be specified in UTC to avoid confusion with time differences (e.g., between Spain and Portugal). The system time should be noted before and after deployment and compared with the GPS clock time to determine the drift over time.
- **Conductivity, temperature, and depth:** this information will be collected using CTD probes: A Sea&Sun Marine Tech CTD 48M for measurements at CPO test site, a Sea-Bird SBE -25 for measurements at BiMEP and Mutriku, and (potentially) a Sea-Bird SBE 16plus V2 SeaCAT for measurements at SEM-REV. In case that some problems occur during the campaigns or with the data, it is considered to resort to available datasets from the SafeWAVE partners or web services (e.g., EMODnet, https://emodnet.eu; Copernicus, https://www.copernicus.eu); while they might present a coarser resolution in space, they can cover much greater spatial and temporal scales compared to monitoring onsite.
- **Sound velocity:** sound velocity in the water column will be precisely calculated from the gathered CTD data.
- **Sea-state:** this information will be monitored with two main objectives: to define the field work and to correlate with the underwater noise levels measured. This information will be gathered from WindGuru (https://www.windguru.cz). Also, it will be requested (with 10 minutes resolution) relating to the sampling period to the National entities responsible (Portugal: Instituto Português do Mar e da Atmosfera

(IPMA); Spain: Agencia Estatal de Meteorologia (AEMet); France: Centre d'Etudes et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement (CEREMA). During the sampling period regarding the static measurements this information will also be recorded as Beaufort scale level.

- **Rain:** rain falling on the sea raise background noise levels. Therefore, this information could be used to characterize distinct soundscapes. This information will be gathered from WindGuru. Also, it will be requested (with 10 minutes resolution) relating to the sampling period to the National entities responsible (listed in the previous item).
- **Wind Speed:** this information will be monitored with two main objectives: to define the field work and to correlate with the underwater noise levels measured. This information will be gathered from WindGuru. Also, it will be requested (with 10 minutes resolution) relating to the sampling period to the National entities responsible (listed in the previous item).
- **Water depth:** this information will be collected using the echosounder of the research vessel before and after each deployment. This data can also be collected from the proper institutions or from available bathymetric datasets (e.g., EMODnet)
- **GPS location:** this will be collected using a GPS. Positions shall be given in the WGS 84 coordinates system, in Degrees, Decimal Minutes units.
- **Operational regime of the device and components:** this information will be provided by the company responsible for the device in each test site. Besides the operational regime, other relevant information will be provided (e.g., bearings, pumps).

7.3.3 Complementary parameters

Complementary parameters correspond to the information that is needed, not only to design the monitoring plan, but also to model underwater noise (Work Package 3), those being:

- Bathymetry
- Seafloor properties (Bottom type)
- Sound Speed profile
- Shipping

7.4 Sampling design and methods

For underwater noise measurements two set-ups will be considered in all test sites:

1) Fixed measurements: 3 hydrophones will be moored around the devices. This allows data collection for a long period of time comparing with mobile measurements (around 1 month vs. 1 day) and will work as control monitoring points for mobile measurements. The sampling frequency selected for the measurements should be high enough so that characterization of the noise radiated in different operating regimes is possible, but without oversampling (a sampling frequency not higher than 96 kHz would be adequate).

2) Mobile measurements: mobile measurements will be considered by integrating acoustic recording systems in the different autonomous vehicles available. This option will require integration and post-processing additional work, so that it will be evaluated as a test in at least one of the study areas. One of these devices is the AUV COMET-300 underwater drone of RTSYS equipped with a hydrophone. In addition, the possibility of incorporating hydrophones in the ITSADRONE ASV of AZTI will be considered. These two new and more advanced monitoring techniques, different from the ones used in the WESE project (see Deliverable 2.1 of the project), will allow to improve the spatial and temporal resolution of the acoustic data that will be acquired around WE devices operating.

Apart from the acoustic data, relevant environmental parameters (such as salinity, temperature) will be registered, as well as other important information that could be used for acoustic modelling validation (explained in sections 7.3.2 and 7.3.3).

When no previous data about the characteristic of the acoustic environment exists, proper sites will be selected with the same characteristics of the device site to characterize baseline conditions (before device deployment). This will allow for assessment of impacts and comparison among sites.

With the level of noise generated by a source, the factor at which the noise is reduced with distance and the level at which the given effect appears, it is possible to calculate a maximum range from the source within which there will be noise. However, both source noise and background noise must be evaluated statistically to have a complete understanding of the effects of noise.

The background noise is affected by a series of variables such as depth, type of substrate, wind speed, number of ships in the area, among other factors. The propagation of sound is affected by variations in temperature and salinity of water, the content of bubbles, among others. In addition, the noise level of the source itself may suffer variations over time.

Consequently, the area affected by the noise can vary greatly over time. For example, the average area affected can be as important as the affected area for 5% of the time. In general, obtaining reliable statistical properties of noise requires many repetitive measurements, allowing spatial effects (spatial resolution) and effects over time (temporal resolution) to be evaluated.

To achieve these measurements, the noise must be monitored over a wide range of distances from the source and the measurements must be repeated until enough confidence is achieved to obtain their statistical properties correctly.

For air measurements, the option of mounting a microphone on the autonomous surface vehicle ITSADRONE will also be considered. However, in the case of Wello Penguin II, the device (at BiMEP) may be equipped with an internal acoustic system to register the sound that is produced within the device itself.

7.4.1 Fixed measurements

This method is based on the deployment of a passive acoustic sensor moored in a specific location and for a long time. Its characteristics are:

- **High temporal resolution** since it allows to register variations due to environmental and seasonal changes in different cycles of operation of the source.
- **Low spatial resolution** since each of them is sampled in a single location and it is not feasible to have a large number of fixed measurements in several directions and several distances at the same time.

To overcome the barrier of the low spatial resolution, three static sampling station will be installed close to each of the four devices under study to achieve good temporal and spatial resolution of the measurements. Since the devices are positioned in shallow waters a bottom mounted system will be used. The configuration will be different at each test site and according to the description below. It is important to notice that in all connecting points for both schemes metal pieces should be avoided. The anchor weight and shape should be adjusted to the bottom type and the expected drag of the system.

The deployment of the hydrophones will be done using two possible systems depending on the site. For sites where the depth is great, a system successfully employed in the WESE project could be used. This system has the advantage of avoiding possible losses of the hydrophone associated with extreme sea conditions. The system is based on a mooring line constituted by a mooring of 50-70 kg, followed by a line on which the hydrophone is placed. The whole line stands upright thanks to a subsurface buoy. Between the mooring and the hydrophone an acoustic releaser is placed allowing the recovery of the hydrophone (Figure 21).

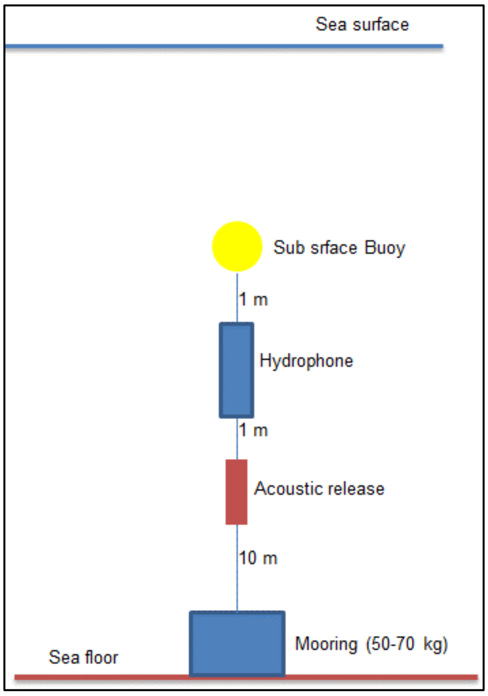

Figure 21. Bottom mounted deployment scheme.

For shallower deployments, the system is like that explained above for deeper waters, but the system is located and recovered through a surface marking buoy (Figure 22).

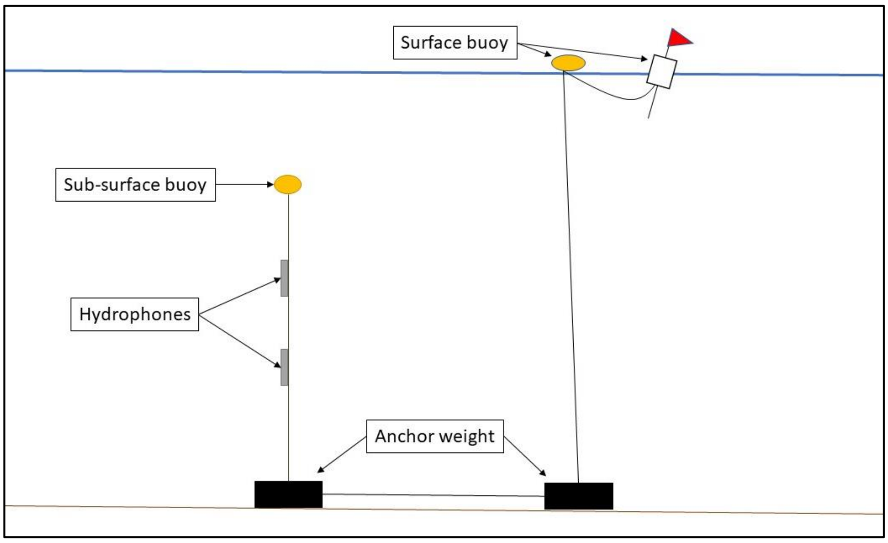

Figure 22. Bottom mounted deployment scheme at Aguçadoura.

In all the sites, the hydrophones will be installed for one month during which they will record for 10 minutes every hour, with a sampling rate of 96 kHz. The selected month will be chosen according to the gathered information (sea state, precipitation.

7.4.1.1 Mutriku test site (Spain) – Mutriku Wave Power Plant

The static measuring stations will be at least 100 m from the device, far enough to ensure far-field conditions (see 7.3.1.2) but close enough to detect noise from the power plant. The planned sampling stations are shown in Figure 23 (coordinates in Table 17).

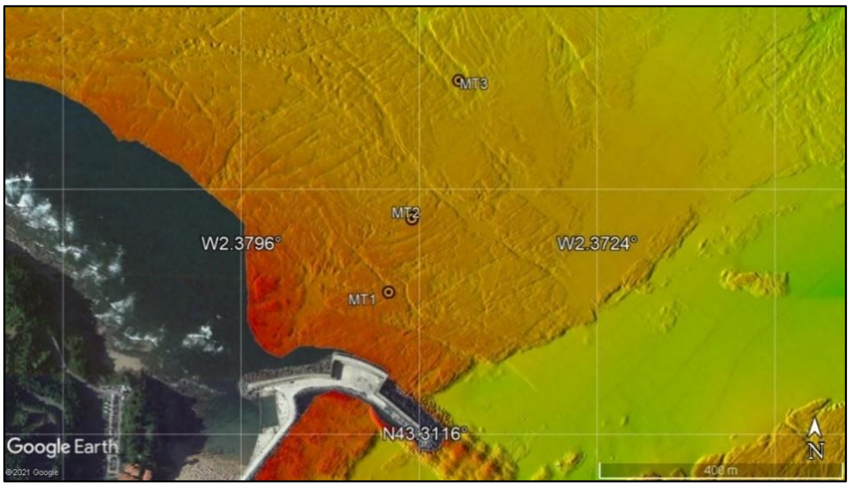

Figure 23. Static sampling stations at Mutriku test site.

Table 17. Geographic coordinates (WGS 84; Degrees, Decimal Minutes) for the static measurements around the Mutriku Wave Power Plant.

Location ID	Latitude	Longitude	Column water depth (m)
MT1	43° 18.822' N	2° 22.596' W	6
MT2	43° 18.887' N	2° 22.567' W	8
MT3	43° 19.008' N	2° 22.511' W	12

7.4.1.2 CPO test site (Portugal) – CPO HiWave

The static measuring stations will be at least 100 m from the device, far enough to ensure far-field conditions (see 7.3.1.2) but close enough to detect noise from the HiWave C4 WEC. The planned sampling stations are shown in Figure 24 (coordinates in Table 18).

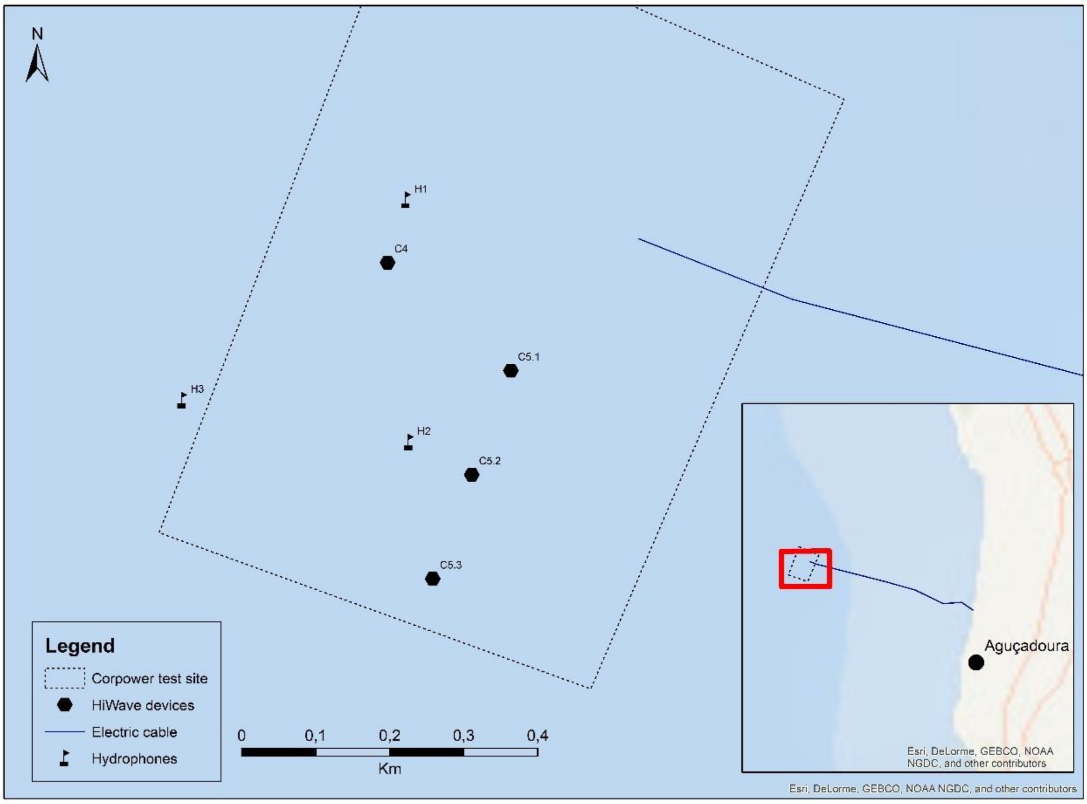

Figure 24. Static sampling stations around the HiWave device in CPO test site (Portugal).

Table 18. Geographic coordinates (WGS 84; Degrees, Decimal Minutes) for the static measurements around the HiWave device in CPO test site.

Location ID	Latitude	Longitude	Column water depth (m)
H1	41° 27.554' N	8° 50.534' W	Between 40-45
H2	41° 27.377' N	8° 50.529' W	Between 40-45
H3	41° 27.407' N	8° 50.749' W	Between 40-45

7.4.1.3 BiMEP test site (Spain) – Wello Penguin II

The static measuring stations will be at least 100 m from the device, far enough to ensure far-field conditions (see 7.3.1.2) but close enough to detect noise from the Penguin II WEC. The planned sampling stations are shown in Figure 25 (coordinates in Table 19).

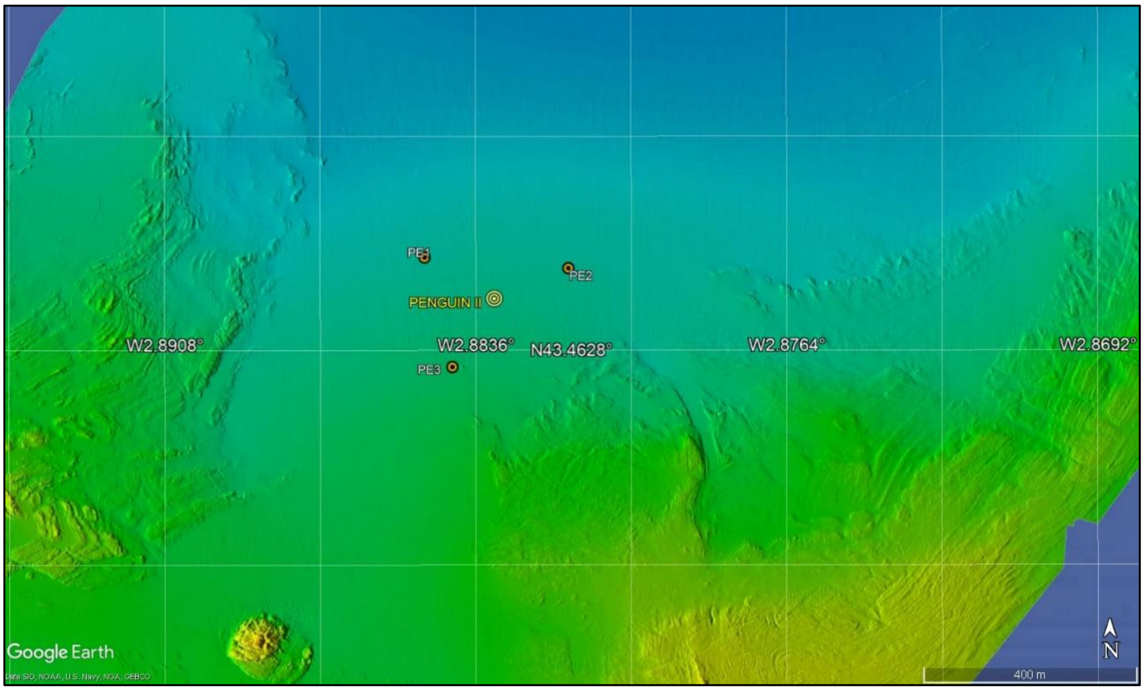

Figure 25. Static sampling stations around Penguin II device in BiMEP test site.

Table 19. Geographic coordinates (WGS 84; Degrees, Decimal Minutes) for the static measurements around the Penguin II device in BiMEP test site.

Location ID	Latitude	Longitude	Column water depth (m)
PE1	43° 27.862' N	2° 53.086' W	70
PE2	43° 27.852' N	2° 52.886' W	70

PE3	43° 27.752' N	2° 53.047' W	64

7.4.1.4 SEM-REV test site (France) – GEPS Techno WAVEGEM

The static measuring stations will be at least 100 m from the device, far enough to ensure far-field conditions (see 7.3.1.2) but close enough to detect noise from the WAVEGEM. The planned sampling stations are shown in Figure 26 (coordinates in Table 20).

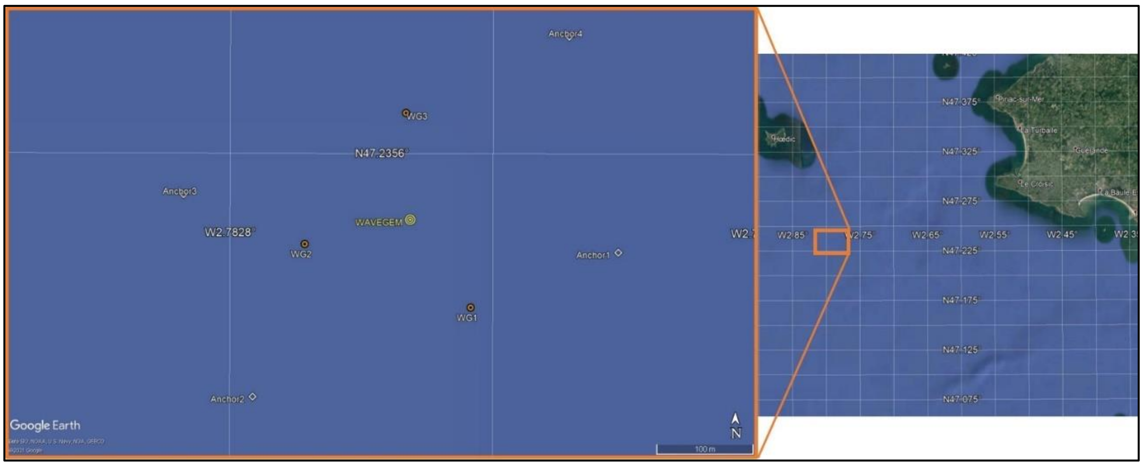

Figure 26. Static sampling stations around WAVEGEM device in SEM-REV test site.

Table 20. Geographic coordinates (WGS 84; Degrees, Decimal Minutes) for the static measurements around the WAVEGEM device in SEM-REV test site.

Location ID	Latitude	Longitude	Column water depth (m)
WG1	47° 14.050' N	2° 46.770' W	Between 40-50
WG2	47° 14.077' N	2° 46.899' W	Between 40-50
WG3	47° 14.159' N	2° 46.823' W	Between 40-50

7.4.2 Mobile autonomous surveys

This method is based on the passive acoustic measurements in different locations using an autonomous vehicle. This method characteristics are:

- **High spatial resolution**, since it allows having a superficial mapping of the underwater noise levels measured at different distances from the source. The depth of the hydrophone will be determined by the characteristics of the water column (should be around mid-section of the water column depth).

- **Low temporal resolution**, since it does not allow to measure for long time periods, but more than conventional boat measurements.

To overcome the barrier of the low temporal resolution, the integration of underwater sound recorders in the NemoSens AUV (or a similar model) of RTSYS or in the ITSADRONE of AZTI (Figure 27) will be investigated. These two platforms can work autonomously for days or weeks.

Figure 27. In the left, NemoSens AUV of RTSYS. In the right, ITSASDRONE developed by AZTI.

Avoiding bad weather windows, they will be able to increase the temporal resolution by repetition of the same sampling campaign.

These surveys will be e carried out in the following study areas:

- Mutriku test site (Spain) – Mutriku Wave Power Plant
- BiMEP test site (Spain) – Wello Penguin II
- SEM-REV test site (France) – GEPS Techno WAVEGEM

The deployment methodology, the definition of the measurement transects, as well as their duration will depend on the technical solution of the hydrophone integration in the autonomous vehicle. The integration of a hydrophone in these autonomous vehicles must guarantee that the noise itself does not distort or influence the frequency components of interest. For this reason, the CTN group will implement noise cancellation algorithms to minimize these possible interferences of the device's own noise with environmental noise.

However, the displays typically used in these devices can be of two types:

- Parallel longitudinal sweeps: when the device is very close to the coast, or when it is not possible to access any point around the device.
- In spiral: when the device is in the open sea, without mobility restrictions.

7.4.3 Airborne measurements

The measurements of airborne noise will be made with an acquisition system designed for this purpose. In the case of integrating a microphone in the ASV, the system will consist of holding it above the sea surface; in the case of integrating the microphone in the Wello Penguin II, the solution will consist in an autonomous airborne within the device.

This solution for recording airborne noise was chosen due to the following reasons:

- It is not recommendable to measure noise directly above the source, or very close to it due to possible unwanted near-field effect. Indeed, as it will be done during underwater noise campaigns, the fixed station will be placed away from the source far enough so that the recorded noise will meet the far-field condition. In the case of Wello Penguin II, a microphone will be deployed inside the device to find out the characteristics of the acoustic reverberant field that is produced, and its possible correlation with underwater noise measurements.
- The speed of sound in air is ~1/4 that in water, and the directivity of noise in air is more accentuated than in water. Therefore, it seems more appropriate to improve the spatial resolution even if losing temporal resolution.
- It is not easy to find a fixed station of environmental noise with autonomy of, for example, 1 month. The airborne acquisition system will be built to facilitate the measurements on the vessel. In that system, it will be included the signal storage system and the autonomy system (e.g., batteries, solar panels, charge controller) and possibly 3G/4G (or similar) connection.

7.5 Calibration of the equipment

To ensure that the noise measurements to be analysed are valid, the equipment without calibration in the last 2 years will be calibrated before campaigns are carried out. In the case of hydrophones already deployed in fixed moorings, these will be calibrated after measurements. The main objectives are i) to check that the equipment works correctly and thus validate the measurements, and ii) to know the sensitivity values against frequency in detail so that the data analysis is as accurate as possible.

The calibration will be performed in CTN's hydroacoustic laboratory (Figure 28) according to the IEC60565 standards.

Figure 28. CTN's hydroacoustic laboratory.

7.6 Data processing

7.6.1 Underwater acoustic data

To characterize the noise radiated by the devices, 3 samples will be selected for each relevant operational regime of the devices: starting operation, medium operation, and full operation. The scale will be determined when data from operational status of the devices is available. For directivity assessment and empirical propagation loss the available records will be used. In this work, both spectrograms and spectral analysis will be used to show the most relevant characteristics of the source. This information will be calculated using the PAMGuide (Merchant et al., 2015). Standards for signal processing will be followed (Betke et al., 2015; IEC, 2019).

7.6.2 Airborne acoustic data

Similarly to the underwater noise, to characterize the airborne noise radiated by the devices it will be distinguished the three operational regimes of the devices: starting operation, medium operation, and full operation. Likewise, both spectrograms and spectral analysis will be used to show the most relevant characteristics of the source, namely sound pressure levels in 1/3 octave in the audible spectrum (20 - 20 kHz).

7.7 Reports

The results from the acoustic monitoring campaigns will be presented in Deliverable 2.3, together with a review of all monitoring work performed (including information about the campaigns, and deviations to the plan and its mitigation).

8. Seafloor integrity monitoring plan

8.1 Introduction

The seafloor constitutes a key compartment for marine life. It includes both the physical and chemical parameters of seabed (e.g., bathymetry, roughness, substrate nature, oxygen supply) as well as the biotic composition of the benthic community.

The Marine Strategy Framework Directive (MSFD, 2008) addresses seafloor integrity in its Descriptor 6 (D6). According to the MSFD, seafloor integrity represents a state "at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected" (MSFD, 2008). According to the MSFD:

- **Integrity:** "comprehending both (i) natural spatial connectivity (avoiding unnatural habitat fragmentation or connectivity), and natural ecosystem processes functioning in their characteristic ways".
- **Not adversely affected:** "the cumulative effect of pressures associated with human activity are at a level that ensures the ecosystem maintains its respective components (structure) along with its natural levels of diversity, productivity, and dynamic ecological processes (functioning). Levels of disturbance (intensity, frequency, and spatial extent) must be at a level that ensures a dynamic recovery potential is maintained".
- **Recovery:** "the impacted seafloor attributes show a clear trend towards their pre-perturbation conditions, and the trend is expected to continue (if pressures continue to be managed) until the attributes lie within their range of historical natural variation. Benthic communities are not static entities, and thus recovery does not require that the ecosystem attributes return to their exact prior state".

With regards to WE projects, some negative impacts to the seafloor integrity could be expected that affect seafloor integrity and hamper the recovery of seafloor attributes, with different magnitude and scale depending on the project phase (e.g., Copping and Hemery, 2020; Vinagre et al., 2020). This is particularly the case of works undertaken during preparation and construction phases which generally involve mining, drilling and/or anchoring works, the installation of mooring systems and transmission cables to land, together with the removal of portions of substrate for the placement of the device itself (bottom-fixed type) or the anchors/supports (floating type). Such works may, for example, result in a localized habitat loss and harm (or kill) marine organisms directly through physical damage of benthic organisms and/or indirectly by the increase in sediment suspension and turbidity which will affect benthic (and possibly pelagic) organisms. During the operational phase, impacts may come, for example, from frequent sweeping of the seafloor by the moorings/cables, driven by wave action. This may have adverse effects (like those mentioned above) on the seafloor morphology, benthic habitats, and benthic/pelagic organisms.

As highlighted by the OES-Environmental 2020 state of the science report (Copping and Hemery, 2020), there are many gaps in knowledge particularly about environmental impacts (for example, related with seafloor disruption, and with disturbance by noise and EMFs). This is because, although several MRE projects, and especially WE projects, have been implemented in the last decade, they have not stayed in the water long enough (i.e., several years) to allow monitoring long-term changes caused in the seafloor by the projects (Copping and Hemery, 2020).

In this sense, it becomes extremely important to continue developing environmental monitoring of WE projects (especially long-term monitoring) to increase knowledge about environmental impacts from such projects, and to address potential gaps in knowledge. This is one of the aims of recent research projects such as the WESE project and the current SafeWAVE project.

8.2 Objectives

This monitoring plan provides the guidelines for the monitoring of seafloor integrity in the areas of the WECs under study. The monitoring plan will be implemented in Task 2.4.

The monitoring should be able to detect the impact of the installation of WECs over benthic (bottom) habitats due to the addition of gravity foundations, piles, or anchors, as well as the sweep of mooring lines, cables, and mechanical moving parts.

8.3 Sampling design and methods

For the monitoring of seafloor integrity two methods will be used at each test site: video techniques by means of Remotely Operated Vehicles (ROV), and side-scan SONAR imagery.

8.3.1 ROV monitoring

The video sampling with ROV is advantageous, for example, by allowing to quickly inspect large areas of the seafloor (providing the data necessary for the characterization of benthic communities) and to identify important habitats (e.g., sandy-bottom, hard-bottom, biogenic) without depth restrictions and in a less time-consuming process.

Sampling in transects should be done with a fixed heading both perpendicular and parallel to the coastline, and at a speed as constant as possible and preferentially below 0.25 m/s (= 0.5 knots) to avoid image blurring.

Adequate sea conditions must be assured for the sampling campaigns, both in terms of wave height and visibility and concerning to the safety of workers. Optimal conditions correspond to a value of 3 in the Beaufort scale.

A ROV dive log must be filled for each sampling station in the surveys (Annex 2).

8.3.1.1 CPO test site (Portugal) – CPO Ocean HiWave

In the CPO test site (HiWave), video sampling will be performed using a Seabotix LBV200-4 ROV equipped with two video cameras, an onboard camera used for navigation and a HD GoPro 4 with a resolution of 1080p for video sampling, and a lighting system of two 700 lumen LED. The ROV includes an ultra-short baseline (USBL) that allows to register the ROV movement underwater, a sonar that allows to scan the surroundings of the ROV looking for outcrops, an altimeter to measure the altitude of the ROV above the seafloor, a laser scaling system (two red laser dots 5 cm apart) which allows scaling the images (for example, to estimate the size of organisms and area occupied by the assemblages), and a small grabber to perform simple underwater operations. It is equipped with a 150 m cable being able to dive down to 120 m depth.

Two monitoring surveys with ROV are foreseen according with the two phases of HiWave WECs deployment. The first will be a baseline survey around the locations estimated for the C4 and the three C5 WECs, together with transects (~80 m long) along the locations estimated for the three hub mooring lines and anchors. This survey is foreseen to be conducted during June/July 2021. The second survey will be conducted one year after the deployment of the C4 WEC and will cover the area around, and as close as possible to, the device. If at the time of this campaign the C5 WECs are already installed, then the monitoring campaign will be adjusted to include the C4 and C5 WECs and the hub mooring lines and anchors (the transects will be done along the moorings as close as possible; the starting points will be the anchors coordinates).

8.3.1.2 BiMEP test site (Spain) – Wello Penguin II

In BiMEP (Penguin II), video sampling will be performed using a SIBIU PRO of Nido Robotics ROV equipped with a 1080p camera, specifically optimized for the underwater environment, along with its four 1500 lumens lights will allow to obtain a clear image in low-light environments. Alike the Seabotix (used in the CPO test site), the SIBIU PRO includes an acoustic tracking system (USBL), an altimeter, a sonar, a laser system. It is equipped with a 150 m cable, being able to operate until 300 m depth.

Two sampling campaigns will be performed, one campaign once the Penguin device is installed and in operation, around summer 2021, and a second campaign a year later (spring-summer 2022) to allow minimal time for potential changes in the seafloor.

During the operation of the Penguin II device, sampling with ROV will cover the following elements in each of the six moorings and mooring lines:

a) The landing point of the lower catenary.

b) The route of the landed lower catenary till the anchors.

c) The anchors.

At the same time, during the operation of the Penguin II device, a visual inspection of the landing point of the umbilical export cable will be done.

8.3.1.3 GEPS Techno WAVEGEM – SEM-REV test site (France)

In SEM-REV (WAVEGEM), video sampling will be performed according to two scenarios. On the one hand, the SEM-REV team can envisage subcontracting to a known subcontractor such as DynamOcean with its miniROV BlueROV2 of Bluerobotics . It allows to work until 100 m of depth. At the front of the ROV there is a high definition (1080p, 30fps), wide-angle, low-light camera optimized for use in the ROV. The ROV is configured with 4 lights providing up to 6 000 lumens. The ROV includes an USBL that allows to register the ROV movement underwater. On the other hand, SEM-REV is purchasing a miniROV; the public procurement process is ongoing and should end before the monitoring campaign is undertaken. The Deeptrekker revolution ROV (or an equivalent ROV) is expected to be selected. This ROV is equipped with an integrated camera (full-HD low light camera) and tracked with an USBL. The depth rating is up to 300 m.

The minimum of two campaigns will performed, one survey in spring-summer 2021 during the operational phase of WAVEGEM, and one in September 2021 just after the decommissioning of the device and moorings. The SEMREV team also envisages trying different approaches with its own ROV to provide feedbacks to the project partners.

The video sampling will be carried out in each four moorings and mooring lines (in contact with seafloor).

8.3.2 Side-scan SONAR monitoring

In each of the three sites, side-scan sonar survey will be performed using the AUV COMET-300 of RTSYS described in section 6.4.2 (Figure 20). Comparing to the images taken with the more traditional monitoring techniques (for example, see WESE project Deliverable 2.1[4]), the COMET will allow to operate the side-scan SONAR closer to the sea bottom, obtaining better quality images, and to cover a larger sampling area.

At each site, several transects around moorings, mooring lines and export cables will be performed. The number of transects will be the enough to have a clear image of these structures and the possible footprint due to the dragging effect of these structures.

8.4 Data processing

Video images will be pre-processed to exclude unnecessary/unsuitable videos or video sections. Besides the characterization of the seafloor (for example, type of substratum, benthic communities), whenever possible, the area potentially affected by the devices/equipment will be estimated (in m^2).

[4] https://wese-project.weebly.com/uploads/1/2/3/5/123556957/wese_report_d2.1._monitoring_plans_for_noise_emf_and_seabed_integrity.pdf

8.5 Reports

The results from the seafloor integrity monitoring campaigns will be presented in Deliverable 2.4, together with a review of all monitoring work performed (including information about the campaigns, and deviations to the plan and its mitigation).

9. Fish communities monitoring plan

9.1 Introduction

The installation of anchorages, prototypes fixed to the bottom or associated with the construction of docks, piers, submarine cables, etc., can lead to the generation of noise and vibrations that generally frighten the fish communities located in the area. According to Gill (2005) sounds of up to 260 dB can cause damage to the auditory system of some species within a 100 m radius. Nedwell and Howell (2004) and Nedwell et al. (2003) analysed the noise level at which certain species of fish and marine mammals exhibit flight behaviour away from the source of noise or vibration, setting the sensitivity or reception capacity of the species at 90 dB.

The disturbances associated with the noise generated by boat traffic during the construction phase can also have an effect on ichthyofauna by causing changes in their behaviour or migratory patterns (Aguilar de Soto, 2005; Sarà et al., 2007).

The most common types of effects on ichthyofauna during the construction phase are the following (Popper, 2003; Aguilar de Soto, 2005; Hastings and Popper, 2005; Popper et al., 2005; Simmonds and MacLennan, 2005; Dong-Energy and Vattenfall-A/S, 2006; Halcrow Group Ltd., 2006; Dalen et al., 2007; OSPAR Commission, 2009; Bailey et al., 2010; Dolman and Simmonds, 2010; Langhamer et al., 2010):

(i) physical effects; (ii) stress and physiological changes; (iii) effects on hearing; (iv) structural and cellular damage; (v) visual effects and disorientation; (vi) effects on behaviour; (vii) effects on the behaviour of the fish; and (viii) effects on the fish population.

During the operation phase, in general, the placement of any artefact in the sea can result in an attracting effect on fish communities, especially if it is floating. Similar effects have been observed by Morrisey et al. (2006) in relation to floating aquaculture structures (e.g., fish cages, mussel rafts). This attraction can lead to changes in the species composition of the study area and alter the predator-prey relationship (Boehlert et al., 2008). The increase of epibiont fauna on wind turbine piles favours the creation of habitat and the presence of species that can be food sources for ichthyofauna (Dong-Energy and Vattenfall-A/S, 2006). A study carried out by Wilhelmsson et al. (2006) in the Baltic found a higher abundance of fish in the vicinity of the turbines, but similar richness and diversity in control areas.

However, the noise and vibrations generated as a result of the operation of the WECs could offset this attracting effect.

On the other hand, the closure of an area to fishing activity may have a beneficial effect on certain species that may be favoured by generating an effect similar to that of a marine reserve. However, the environmental monitoring plan carried out at the Horns Rev offshore wind farms in 2004 and Nysted in 2001 showed that the possible artificial reef effect detected was negligible (DEA, 2006). In any case, this possible positive effect will have to be verified by appropriate monitoring during the lifetime of the infrastructure (Michel et al., 2007).

Effects associated with the electromagnetic field generated by submarine cables may also occur during the operation phase. According to Gill et al. (2005) and Halcrow Group Ltd. (2006), the electromagnetic fields associated with the cable have the capacity to affect primarily elasmobranchs (sharks and rays) by altering the sensitivity of these species to the electromagnetic microfields generated by their potential prey and consequently altering their feeding capacity. These authors also indicate that, depending on the intensity of the electromagnetic field, these species will be attracted or repelled to it. Thus, three possible effects can be expected: (i) their feeding behaviour may be interrupted or altered in elasmobranch species resident in an area where the cable has been laid; (ii) the attraction by the cable and the generation of artificial aggregations of elasmobranchs in the area where the cable has been laid may be interrupted or altered; (iii) the attraction by the cable and the generation of artificial aggregations of elasmobranchs in the area where the cable has been laid may be interrupted or altered.

The environmental study by Andrulewicz et al. (2003) on the possible effects generated by the installation and operation of a DC high-voltage power line between Poland and Sweden (Baltic Sea waters) concludes that migrating fish in the vicinity of the cable may be disturbed by the magnetic field created by the cable, which is no longer felt at a distance of 20 m or more.

9.2 Objectives

This monitoring plan provides the guidelines for the monitoring of fish communities around the Penguin II device in BiMEP. The monitoring plan will be implemented in Task 2.5.

9.3 Sampling design and methods

This monitoring will be done by means of active acoustic monitoring trough an echo-sounder developed by ZUNIBAL and integrated in the Autonomous Superficial Vehicle (ASV) ITSASDRONE developed by AZTI (Figure 29).

Figure 29. ITSASDRONE of AZTI.

ITSASDRONE is an autonomous sea surface drone for long term missions on the sea surface (3 months or more), capable of carrying out different tasks operating autonomously, by means of an automated remote control with radio or satellite communication. It is a drone that operates 100% on renewable energy in the marine environment and with a zero-emission propulsion system. The applications of the drone may range from oceanographic, meteorological, or biological research to control by marine authorities, including target monitoring. The system has a length of 199 cm, 117 cm beam, 50 cm draft and 50 kg of weight. With 2 electric thrusters it can reach 3-4 knots.

The echo sounder of ZUNIBAL integrated in the ITSASDRONE is a single beam ZSR 120 kHz scientific echo sounder with an Airmar transducer with a frequency range of 85-135 kHz (Figure 30) that can collect and store accurate acoustic backscattering data that can be post-processed and replayed (Figure 31).

Different trials with ITSASDRONE will be done at BiMEP test site to identify the best configuration in terms of a compromise between the autonomy of the device and the navigation speed so that it is enough to counteract the effect of currents and wind. Also, the weather windows advantageous for the system operation will be studied.

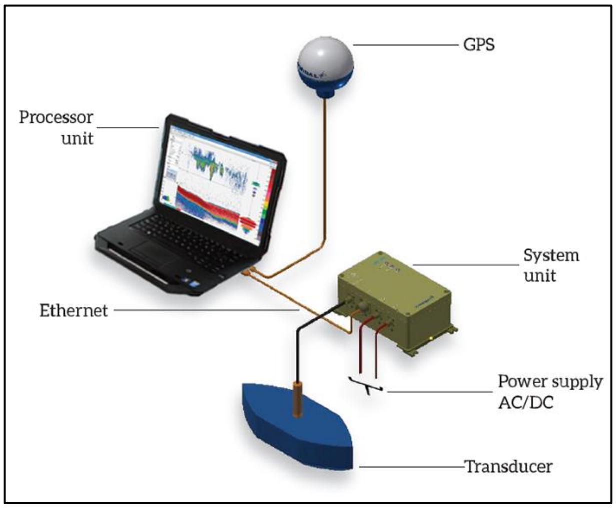

Figure 30. ZUNIBAL echo sounder scheme integrated in the ITSASDRONE of AZTI.

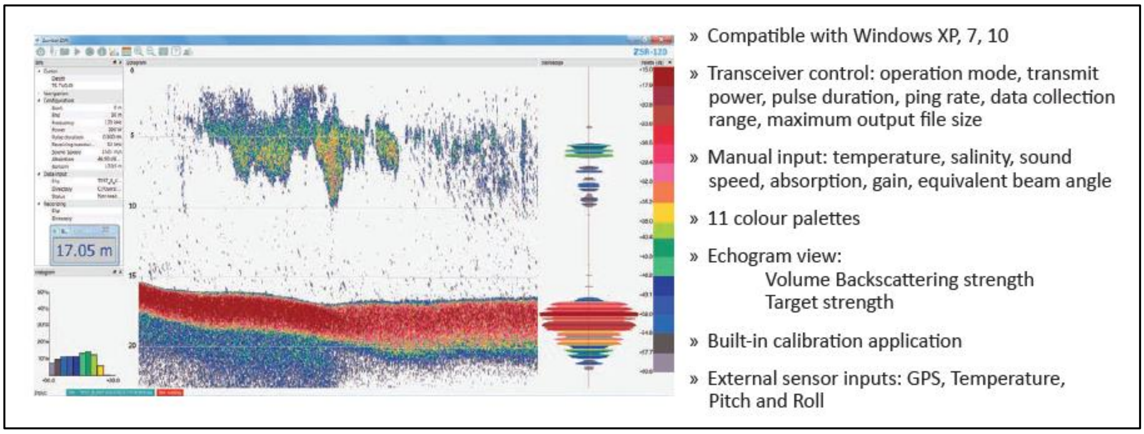

Figure 31. Backscattering data of ZUNIBAL echo sounder integrated in the ITSASDRONE of AZTI.

Different transects will be performed around the Penguin II device and others far enough to act as control sites to identify the distribution of fish shoals around the WEC.

9.4 Data processing

Data coming from the echo sounder will be processed for identification of significant fish shoals. With the data coming from the echo sounder, the possible aggregation effect of the device will be evaluated, and with the underwater camera the identification of species will be done.

9.5 Reports

The results from the fish communities monitoring campaigns will be presented in Deliverable 2.5, together with a review of all monitoring work performed (including information about the campaigns, and deviations to the plan and its mitigation).

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11. Annexes

Annex 1. Recording sheet for underwater noise monitoring.

Location		Survey start date		Survey end date	
Device		Team			
Equipment					
Serial number					

Sampling station	Start Time (hh:mm)	End time (hh:mm)	Coordinates (WGS 84; Degrees, Decimal Minutes)		Water column depth (m)	Hydrophone depth (m)	Wind speed (knots)	Sea-state (Beaufort scale)	Other sources of noise
			Latitude	Longitude					

Annex 2. ROV sampling dive log.

Mission name			
Purpose of dive			
ROV Operator(s)			
Date		Location	
Weather		Waves	
Bottom type		Current speed	
Coordinates (WGS 84; Degrees, Decimal Minutes)			
Additional notes			
Start time		End time	
Max tether used (m)		Max Depth	
Video(s) ID(s)			
GoPro videos ID(s)			
Comments			

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