WESE

WAVE ENERGY IN SOUTHERN EUROPE

DELIVERABLE 2.1 Monitoring plans for Noise, Electromagnetic Fields and Seabed Integrity

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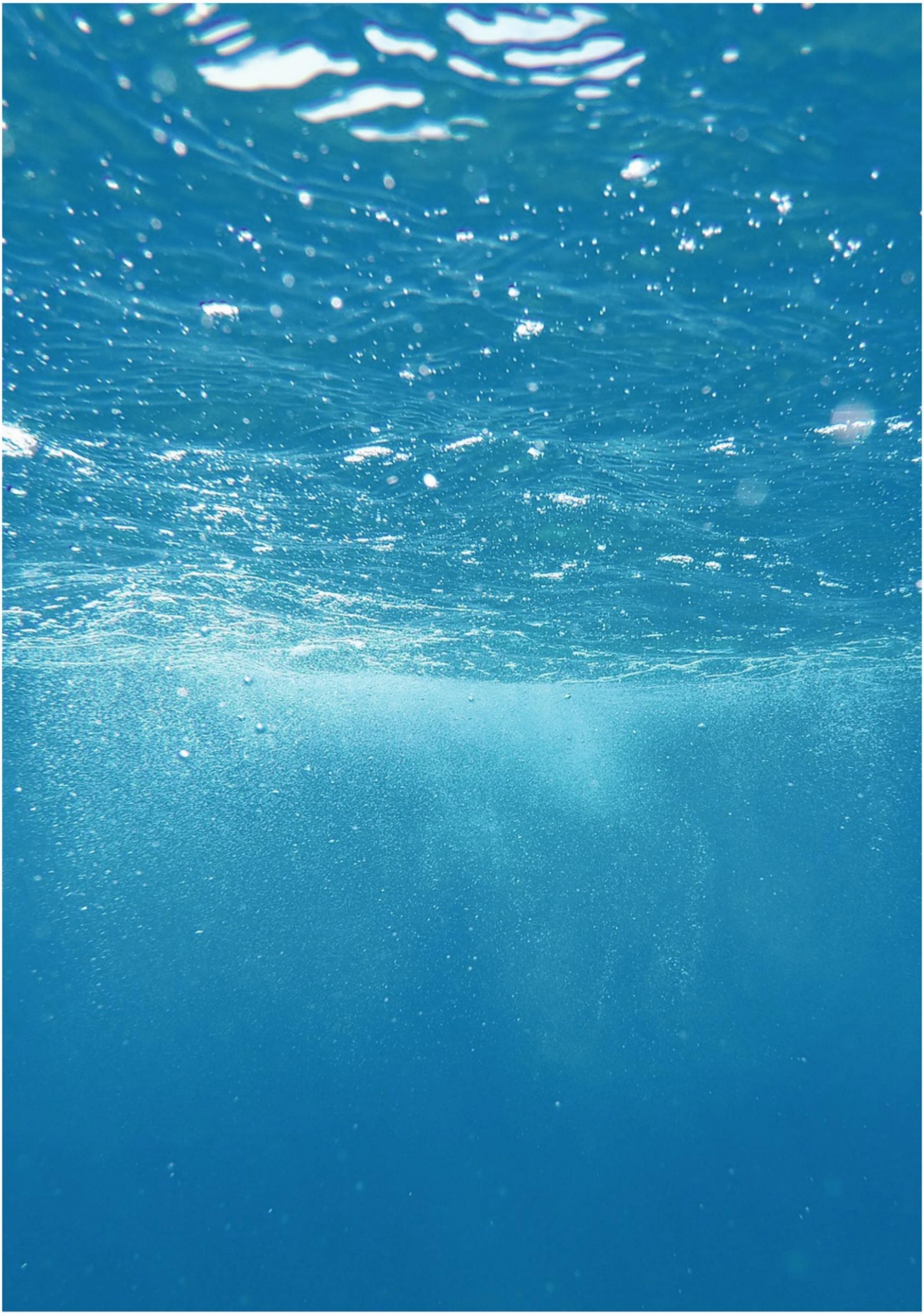

WP 2 Environmental Monitoring

Deliverable 2.1 Monitoring plans for Noise, Electromagnetic Fields and Seabed Integrity

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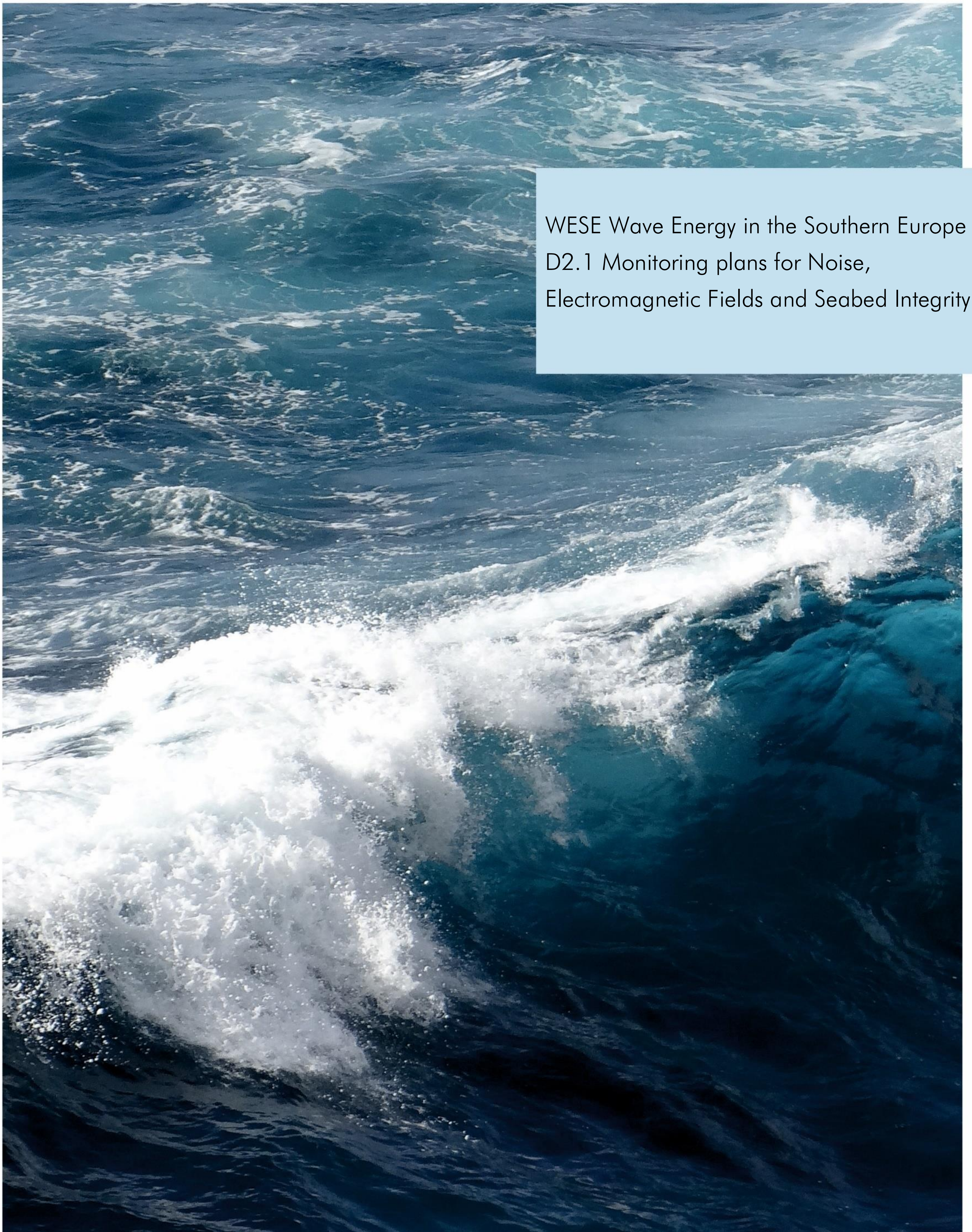

WESE Wave Energy in the Southern Europe

D2.1 Monitoring plans for Noise, Electromagnetic Fields and Seabed Integrity

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1. WESE 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. Therefore, the ocean energy development is one of the main pillars of the EU Blue Growth strategy. While the technological development of devices is growing fast, their potential environmental effects are not well-known. In a new industry like MRE, and Wave Energy (WE) in particular, there may be interactions between devices and marine organisms or habitats that regulators or stakeholders perceive as risky. In many instances, this perception of risk is due to the high degree of uncertainty that results from a paucity of data collected in the ocean. However, the possibility of real risk to marine organisms or habitats cannot be ignored; the lack of data continues to confound our ability to differentiate between real and perceived risks. Due to the present and future demand for marine resources and space, human activities in the marine environment are expected to increase, which will produce higher pressures on marine ecosystems; as well as competition and conflicts among marine users. This context continues to present challenges to permitting/consenting of commercial-scale development. Time-consuming procedures linked to uncertainty about project environmental impacts, the need to consult with numerous stakeholders and potential conflicts with other marine users appear to be the main obstacles to consenting WE projects. These are considered as non-technological barriers that could hinder the future development of WE in EU and Spain and Portugal in particular were, for instance, consenting approaches remain fragmented and sequential. Consequently, and in accordance with the Ocean Energy Strategic Roadmap published in November 2016, the main aim of the project consists on overcoming these non-technological barriers through the following specific objectives:

1. Development of environmental monitoring around wave energy converters (WECs) operating at sea, to analyse, share and improve the knowledge of the positive and negative environmental pressures and impacts of these technologies and consequently a better knowledge of real risks.
2. The resulting data collection will be used to apply and improve existing modelling tools and contribute to the overall understanding of potential cumulative pressures and impacts of larger scale, and future, wave energy deployments.
3. Development of efficient guidance for planning and consenting procedures in Spain and Portugal for WE projects to better inform decision-makers and managers on

environmental real risks and reduce environmental consenting uncertainty of ocean WE introducing the Risk Based Approach suggested by the RICORE, a Horizon 2020 project, which underline the difficulties for developers with an existing fragmented and sequential consenting approaches in these countries;

4. Development and implementation of innovative maritime spatial planning (MSP) Decision Support Tools (DSTs) for Portugal and Spain for site selection of WE projects. The final objective of such tools will be the identification and selection of suitable areas for WE development, as well as to support decision makers and developers during the licensing process. These DSTs will consider previous findings (both environmental and legal, found in RiCORE) and the new knowledge acquired in WESE in order to support the development of the risk-based approach mentioned in (3);

5. Development of a Data Sharing Platform that will serve data providers, developers and regulators. This includes the partners of the project. WESE Data Platform will be made of a number of ICT services in order to have: (i) a single web access point to relevant data (either produced within the project or by others); (ii) Generation of OGC compliant requests to access data via command line (advanced users); (iii) a dedicated cloud server to store frequently used data or data that may not fit in existing Data Portals; (iv) synchronized biological data and environmental parameters in order to feed models automatically.

2. Executive summary

In the WESE project scope, Work Package 2 aims to collect, process, analyse and share environmental data collected in sites where Wave Energy Converters (WEC) are operating in real sea conditions in Spanish and Portuguese coastal waters, representing different types of technology, sites and, therefore, types of marine environment (onshore, nearshore and offshore) that can potentially be affected by wave energy projects: (i) Idom-Oceantec MARMOK-A-5, installed in the Biscay Marine Energy Platform (BiMEP) in Spain; (ii) Wave Roller (AW-Energy), installed in Peniche (Portugal) and (iii) Mutriku Wave Power Plant, in operation in Spain.

Data will be collected for three of the priority areas of research: 1) risk to marine animals from sound generated by wave devices, 2) changes in physical systems (energy removal) and 3) effects of Electromagnetic Fields (EMF) emitted by the energy transfer cables.

Consequently, the aim of the present deliverable is to present the specific monitoring plans developed for noise (Section 5), EMF (Section 6) and seabed integrity monitoring (Section 7), covering the main types of technology location described in Section 3: onshore (Mutriku Wave Power Plant), nearshore (WaveRoller) and offshore (Idom-Oceantec MARMOK-A-5).

3. Objective

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.

In the WESE project scope, Work Package 2 aims to collect, process, analyse and share environmental data collected in sites where Wave Energy Converters (WEC) are operating in real sea conditions in Spanish and Portuguese coastal waters, representing different types of technology, sites and, therefore, types of marine environment (onshore, nearshore and offshore) that can potentially be affected by wave energy projects (Table 1).

Table 1. Wave Energy Devices under study.

Device	Technology	Site	Location
WaveRoller	Oscillating Wave Surge Converter	Peniche, Portugal	Nearshore
MARMOK-A-5	Floating Oscillating Water Column	BiMEP, Spain	Offshore
Mutriku Wave Power Plant	Oscillating Water Column	Mutriku, Spain	Onshore

Within WP 2, the main objective of Task 2.1 and the present Deliverable is to develop the environmental monitoring plans for noise, electromagnetic fields (EMF) and seabed integrity around the WECs above described.

The results of these monitoring plans are the subject of subsequent Deliverables (D2.2, 2.3 and 2.4)

4. Description of test sites and devices under study

4.1 WaveRoller – Peniche test site (Portugal)

The WaveRoller system, developed by AW-Energy (aw-energy.com), is in the Site of Community Importance (SCI) Peniche/Santa Cruz (PTCON0056) defined in the EC Habitats Directive (HD, 1992) of Rede Natura 2000. It is positioned on the Portuguese West Coast in a sandy bottom at 400 m of Almagreira beach (Peniche; 39º22'43.39''N, 9º18'54.87''W) between the -10 m and the -11 m bathymetries.

The WaveRoller unit is mounted on a large concrete base and consists of an oscillating bottom hinged WEC 42 m long and 18 m wide (with a steel flap 18 m wide and 10 m high) representing a total area of 860 m^2, of which 756 m^2 integrate the maritime public domain.

4.2 Marmok-A-5 – BiMEP test site (Spain)

The Biscay Marine Energy Platform (BiMEP, www.bimep.com) 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 1).

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.

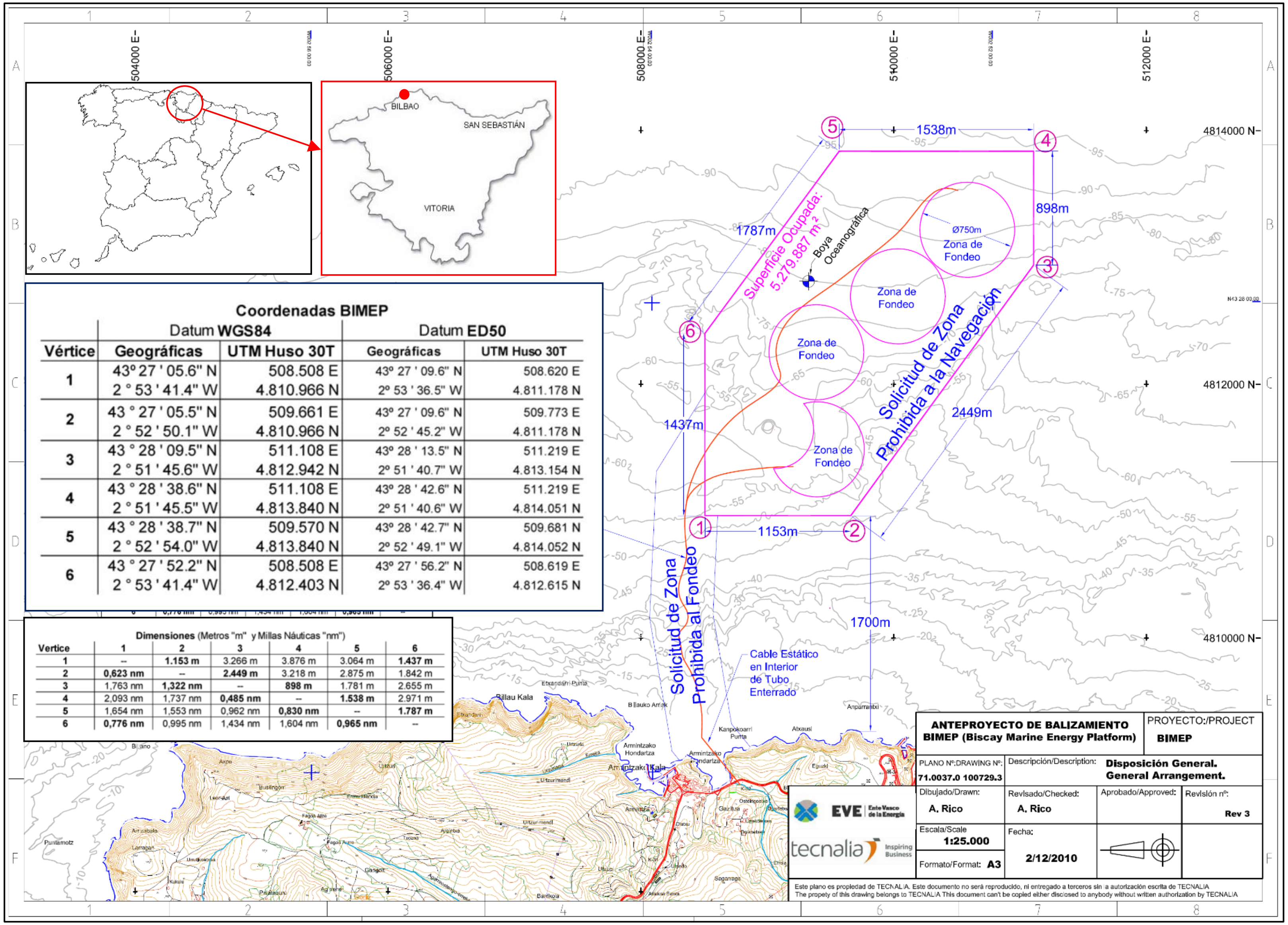

Figure 1. General arrangement of BiMEP.

Today, BiMEP hosts the first floating wave energy device connected to the grid in Spain, the MARMOK-A-5 device developed by the Basque company Oceantec Energías Marinas (www.oceantecenergy.com). This company, promoted by TECNALIA and Iberdrola, was purchased by Idom Consulting, Engineering and Architecture, S.A.U (Idom) in September 11, 2018. As a result of this purchase agreement, 100% of Oceantec assets and businesses become the property of Idom.

The MARMOK-A-5, developed by IDOM-Oceantec, is a reduced floating device prototype oscillating water column (OWC), with a point absorber configuration, deployed at sea in October 2016 in Armintza, in Biscay Marine Energy Platform (BiMEP), in the Northern Coast of Spain (43°28'9.52''N, 2°52'11.42''W) (Figure 2). It is positioned at a depth of 80 m and moored to the seafloor trough 4 mooring lines (Figure 3).

The device is typically known as SPAR BUOY OWC. It consists of a simple and robust buoy that moves by the action of the waves and is composed of three parts: a float that moves by the effect of waves, a hollow cylinder that contains the water column and a last lower element that provides stability and inertia. The size of the OWC is 42 m length and 5 m diameter, with a capacity of 30 kW (Figure 4). It is currently operational, and it will be removed in May 2019.

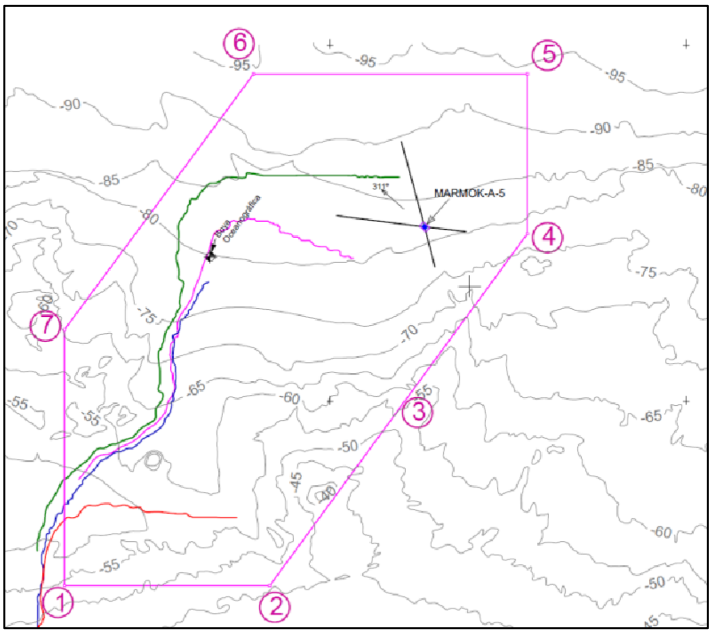

Figure 2. Location of MARMOK-A-5 inside BiMEP area.

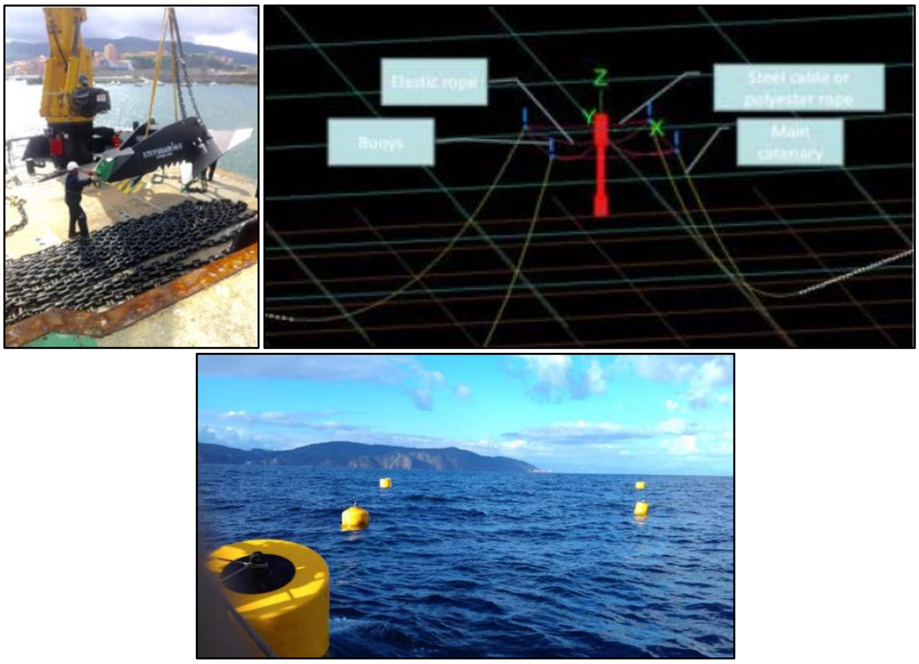

Figure 3. Detail of the MARMOK-A-5 mooring and mooring lines system (Source: https://appa.es/wp-content/uploads/descargas/seminarios/Jose-L-Aguiriano-OCEANTEC.pdf).

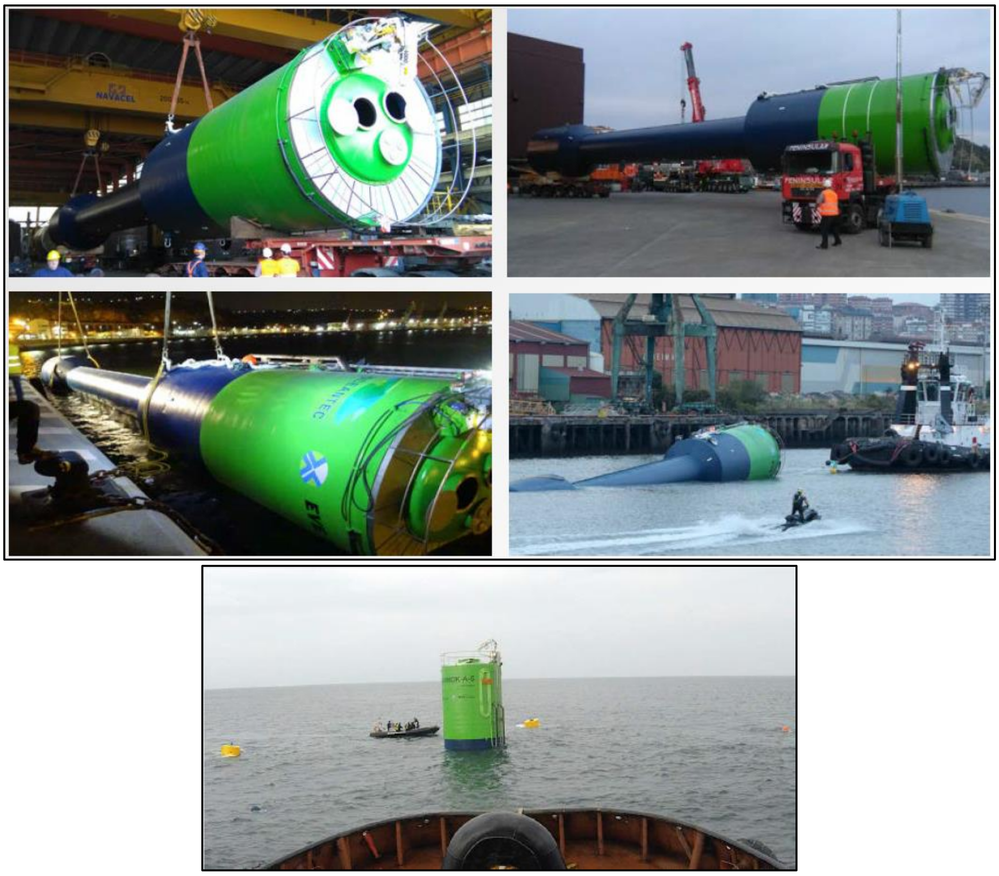

Figure 4. MARMOK-A-5 transportation and installation in October 2016 (Source: https://appa.es/wp-content/uploads/descargas/seminarios/Jose-L-Aguiriano-OCEANTEC.pdf).

4.3 Mutriku power plant – Mutriku test site (Spain)

The Wave Energy Plant of Mutriku is in the Basque Country, in the Northern Coast of Spain (43°18’45.51’’N, 2°22’37.68’’W). 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 1.6GWh of electricity.

The power plant is a grid-connected plant, integrated within an existing breakwater at Mutriku harbour (Figure 5). 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 6) and electrical generator of 18.5 kW for each air chamber, yielding the total 296 kW.

Figure 5. Mutriku Wave Power Plant.

Figure 6. Mutriku Wave Power Plant turbines inside the plant.

The idea of adding a wave energy generating plant into the breakwater design began in 2002, just as the consenting procedure for the breakwater was on the verge of completion. In 2005, the breakwater was allocated with a design that did not include the wave energy generation. This design was later modified to include the wave energy generation in 2006. The project began construction in March 2009 at a cost of 2 million euros. It has started operating officially in July 2011 and has been successfully operating since then. Until June 2018 the plant has supplied to the grid over 1.6GWh of electricity. 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.

5. Noise monitoring plan

5.1 Introduction

Noise is defined according to the MSFD 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 by work 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 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 three wave energy devices under study.

5.1.1 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. Resulting records will be used for validation and calibration of acoustic models (WP 3, Task 3.2) therefore this monitoring plan considers all the requirements need for this task.

The main objective is to characterize underwater noise radiated by three wave energy devices (WaveRoller, MARMOK-A-5 and Mutriku power plant) and airborne noise from MARMOK-A-5 and Mutriku power plant. Also, empirical propagation loss and directivity assessment will be considered.

5.1.2 Previous work

5.1.2.1 WaveRoller – Peniche test site (Portugal)

The first underwater acoustic monitoring activities at the WaveRoller test site in Peniche, Portugal started in 2010 under the SURGE Project[1]. Under this project two campaigns of

[1] Funded by European Commission, call FP7-ENERGY-2008-TREN-1, Grant Agreement no.239496 - Simple Underwater Renewable Generation of Electricity (SURGE).

one day were carried out to assess the background noise, without the presence of the WaveRoller device under test. In September of 2014 an experiment was carried out during 24 h to characterize the sound emitted by the WaveRoller. The main results are presented in Cruz et al. (2015).

5.1.2.2 BIMEP test site

In the BiMEP test site, two environmental monitoring programs (EMP) were developed by AZTI (www.azti.es) for the monitoring of the underwater sound: (1) a first EMP in 2012 before the installation of any WEC or structure; (2) a second EMP in 2013 during the installation of submarine cables.

During the pre-operational phase in 2012, a sonobuoy, developed by the Universidad Politécnica de Cataluña, was moored at 40 m depth. The sonobuoy was able to detect and classify automatically all the acoustic events above the ambient noise (presence of cetaceans and noise) and store the information. It was moored on the 6 of June 2012 and for 5 months the presence of marine mammals and underwater ambient noise was monitored and later analysed for 1/3 octave bands 63 Hz and 125 Hz as recommended by the Marine Strategy Framework Directive (MSFD, 2008). The mean value recorded during the sampling period for the 1/3 octave bands of 63 Hz and 125 Hz was about 90 dB and 85 dB respectively.

During the installation of the cables in BiMEP, two sampling campaigns (14 sampling stations each time) were undertaken. One, before the installation of cables to evaluate the sound background levels and one during the installation operations. Later, a measurement of sound propagation was undertaken during the cable installation. The results showed a background level of 70-80 dB. The acoustic signal during cable installation is characterized by a 11 kHz frequency and 188,5 dB re 1μPa which can affect a 400 km^2 area. Impacts over marine mammal's communities were not expected due to the temporality, the season and intensity of the installation operations.

5.1.2.3 Mutriku power plant – Mutriku test site (Spain)

An environmental monitoring program (EMP) was developed by AZTI (www.azti.es) for the monitoring of the underwater sound produced by the Mutriku OWC Plant in 2016. This program was funded by the Science, Research and Development Section of the Regional Government (Diputación Foral de Gipuzkoa).

Two sampling campaigns were undertaken in 13 sampling stations during summer and winter 2016. In each sampling station, a 10 minutes sound was recorded and was later processed and analysed for 1/3 octave bands as recommended by the MSFD (MSFD, 2008). No evidence of significant acoustic impact coming from the Mutriku OWC Plant was observed in this frequency bands.

On the 5th of June 2018 a permanent acoustic underwater monitoring station cabled to the Mutriku OWC Plant was installed allowing a continuous real-time data monitoring of the underwater noise generated by the plant. Additionally, it will allow monitoring trends in the ambient noise level within the 1/3 octave bands 63 Hz and 125 Hz as recommended by the MSFD (MSFD, 2008). These data are accessible and can be downloaded trough the web page of EMODnet Physics[2] data portal.

5.2 Monitoring parameters and equipment

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

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

5.2.1 Acoustic parameters

5.2.1.1 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 the 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 measures is correct for such consideration.

[2] http://www.emodnet-physics.eu/Map/platinfo/pigenericdownload.aspx?platformid=372740.

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

- **Frequency content:** radiated noise for each metrics (5.3.1) 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.

Although underwater noise data are available, these will be considered as preliminary or indicative data. The measurements for the device noise characterization, empirical propagation loss and directivity of sound will be made following considerations specific for each device.

All underwater records will be carried out using an underwater sound recorder, model SoundTrap ST300 HF (manufactured by Ocean Instruments[NZ]). It has a working frequency range of 20 Hz to 150 kHz. The main characteristics are presented in Table 2.

Table 2. Characteristics of the 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, +/- 8g, Sampling up to 1 Hz

5.2.1.3 Airborne noise

In addition to the underwater noise measurements, airborne noise measurements will be made in the vicinity of the MARMOK-A-5 and Mutriku power plant. Likewise, measurements will be made of both the background and radiated noise.

The different speed of propagation of acoustic waves in the air with respect to the water, as well as the different absorption, has implications that will affect the monitoring strategy:

- The speed of propagation of acoustic waves in air (~343 m/s) is somewhat less than a quarter 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 units). For this reason, monitoring must be carried out in the vicinity of the devices, in order to obtain measurements that are adequate. This aspect is fundamental to limit the possible impact of airborne noise.

5.2.2 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 a CTD probe, model CTD 48M (manufactured by Sea&Sun Marine Tech) for the WaveRoller measurements and a CTD SEABIRD SBE-25 (manufactured by Sea Bird Scientific) for MARMOK-A-5 and Mutriku measurements.
- **Sound velocity:** for the measurement of sound velocity, a sound profiler SVP 15 (manufactured by RESON) will be used in MARMOK-A-5 and Mutriku sites.
- **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. Due to safety reasons, field work will be planned to start with up to 1.5 m wave height. This information will be monitored in WindGuru. For the sampling period this information (with 10 minutes resolution) will be requested to the National entities responsible (Portugal: Instituto Português do Mar e da Atmosfera (IPMA), Spain: Agencia Estatal de Meteorologia (AEMet). During the sampling period regarding the empirical propagation loss experiment this information will also be recorded as Beaufort scale level.
- **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. Due to safety reasons, field work will be planned to start with up to 5.4 m/s (10 knots) wind speed. This information will be monitored in WindGuru. For the sampling period this information will be requested (with 10 minutes resolution) to the National entities responsible (Portugal: Instituto Português do Mar e da Atmosfera (IPMA), Spain: Agencia Estatal de Meteorologia (AEMet). During the sampling period regarding the empirical propagation loss experiment this information will be gathered from the anemometer (if available in the vessel) and recorded as Beaufort scale level.
- **Water depth:** this information will be collected using the echosounder of the research vessel before and after each deployment.

- **GPS location:** this will be collected using a handheld GPS Garmin GPSmap 60 CSx. Positions shall be given in WGS84 coordinates.
- **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).

5.2.3 Complementary parameters

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

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

5.3 Sampling design and methods

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 this, e.g., 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.

To cover the measurements in terms of temporal resolution and spatial resolution, the use of two different methods is proposed: a **'static measuring station'** and a **'mobile survey vessel'**.

The two proposed methods are shown in Figure 7.

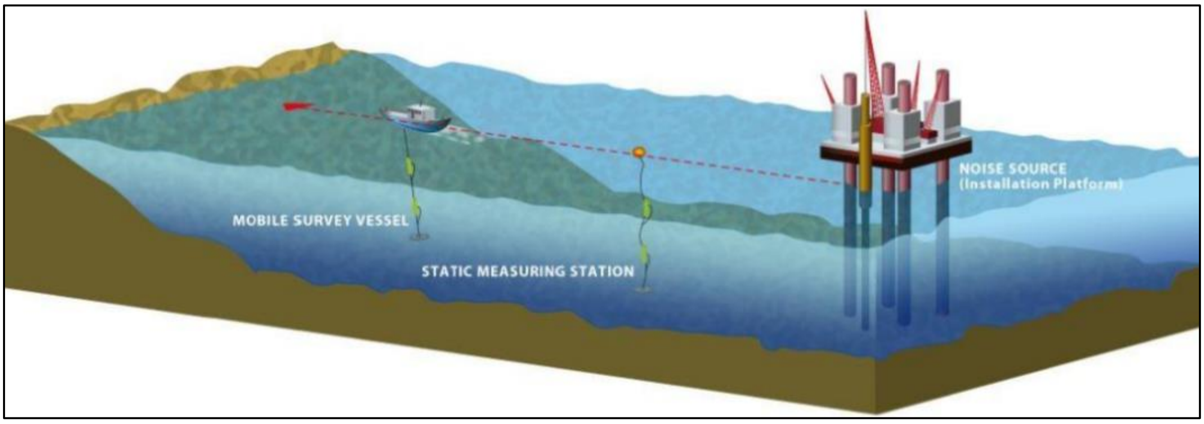

Figure 7. Scheme of the two principal measuring methods.

5.3.1 Static 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 it is sampled in a single location.

A static sampling station will be installed close to each of the three devices under study to achieve good temporal 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.

Figure 8 shows the system to be used in Peniche to measure underwater noise radiated by the WaveRoller device.

Figure 9 shows the system to be used in Mutriku and BiMEP areas. In this case, there is no surface buoy but instead an acoustic release for the recovery of the equipment due to the extreme sea conditions in the Cantabrian Sea.

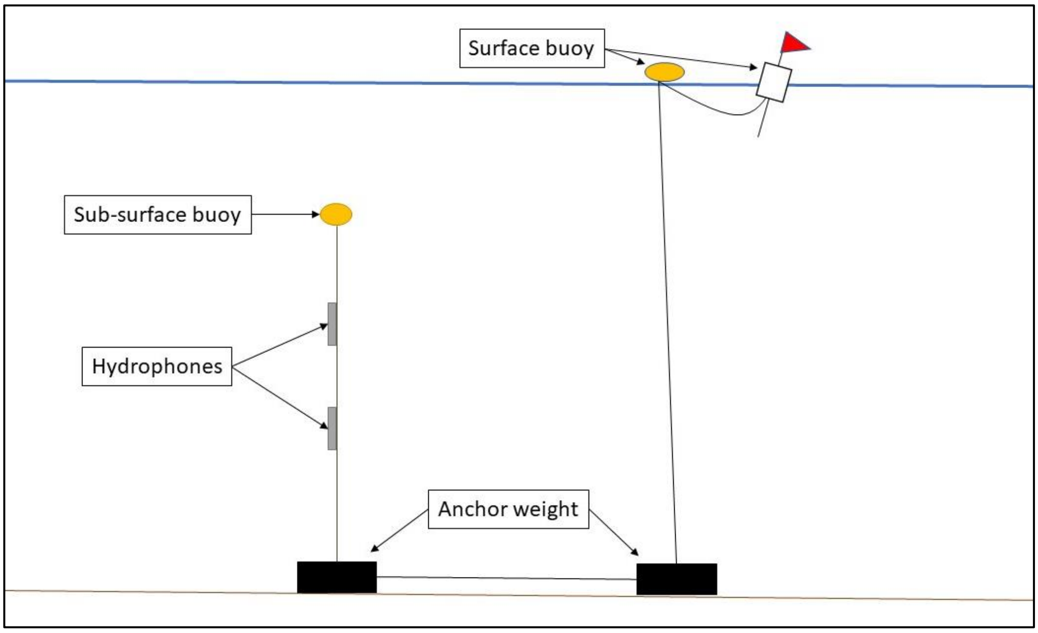

Figure 8. Bottom mounted deployment scheme at Peniche.

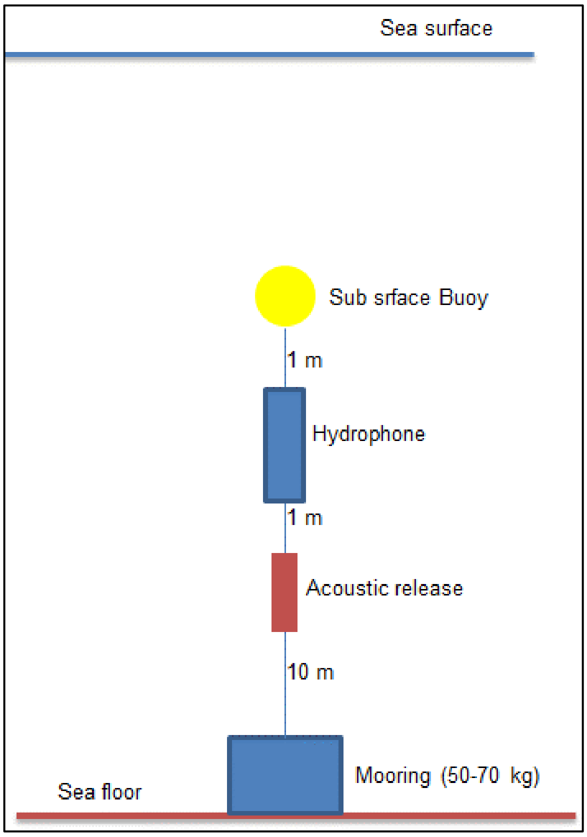

Figure 9. Bottom mounted deployment scheme at BiMEP and Mutriku.

5.3.1.1 WaveRoller – Peniche test site (Portugal)

The static measuring station will be at 100 m from the device to ensure far-field conditions (see 5.2.1.2) (Table 3; Figure 10). The hydrophone will be deployed at mid-section of the water column depth.

The hydrophone will be installed for periods of one month, in two different seasons: summer (July) and end of autumn (October).

During the sampling period the hydrophone will be recording 10 minutes every hour, selecting a sample rate of 288 kHz.

Table 3. Geographic coordinates (WGS84, decimal degrees) of the static measurements sampling station (blue circle) at the WaveRoller test site.

Location ID	Latitude (°)	Longitude (°)	Column water depth (m)
WR_SS1	39.3824	-9.3163	12

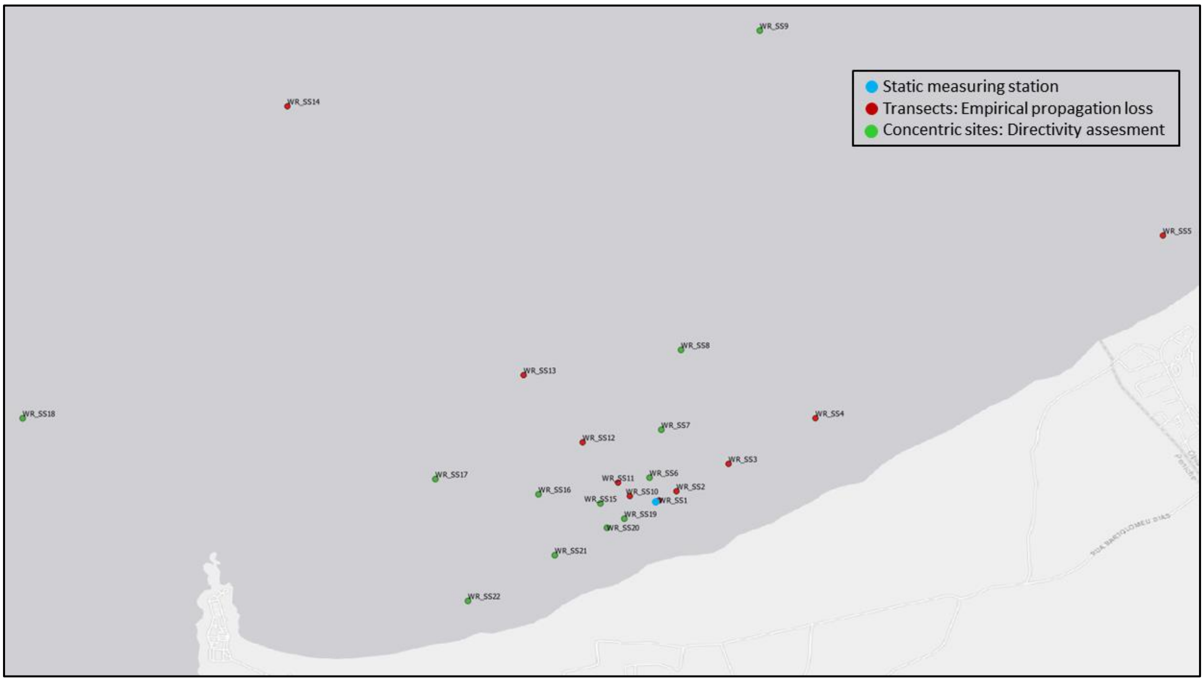

Figure 10. Sampling stations at the WaveRoller test site.

5.3.1.2 Marmok-A-5 – BiMEP test site (Spain)

The static measuring station will be at 100 m from the device to ensure far-field conditions (see 5.2.1.2) (Table 4; Figure 11). It is important to notice that the static station matches with one of the mobile locations (MA5_SS1). The hydrophone will be installed during April, for a period of one month. During the sampling period the hydrophone will be recording 10 minutes every hour, selecting a sample rate of 288 kHz.

Table 4. Geographic coordinates (WGS84, decimal degrees) for the static measurements at the Marmok-A-5 test site.

Location ID	Latitude (º)	Longitude (º)	Column water depth (m)
MA5_SS1	43.4693	-2.8327	78

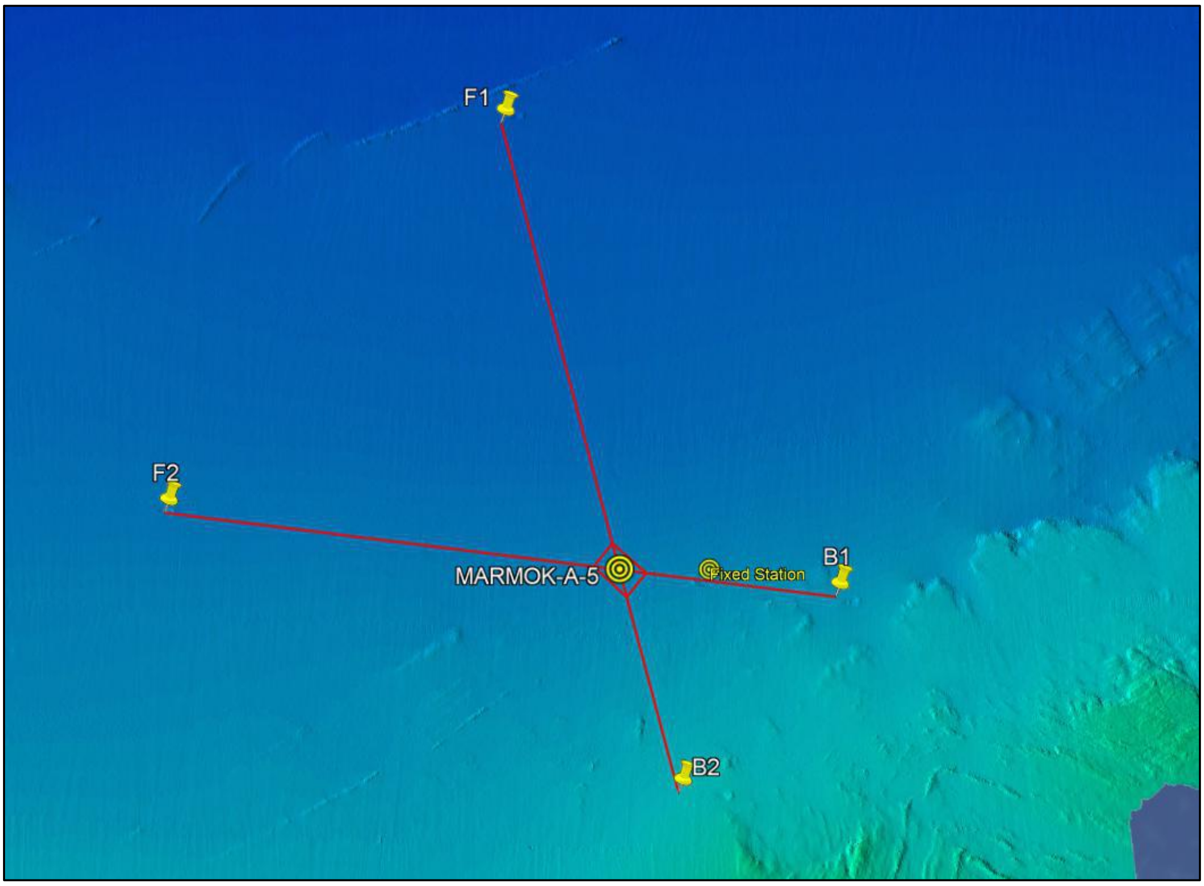

Figure 11. Static sampling (fixed) station at Marmok-A-5 test site. B1, B2, F1 and F2 corresponds to the moorings of the device. In red, the mooring lines.

5.3.1.3 Mutriku power plant – Mutriku test site (Spain)

The static measuring station will be at least 1000 m from the device in order to ensure far-field conditions and to avoid danger with the power plant. It is important to notice that the static station matches with one of the mobile locations (MT_SS12) (Figure 12).

The hydrophone will be installed for periods of one month in two different seasons: summer (July) and end of autumn (October).

During the sampling period the hydrophone will be recording 10 minutes every hour, selecting a sample rate of 288 kHz.

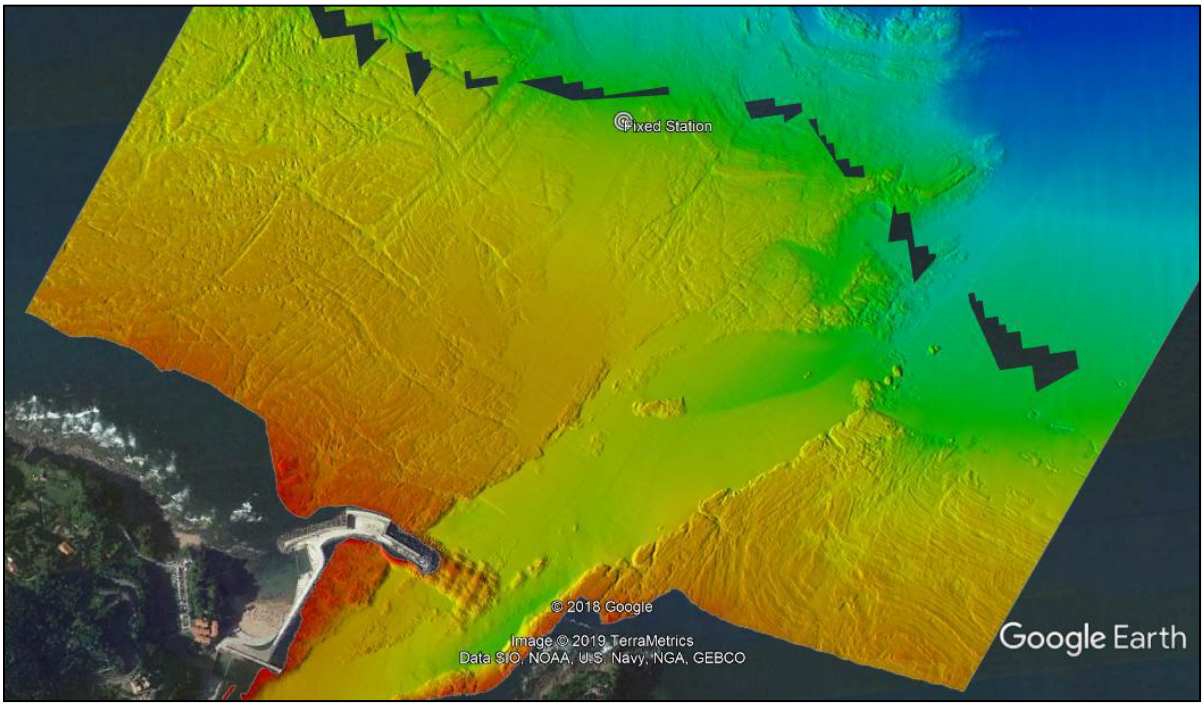

Figure 12. Static sampling (fixed) station at Mutriku test site.

5.3.2 Mobile surveys

This method is based on the passive acoustic measurements in different locations during a short period of time using a vessel. Its 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.

There will be one or more campaigns with a vessel in which measurements will be taken from different locations in a short period of time (if possible, in the same day). The main objective of these surveys is to obtain information for:

- **Empirical propagation loss:** to empirically determine the propagation loss to estimate the source level, measurements will be made as a function of distance from the source from a vessel. For this, the vessel will move along 2 linear transects away from the source, stopping to measure at different distances defined for each device. The first transect will be perpendicular to the bathymetry and the second transect will be parallel to the bathymetry.

- **Directivity assessment:** To empirically assess source directivity, underwater noise will be measured in a series of concentric locations from the source, so that the noise radiated in all directions will be covered as much as possible. Note that in many cases it will coincide with transect locations.

For the empirical propagation loss experiment a hydrophone will be deployed from the boat. The hydrophone deployment will be done according to the scheme presented in Figure 13. An elastic rope will be used to reduce the tension and vibration of the cable. The boat will be drifting during the sampling period.

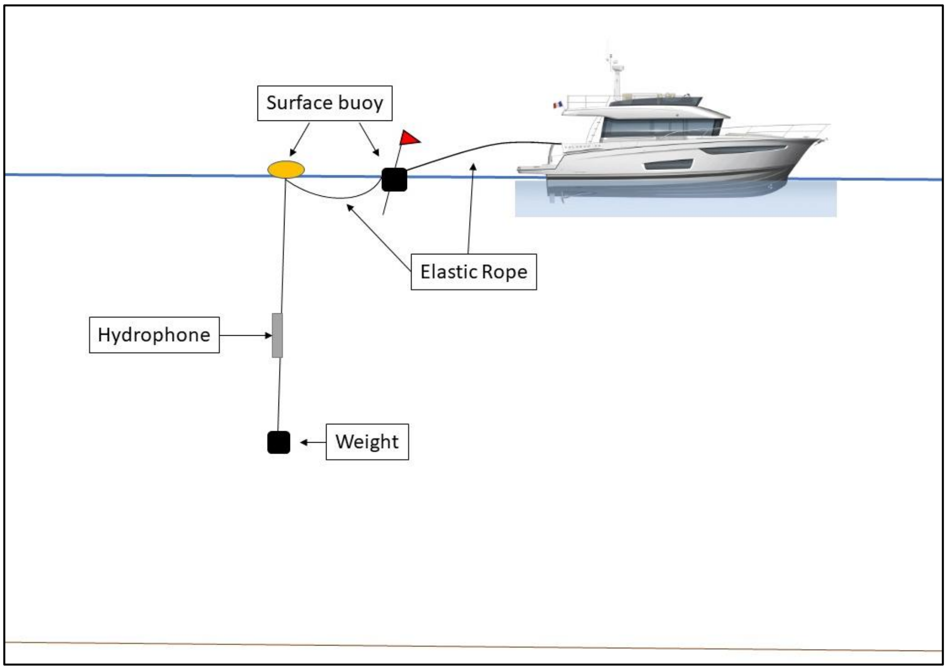

Figure 13. Deployment scheme for mobile surveys.

At each sampling station, 5 minutes of background noise will be recorded. Two replicates for each station will be considered. Each replicate will correspond to one set of sampling points, and each set will be replicated set after set. The hydrophone will be recording continuously considering a sample rate of 288 kHz, and the samples will be selected during post-processing. The sampling stations for each test site are defined below. The measurements will be taken as following:

1. Position the vessel according to the distribution of the sampling stations indicated in section 5.3.2.1 (WaveRoller), 5.3.2.2 (Marmok-A-5) and 5.3.2.3 (Mutriku power plant).
2. Carry out a CTD cast.
3. Stop the boat engines.
4. Deploy the equipment into water.
5. Record in the 'recording sheet' (Annex I) the absolute position of the measure, the start and end time and the possible incidents. The sampling period will start 1 minute after releasing the white surface buoy.

5.3.2.1 WaveRoller test site

Measurements will be taken in 22 sampling stations (Table 5; Figure 10). Due to the bathymetry of the area, all measurements will be made at -5 m depth. In this way, it is assured that the measurements are not influenced by the surface and background effects and that they are all referenced to the same depth.

The measurements will take place in two different seasons: summer (July) and autumn (October). To optimize mobilization costs the measurements will take place on the same day of the deployment and recovery of the static measurement.

Table 5. Geographic coordinates (WGS84, decimal degrees) of the sampling points for mobile measurements at the WaveRoller test site.

Location ID	Latitude (º)	Longitude (º)
WR_SS1	39.3825	-9.3163
WR_SS2	39.3829	-9.3153
WR_SS3	39.3844	-9.3125
WR_SS4	39.3869	-9.3077
WR_SS5	39.3970	-9.2884
WR_SS6	39.3836	-9.3168
WR_SS7	39.3863	-9.3162
WR_SS8	39.3907	-9.3151
WR_SS9	39.4084	-9.3107
WR_SS10	39.3826	-9.3179
WR_SS11	39.3833	-9.3186
WR_SS12	39.3856	-9.3205
WR_SS13	39.3893	-9.3238
WR_SS14	39.4042	-9.3368
WR_SS15	39.3822	-9.3195

WR_SS16	39.3827	-9.3230
WR_SS17	39.3835	-9.3287
WR_SS18	39.3869	-9.3515
WR_SS19	39.3814	-9.3182
WR_SS20	39.3808	-9.3192
WR_SS21	39.3793	-9.3221
WR_SS22	39.3768	-9.3269

5.3.2.2 Marmok-A-5 test site

Measurements will be done in 20 sampling stations (Table 6; Figure 14). Due to the bathymetry of the area, all measurements will be made at -10 m depth. In this way, it is assured that the measurements are not influenced by the surface and background effects and that they are all referenced to the same depth.

The measurements will take place during April. To optimize mobilization costs the measurements will take place on the same day of the deployment and recovery of the static measurement.

Table 6. Geographic coordinates (WGS84, decimal degrees) of the sampling points for mobile measurements at the Marmok-A-5 test site.

Location ID	Latitude (º)	Longitude (º)
MA5_SS1	43.4694	-2.8686
MA5_SS2	43.4693	-2.8624
MA5_SS3	43.4693	-2.8327
MA5_SS4	43.4713	-2.8672
MA5_SS5	43.4757	-2.8611
MA5_SS6	43.4703	-2.8698
MA5_SS7	43.4748	-2.8698
MA5_SS8	43.4964	-2.8698
MA5_SS9	43.4713	-2.8724
MA5_SS10	43.4757	-2.8785
MA5_SS11	43.4694	-2.8711
MA5_SS12	43.4694	-2.8772
MA5_SS13	43.4694	-2.9069
MA5_SS14	43.4674	-2.8724
MA5_SS15	43.4630	-2.8786
MA5_SS16	43.4685	-2.8698
MA5_SS17	43.4640	-2.8698
MA5_SS18	43.4423	-2.8699
MA5_SS19	43.4674	-2.8672

MA5_SS20	43.4630	-2.8611

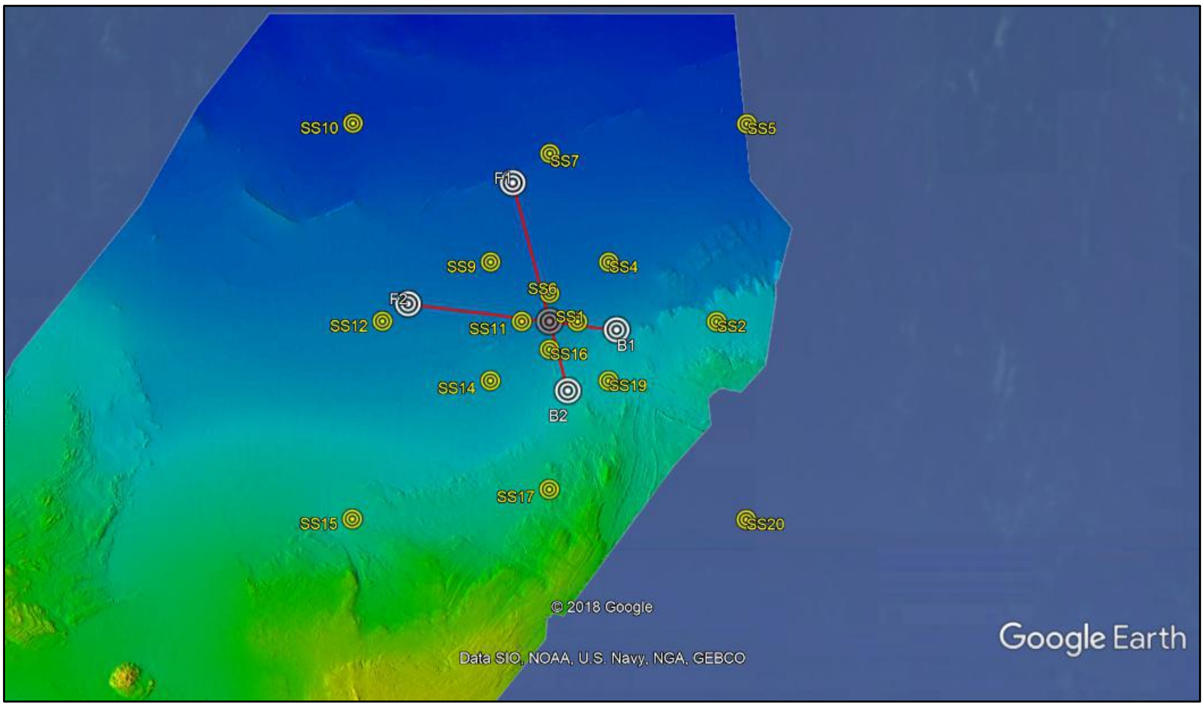

Figure 14. Mobile sampling stations for MARMOK-A-5 in BiMEP. B1, B2, F1 and F2 corresponds to the moorings of the device. In red, the mooring lines.

5.3.2.3 Mutriku power plant

Measurements will be done in 22 sampling stations (Table 7; Figure 15). The measurements will take place in two different seasons: summer (July) and autumn (October). To optimize mobilization costs the measurements will take place on the same day of the deployment and recovery of the static measurement.

Due to the bathymetry of the area, all measurements will be made at -10 m depth. In this way, it is assured that the measurements are not influenced by the surface and background effects and that they are all referenced to the same depth.

Table 7. Geographic coordinates (WGS84, decimal degrees) of the sampling points for mobile measurements at the Mutriku test site.

Sampling stations ID	Latitude (º)	Longitude (º)
MT_SS1	43.3122	-2.3757
MT_SS2	43.3117	-2.3746
MT_SS3	43.3103	-2.3715
MT_SS4	43.3080	-2.3661
MT_SS5	43.3131	-2.3744

MT_SS6	43.3137	-2.3708
MT_SS7	43.3149	-2.3648
MT_SS8	43.3194	-2.3410
MT_SS9	43.3134	-2.3761
MT_SS10	43.3142	-2.3755
MT_SS11	43.3165	-2.3737
MT_SS12	43.3204	-2.3705
MT_SS13	43.3359	-2.3580
MT_SS14	43.3144	-2.3774
MT_SS15	43.3170	-2.3783
MT_SS16	43.3213	-2.3799
MT_SS17	43.3388	-2.3861
MT_SS18	43.3131	-2.3778
MT_SS19	43.3135	-2.3789
MT_SS20	43.3149	-2.3821
MT_SS21	43.3122	-2.3757
MT_SS22	43.3117	-2.3746

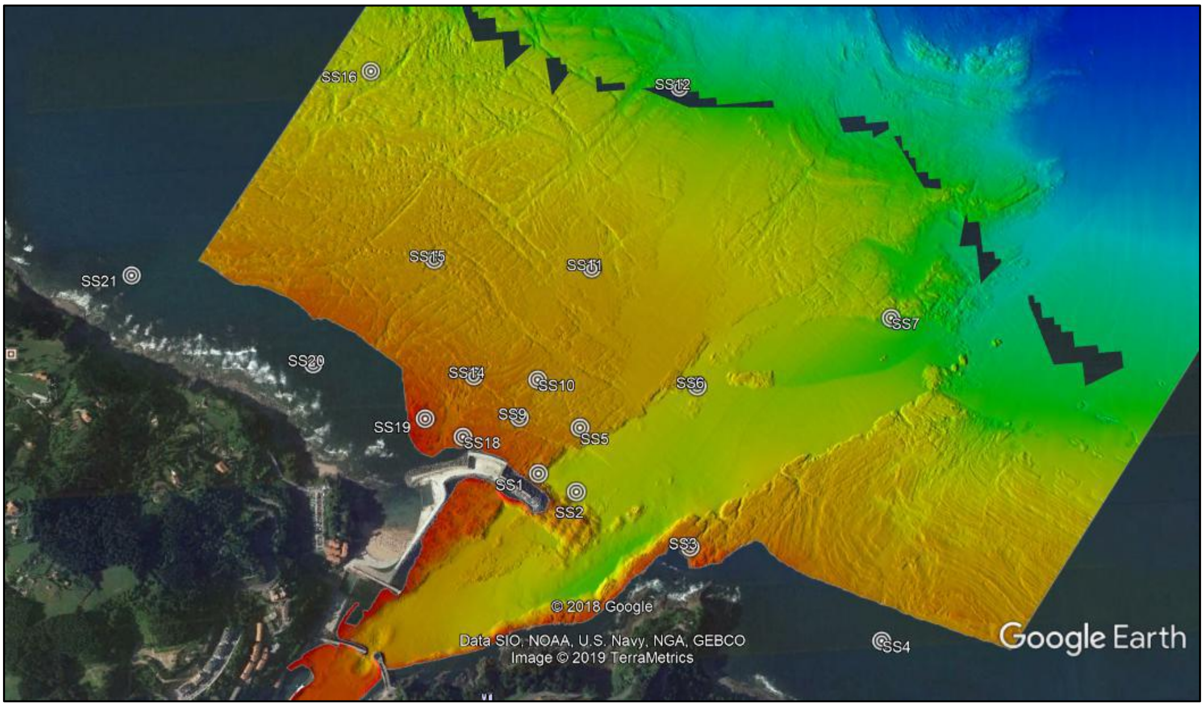

Figure 15. Mobile sampling stations for Mutriku wave power plant.

5.3.3 Airborne measurements

The measurements of airborne noise will be made with an acquisition system designed for this purpose. Basically, the system will consist of holding a microphone between 3 m and 5 m above the sea surface and performing 5 minutes recordings. This way, airborne and underwater measurements can be made simultaneously on the same vessel.

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

1. It is not practical to measure noise directly above the source, or very close to it. 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 this sense, it is unfeasible to place a fixed station for the microphone above the source;
2. The speed of sound in air is about 5 times lower than 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;
3. 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.

5.3.4 Auxiliary measurements

5.3.4.1 Conductivity, temperature and depth

During static measurements, CTD cast will take place before the deployment and after equipment recovery. From the information taken by the CTD (conductivity and temperature), density and sound speed profiles can be calculated using standard equations. In the context of the WESE project, the international standard algorithm, often known as the UNESCO algorithm (Chen and Millero, 1977), will be used[3].

5.3.4.2 GPS location

GPS positions should be stated in WGS84, in decimal degrees (minimum of four decimals). GPS locations will be collected before and after each deployment. Before the deployment it will be considered the GPS location at the time the surface yellow buoy is released. After deployment, the GPS location will correspond to the moment that the white surface buoy is collected.

[3] http://resource.npl.co.uk/acoustics/techguides/soundseawater/content.html#UNESCO, accessed on the 01/02/2019

5.4 Calibration of the equipment

To ensure that the noise measurements to be analysed are valid, the equipment to be used will be calibrated after all the campaigns been carried out. The main objectives are:

- Check that the equipment works correctly and thus validate the measurements.
- 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 16) which offers as a main service the calibration of underwater transducers according to the IEC60565 standards.

Figure 16. CTN's hydroacoustic laboratory.

5.5 Data storage

5.5.1 Acoustic data

The underwater recorders that will be used have an internal memory to store raw data. The data will be copied to a hard disk in a different folder for each campaign. Each folder should contain a text file describing its content.

5.5.2 Auxiliary data

Both CTD casts and GPS information will be stored in excel files. The files will be placed in the folder of the corresponding campaign.

5.6 Data processing

5.6.1 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. For directivity assessment and empirical propagation loss the available records will be used. In this work, both spectrograms and spectral analyses will be used to show the most relevant characteristics of the source. This information will be calculated using PAMGuide (Merchant et al., 2015). Also, the standards for signal processing resulting from the BIAS project will be considered (Betke et al., 2015).

5.6.2 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 analyses 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).

5.7 Reports

The results of the monitoring works will be presented in Deliverable 2.3.

At the end of each campaign an interim report will be prepared. These reports will not include data analysis but information about the campaigns, changes to the initial plan (if they occur) and why and how they were implemented.

6. Electromagnetic fields monitoring plan

The electromagnetic field (EMF) can be described as a physically significant field generated by an electric charge. As the name suggests, EMFs can be viewed as a combination of two individual fields, the electric field $(\vec{\boldsymbol{E}})$ and the magnetic field $(\vec{\boldsymbol{B}})$, 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 Vm^{-1}, 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 EMFs coming from natural sources and, therefore, they may also respond to EMFs 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 Thomsen et al. (2015), several steps can be taken to fill in the gaps, one of them being the development of techniques for measuring EMFs and its measurement at different sites and for different devices and cables.

The characterization of EMFs 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 8, 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 8. 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 seabed (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 seabed (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;

6.1 Magnetic Fields desk-based assessment

To propose a monitoring plan, one must estimate the EMFs characteristics at the site of measurement. This is of most importance, as the sensors must have sensitivity and frequency span capable to characterize the expected EMFs at the site.

For the purpose of this work, two main types can be distinguished:

- The ambient background EMFs;
- The EMFs generated by the submarine power cables;

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

6.1.1 Ambient electromagnetic fields

Regarding the ambient EMFs, these 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 (≈ 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. In fact, this relation is given by the following equation $\vec{E} = \vec{v} \times \vec{B}$ (Finlay 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 magnetic field).

Despite the existence of other sources (geo- and solar-related phenomena well described in Slater et al., 2010), the movement of electrically conductive seawater through the earth's magnetic field is responsible for most of the nearshore ambient EMFs. 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 even 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 (0.03 Hz to 1 Hz).

To estimate the electric fields generated by the wave motion, one must compute the water particles velocity. For very shallow waters the expressions are $\hat{u}_x = \frac{w.a}{k.d}$ for the horizontal component and $\hat{u}_z = w.a\left(1 + \frac{z}{d}\right)$ for the vertical component, 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. The depth of interest must be close to the sea bottom depth where the power cable is laid. There, the motion of water particles is very close to a flat ellipse (Figure 17). Hence, only the horizontal component will be considered.

Reciprocally, the varying electric fields induce a magnetic field as predicted by the Ampere-Maxwell law. However, these are extremely week (bellow Nano unit for our scenario). Thus, these are not considered. Table 9 summarizes the estimates of what is believed to be the most important ambient EMFs sources.

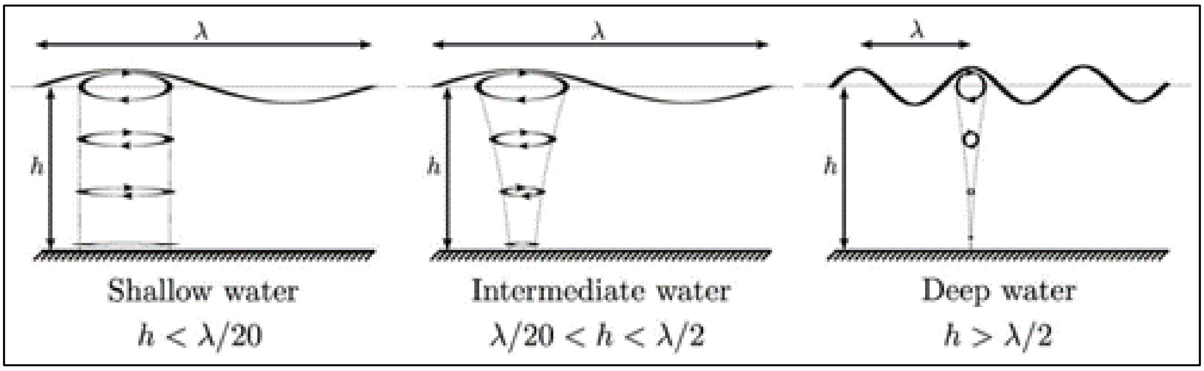

Figure 17. Representation of the motion of water particles for different depths.

Table 9. Expected range for EMFs in BiMEP (MARMOK-A-5) and Peniche (WaveRoller).

	BiMEP		Peniche	
	Amplitude	Frequency	Amplitude	Frequency
Magnetic Fields (Geomagnetic[4])	$46\,\mu T$	$0\,Hz$	$44\,\mu T$	$0\,Hz$
Electric Fields (Motion Induced[5])	$15 - 125\,\mu V/m$	$0.03 - 1\,Hz$	$14 - 120\,\mu V/m$	$0.03 - 1\,Hz$

6.1.2 Subsea power cable electromagnetic fields

Energized subsea power cables are known sources of EMFs. 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

[4] Obtained using NOAA magnetic field calculator (https://www.ngdc.noaa.gov/geomag)
[5] For motion induced calculations, we computed the velocity of water for both smooth (Hs = 0.5 m, Tp = 7 s) and rough (Hs = 4 m, Tp = 12 s) wave conditions, and assuming nearshore water depth of -5 m.

(electric potential), called electrostatic fields, and by time-varying magnetic fields, called induced electric fields. All these phenomena are 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 capacity 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 10.

Table 10. Phase current expected in BiMEP (MARMOK-A-5) and Peniche (WaveRoller).

	P Device Power	V_{LL} Transmission Voltage	I Phase Current
BIMEP (MARMOK-A-5)	30 kW	13.2 kV	1.3 A
Peniche (WaveRoller)	420 kW	10 kV	24.2 A

For this desk-based assessment, the E and B normalized curves from Slater *et al.* (2010) will be used (Figure 18). These were computed using a generic 3-phase subsea power cable with a typical cross-section layout. Although not totally accurate (e.g., cable dimensions are not the same), this approach allows for a quick assessment of the order of magnitude of the EMFs expected from both subsea cables (Table 11).

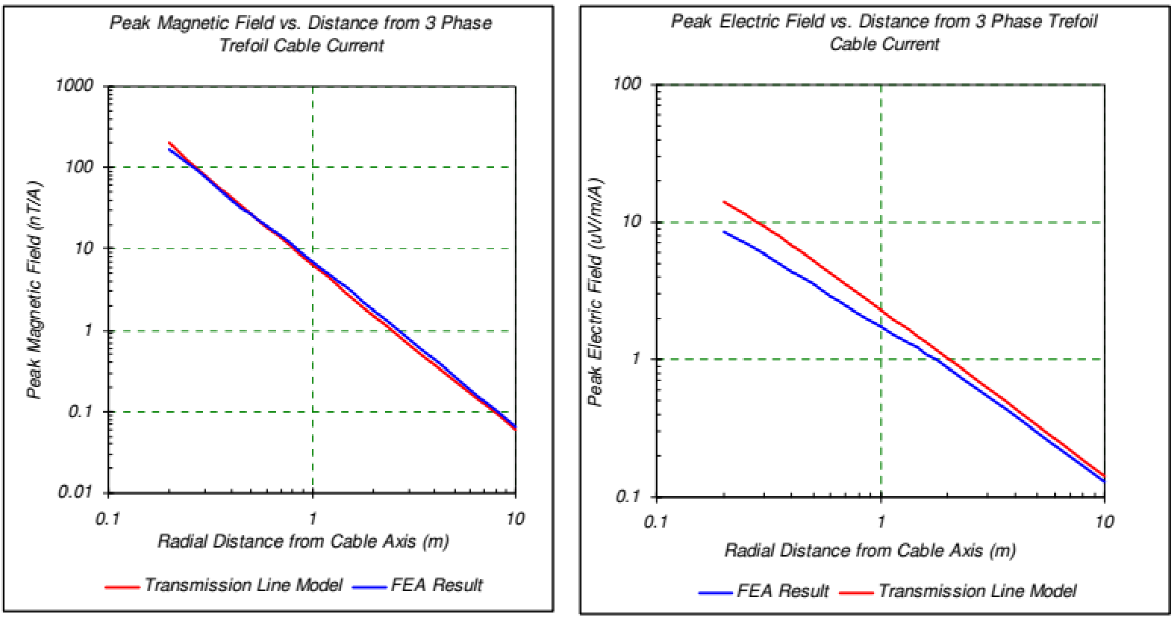

Figure 18. Normalized Electric and Magnetic fields generated by a 3-phase power cable as shown in Slater et al. (2010).

Table 11. Expected EMFs generated around Marmok-A-5 (BiMEP) and WaveRoller (Peniche) submarine cables.

	Marmok-A-5			WaveRoller		
	Amplitude		Frequency	Amplitude		Frequency
	0.2 m	10 m		0.2 m	10 m	
Magnetic Fields	$200\ nT$	$60\ pT$	$50\ Hz$	$4.8\ \mu T$	$1.4\ \mu T$	$50\ Hz$
Electric Fields	$10\ \mu V/m$	$0.15\ \mu V/m$	$50\ Hz$	$240\ \mu V/m$	$3.6\ \mu V/m$	$50\ Hz$

6.1.3 Objectives

The main objective of this monitoring plan is to provide the guidelines for the monitoring of the EMF fields of the power cables working in BiMEP (Spain) and Peniche (Portugal) sites.

6.2 Monitoring parameters and equipment

6.2.1 WaveRoller – Peniche test site (Portugal)

At the WaveRoller test site, only magnetic fields will be accessed. These are measured using magnetometers which are capable to measure the strength, frequency and direction of magnetic fields.

With regard to the minimum characteristics of the magnetic field sensor, it should be able to capture the frequency span and order of magnitudes of the signals defined in section 6.1

and compiled in Table 11. In short, the frequency span should cover from the geomagnetic DC values to the fundamental frequency of the cable current (although higher harmonics should be considered). On the dynamic range side, the sensor should be able to capture both the ambient fields and the ones produced by the energized subsea cable.

A fluxgate type sensor model Bartington Mag690 will be used to measure the magnetic fields. The specifications of the equipment are presented in Table 12. 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 (48kS/s) capable to capture both the signal frequency and noise floor required.

Table 12. Technical specification of the magnetic field sensor.

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

6.2.2 Marmok-A-5 – BiMEP test site (Spain)

In the Marmok-A-5 test site, the PASSEM system developed by MAPPEM Geophysics (http://www.mappem-geophysics.com/) will be used. The PASSEM System is one of MAPPEM Geophysics' marine electromagnetic instruments. It is dedicated to very high sensitivity passive electromagnetic measurements for the assessment of electromagnetic environments.

The PASSEM system is a towed instrument (Figure 19), including 4 channels for very high sensitivity electric field dipoles and a 3-axis fluxgate magnetometer, simultaneously recorded. Data are recorded at 2kHz. The system is also equipped with altitude and navigation sensors to recalculate its position underwater (2-axis tilt meters, pressure depth sensor and altimeter). The position of the instrument is determined from navigation sensors and from the length of the deployed cable (counting sheave). The GPS records position and time of the measurements.

The PASSEM system can measure simultaneously 4 independent electric dipoles. This feature allows having two different dipole lengths at different positions on the sensor cable (Figure 19). This geometry allows comparing data sets and helping analysis, to compare local to remote electric field sources.

Figure 20 shows the noise spectral density of the acquisition system, measured in laboratory for 1 minute. Sensitivity is therefore in the order of 1nV/vHz down to low frequencies.

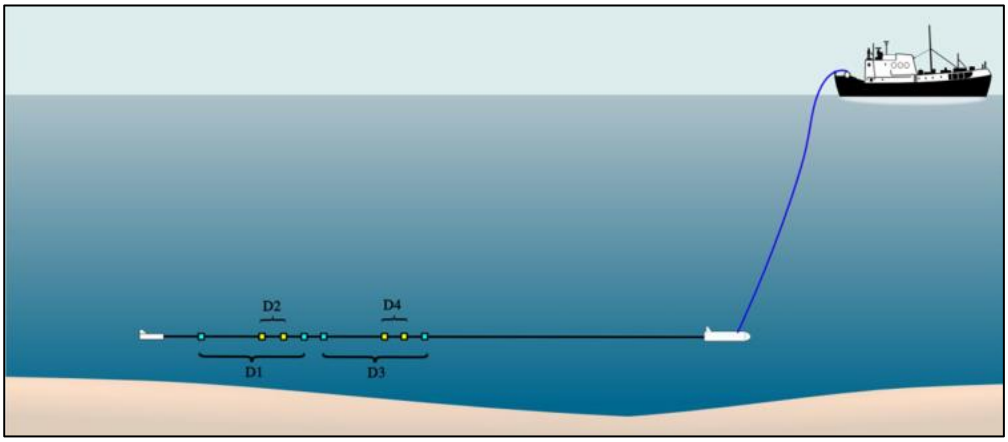

Figure 19. PASSEM schematics (D1-D4 are the electric dipoles).

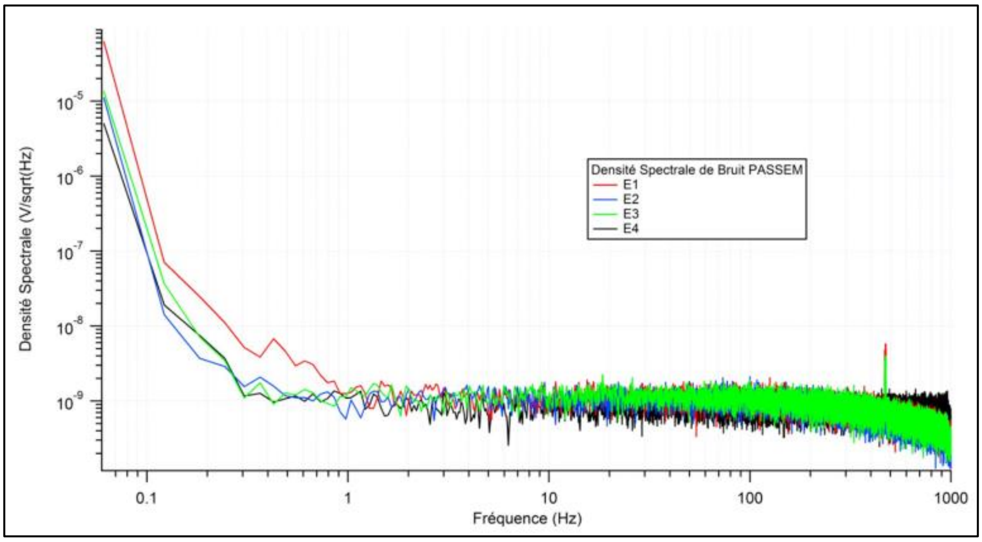

Figure 20. Electric field Noise spectral density measured in laboratory for 1minute.

The full magnetic vector is recorded via a fluxgate 3 axis magnetometer. Data are recorded simultaneously with electric dipoles. Acquisition rate is 2 kHz. The sensor is within the main instrument, then susceptible to the instrument movements due to cable traction and ship movements. Intrinsic noise of the sensor is lower than 10pT/vHz.

Data analysis show external electromagnetic signals. Signals are in mostly weak, the noise being identified as natural geo-electric signals (variations due to solar winds), signals from movement of water mass in the earth magnetic field (e.g., due to swell) and terrestrial signals like 50Hz power lines and its harmonics. In case of the presence of an electrical cable or infrastructure, signals induced by them can be seen.

Figure 21 shows an example of recorded data. The main data sources can easily be identified. First the swell, which has a powerful signal of about 0.1Hz, followed by geoelectric and equipment movement noises around 1Hz, and then Human origin signals, with sharp signals, the main being the 50Hz powerline signals and its harmonics (mainly coming from 3-phase power). Signals from cables will eventually come on top of these usual signals.

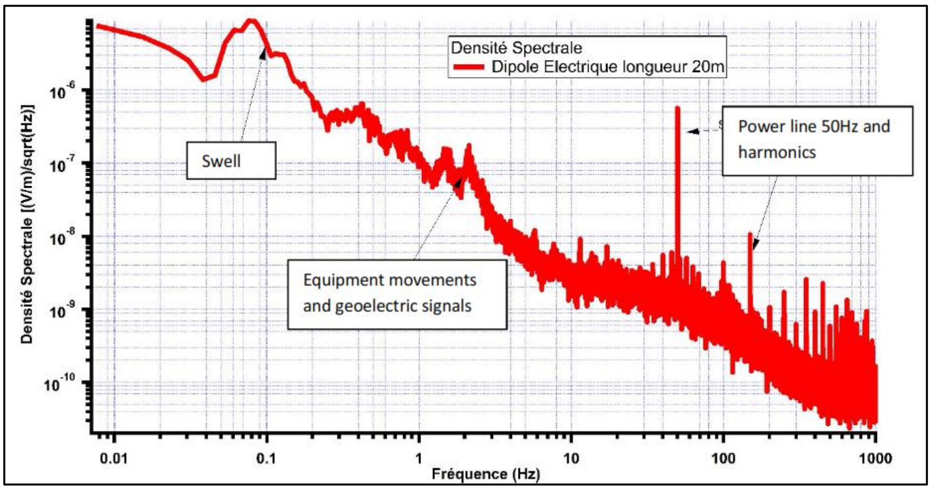

Figure 21. Simplified example of electric field spectral data.

6.3 Sampling design

6.3.1 Sampling stations

6.3.1.1 WaveRoller test site

Measurements will take place at the connecting point of the cable in the substation (sampling point 1) and along the pathway of the submarine cables (sampling stations 2, 3 and 4) (Table 13; Figure 22). At each sampling point, 5 replicate samples will be taken. Measurements will only be taken onshore, as the magnetic permeability of air and water is identical. Additionally, at each sampling station perpendicular measurements at 0.5 m and 5 m distance will be taken.

Table 13. Geographic coordinates (WGS84, decimal degrees) of the sampling points for EMFs measurements at the WaveRoller test site.

Sampling stations ID	Latitude (°)	Longitude (°)
2	-9.3027	39.3833
3	-9.3030	39.3838
4	-9.3034	39.3843

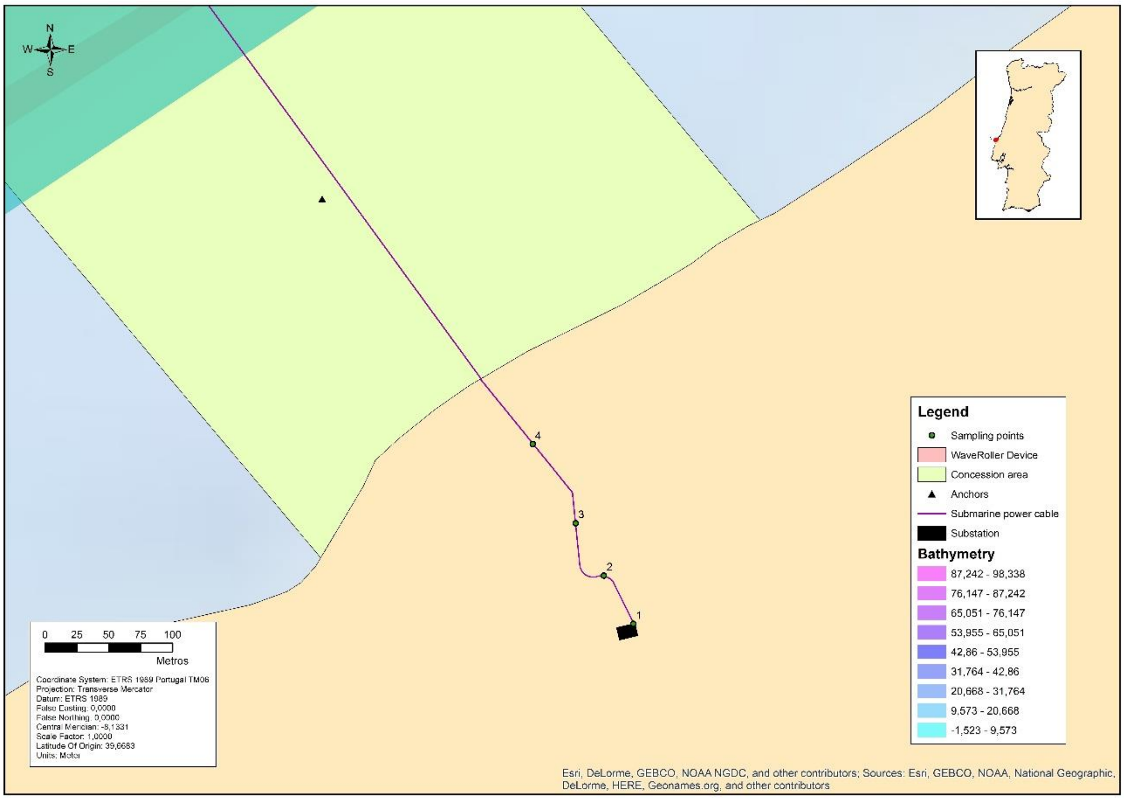

Figure 22. Sampling stations for magnetic fields at the WaveRoller test site.

6.3.1.2 Marmok-A-5 (BiMEP) test site

The PASSEM system will continuously record the EMFs along different profiles in the area, and the electric field in one location in the vicinity of the vertical cable in the water column, next to the WEC installed in BiMEP. As the system is towed, the large zone can be surveyed rapidly. The main profiles will be distributed along the bathymetry to be able to stay close to the seabed (parallel to the bathymetry lines and perpendicular to the cables).

The power delivered by the power generator is alternative current at 50Hz. Therefore, these signals will add to the signals coming from the land-based installations. As no survey could be done to record the 'zero state' prior to the deployment of the WEC, part of the survey time will be dedicated to record the background signals at some distance from the WEC.

Then, lines crossing the power export cable will be recorded, at a minimum of 5 different locations along the cable.

6.3.2 Sampling period and frequency

6.3.2.1 WaveRoller test site

Measurements will take place before the installation and during the operation phase of the WaveRoller. Field work will be as much as possible aligned with the schedule for acoustic or seabed integrity monitoring. To capture magnetic fields from different cable currents, measurements will take place with different operational sea-states. Each measurement will last 10 minutes, correlated as far as possible with the cable current instant values.

6.3.2.2 Marmok-A-5 (BiMEP) test site

Measurements will take place during the operation phase of the Marmok-A-5 device. Field work will be as much as possible aligned with the schedule for acoustic or seabed integrity monitoring. The sampling campaign will last one day.

6.4 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. These features are all present in the SCU1 signal conditioning unit.

The output from all fluxgate sensors will contain noise from the driving electronics. For the Mag690 this noise is at 15 kHz, which is well above the bandwidth of the sensors. 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 15kHz excitation with the sampling clock of the digitizer.

The level of unwanted breakthrough at 15kHz 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 surveillance and 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 between 0.01 and 10Hz, and a band pass filter can be used to provide the required signal.

The Magmeter and PSU1 power supply units, which can be used with all sensors, contain three low pass filters with a -3 dB point at 4.5 kHz together with three high pass filters with a -3 dB point at 0.1 Hz.

The SCU1 signal conditioning unit provides filters with independent control of the low and high pass filter sections, together with offset and gain control for the output of each axis.

6.5 Reports

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

7. Seabed integrity monitoring plan

7.1 Objectives

The main objective of this monitoring plan is to provide the guidelines for the monitoring of seabed integrity in the areas of the WECs under study, namely addressing the physical changes that can be expected due to the addition of gravity foundations, piles or anchors, as well as the sweep of mooring lines, cables and mechanical moving parts and the consequent impacts over benthic (bottom) habitats.

7.2 Previous work

7.2.1 WaveRoller – Peniche test site (Portugal)

Regarding seabed monitoring, within the SURGE project, a baseline survey of the habitats and benthic communities in the WaveRoller area was undertaken in 2013, both by means of grab sampling and video imaging with a Remote Operated Vehicle (ROV).

During the four years of SURGE project, the WaveRoller device was deployed twice totalling six weeks at sea. The short deployment period made difficult to assess the impacts of the WaveRoller device on the bottom habitats and benthic communities but allowed to improve the understanding of those seabed attributes in the WaveRoller area.

The abiotic factors such as temperature and wave dynamics were likely to be the most important factors affecting the composition and distribution of benthic assemblages, which registered low biodiversity and similar distributions across the sampling stations and over time.

The ROV survey showed similar results as the grab sampling and additionally found rocky outcrops with higher biodiversity and biomass than the surrounding sandy substrate, densely covered by epibenthic fauna and dominated by *Sabellaria alveolata* biogenic reef (EUNIS habitat A5.61: Sublittoral polychaete worm reefs on sediment) (https://eunis.eea.europa.eu/).

No critical factors were found that could affect the deployment of the WaveRoller device.

7.2.2 Marmok-A-5 – BiMEP test site (Spain)

There are several studies carried out before the installation of the MARMOK-A-5 in the BiMEP area, including ROV surveys in June 2012 and December 2013, and grab samples in October 2012 and May 2014 (unpublished data), which could be used as a baseline.

In such studies, several benthic EUNIS habitats (https://eunis.eea.europa.eu/) were identified:

- A3: Infralittoral rock and other hard substrata
- A4: Circalittoral rock and other hard substrata
- A5.14: Circalittoral coarse sediment
    - A5.142: *Mediomastus fragilis*, *Lumbrineris* spp. and venerid bivalves in circalittoral coarse sand or gravel
    - A5.145: *Branchiostoma lanceolatum* in circalittoral coarse sand with shell gravel
- A5.45: Deep circalittoral mixed sediments
    - A5.451: Polychaete-rich deep Venus community in offshore mixed sediments.

Most of the study area is probably populated by the A5.451 community, with a mosaic of rocky outcrops and coarse sediment beds that accommodate the remainder of the abovementioned assemblages. The characterization undertaken highlighted the high biological value of the communities associated to the abovementioned outcrops, which should be avoided when installing the moorings.

7.3 Monitoring parameters and equipment

The monitoring includes the inspection of the sea bottom around moorings and mooring lines to evaluate the footprint associated with the possible dragging or chafing effect of materials such as chains, wires, ropes or cables across the seabed. Another effect derived from moorings involves the artificialization of substratum. If anchor points are mainly located on sedimentary bottoms, an accumulation of anchors may lead to a significant change in proportion of hard/soft substratum in the installation area.

The monitoring will be done by means of two techniques: (i) visual inspection with a ROV and (ii) Side Scan Sonar characterization of the seabed. Together with the existing information from previous works (see Section 7.2) this monitoring will allow to identify changes in seafloor characteristics associated with the pressures described above.

Table 14 describes the parameters to be monitored and the source of their information. Table 15. List of equipment needed/available from the WESE members. describes the equipment available from each WESE partner to assess the different parameters.

Table 14. Monitoring parameters and sources of information.

Parameters	Feature	Source of information	Complementary parameters	Source of information
Habitat	Habitat type e.g., Sand-bottom, rocky-bottom, biogenic	- ROV sampling - Side Scan Sonar sampling	- Type of sea-bottom - Bathymetry	- *In situ* measurement

Table 15. List of equipment needed/available from the WESE members.

	Habitat and Benthic Communities	Statistical Analysis
AZTI	ArcGIS ROV SEAEYE Falcon DR (rented) Side Scan Sonar (rented)	Canoco for Windows 4.5 CanoDraw for Windows PASW Statistics 17 PRIMER 6 WinTWINS 2.3
WavEC	ArcGIS ROV Seabotix LBV200-4 HD GoPro 4 camera	PRIMER 6 + PERMANOVA Minitab 18

7.4 Sampling design

7.4.1 Sampling methods

A non-destructive method using video techniques by means of a ROV and Side Scan Sonar measurements will be used. Both techniques are advantageous, e.g., by allowing to quickly inspect large areas of the seabed (providing the data necessary for the characterization and identification of benthic habitats (e.g., sandy-bottom, hard-bottom, biogenic) without depth restrictions, in a less expensive and less time-consuming process.

7.4.1.1 WaveRoller – Peniche test site (Portugal)

In Peniche (WaveRoller), 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. The ROV includes a laser scaling system (two red laser dots 5 cm apart) which allows scaling the images, and a small grabber to perform simple underwater operations. It is equipped with a 200 m cable being able to dive down to -120 m depth and can be operated from virtually any structure (e.g., platform, vessel).

Sampling with the ROV will be done along 7 transects (of 100 m) taking the depth gradient and the main currents of the location into account: 6 transects in the adjacent areas of the WaveRoller device and 1 transect along the submarine cable (Table 16; Figure 23). The aim is to assess changes in the seabed morphology in the area caused by the WaveRoller and by the submarine cable.

Sampling should be done with a fixed heading both perpendicular and parallel to the coastline, and at a speed as constant as possible and below 0.25 ms^{-1} (= 0.5 knots) to avoid image blurring.

Table 16. Geographic coordinates (WGS84, decimal degrees) of the sampling points for ROV sampling at the WaveRoller test site.

Sampling stations ID	Latitude (°)	Longitude (°)
#1	39.3873	-9.3088
#2	39.3889	-9.3087
#3	39.3885	-9.3092
#4	39.3889	-9.3071
#5	39.3896	-9.3087
#6	39.3899	-9.3091
#7	39.3897	-9.3072

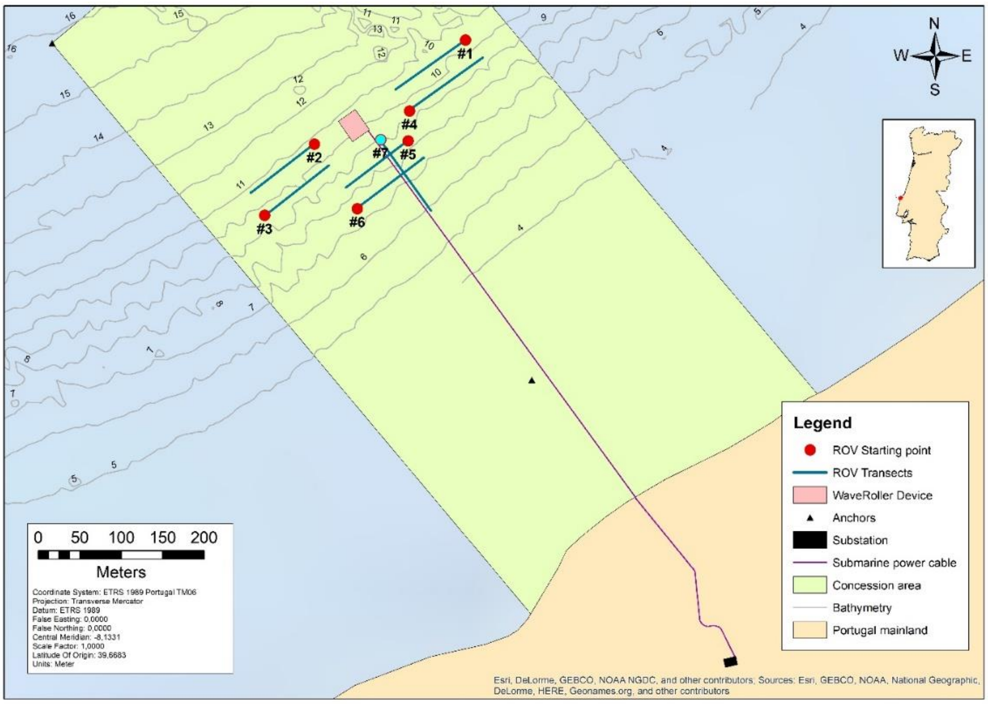

Figure 23. Sampling stations for ROV sampling at WaveRoller deployment and surrounding areas.

7.4.1.2 Marmok-A-5 – BiMEP test site (Spain)

In BiMEP (Marmok-A-5), similarly to the WaveRoller test site, video sampling will be performed using a SEAEYE Falcon DR ROV equipped with two video cameras: an onboard camera used for navigation and a full HD camera with a resolution of 1920×1080 px at a 16 Mbit/s bit rate for video sampling. The ROV includes a laser system which allows scaling the images, a manipulator system capable of lifting 10 kg that allows taking some samples, an acoustic tracking system to calculate the position of the ROV relative to the vessel, an altimeter to measure the altitude of the ROV above the seafloor and a sonar that allows to scan the surroundings of the ROV looking for outcrops. It can operate at a maximum of 1000 m water depth, although it is equipped with a 300 m cable.

The ROV will be used to monitor the areas where the moorings and mooring lines of the MARMOK-A-5 device are installed, and the areas where electric cables and connectors that provide service to the MARMOK-A-5 device are installed.

For comparison purposes, the surrounding area (not affected by the movement of moorings and dynamic cables) will be also recorded. Sampling will be done at a lower speed as possible, but pictures will also be taken to facilitate the identification of some organisms.

Videos up to 3 min 30 s will be recorded at each site.

Together with the video techniques described above, a side scan sonar characterization of the sea bottom will be undertaken with a GeoAcoustics de 100/410 kHz profiler (Figure 24). This characterization will be done around the mooring, mooring lines and cables providing service to the MARMOK-A-5 device. The position of the side scan sonar will be examined by means of a GPS TRIMBLE 850 SPS connected to a USBL transponder and a laptop with the software HYPACK2017.

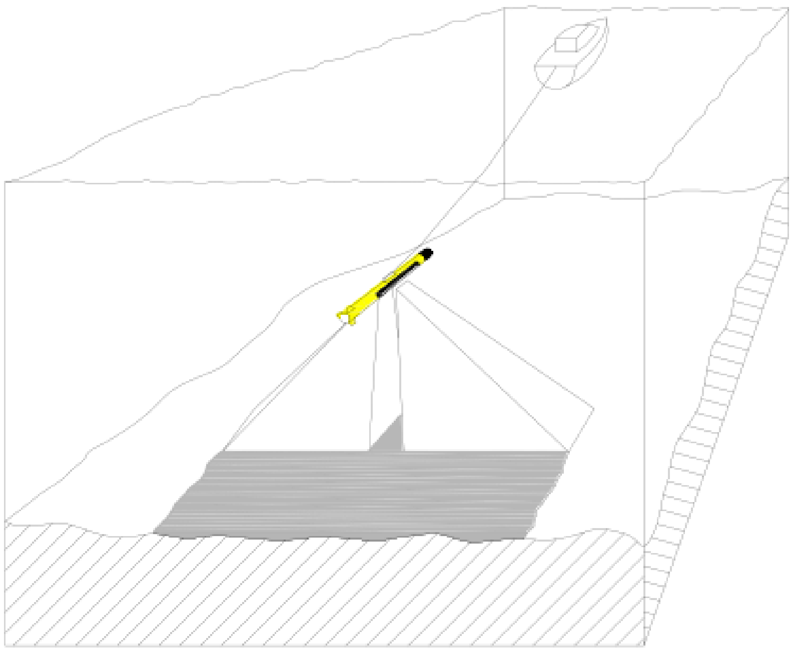

Figure 24. Side Scan sonar acquisition method.

7.4.2 Sampling effort and sea conditions

The ROV sampling should be undertaken after allowing minimal time for potential changes in the seabed to be observed. The WaveRoller system is expected to be deployed at sea during October 2019. One monitoring campaign will be performed during the spring-summer period of 2020.

The Marmok-A-5 device will be decommissioned during May 2019. Hence, the monitoring campaign in Armintza will be undertaken during April or May 2019.

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.

Annex II presents the ROV dive log sheet to be filled for each sampling campaign.

7.5 Data analysis

7.5.1 Video imaging analysis

Video and Side Scan Sonar images will be pre-processed to exclude unnecessary/unsuitable images or videos. The objective of the analysis will be to identify the footprint in m^2 generated by moorings and mooring lines over the surrounding sediments and consequently to infer about the possible impact over benthic habitats.

7.6 Reports

The results from the WaveRoller and Marmok-A-5 monitoring campaigns will be presented in Deliverable 2.4, together with a review of all monitoring work performed (including deviations to the plan).

8. References

Betke K., Folegot T., Matuschek R., Pajala J., Persson L., Tegowski J., Tougaard J., Wahlberg M., 2015. BIAS Standards for Signal Processing. Aims, Processes and Recommendations. Amended version. Eds.: Verfuß U.K., Sigray P., 28 pp.

Cruz E., Simas T., Kasanen E., 2015. Discussion of the effects of the underwater noise radiated by a wave energy device - Portugal. Proceedings of the 11th EWTEC – European Wave and Tidal Energy Conference, Nantes, France, p. 09C3-3-3.

Finlay C.C., Maus S., Beggan C.D., Bondar T.N., Chambodut A., Chernova T.A., Chulliat A., Golovkov V.P., Hamilton B., Hamoudi M., Holme R., Hulot G., Kuang W., Langlais B., Lesur V., Lowes F.J., Lühr H., Macmillan S., Mandea M., McLean S., Manoj C., Menvielle M., Michaelis I., Olsen N., Rauberg J., Rother M., Sabaka T.J., Tangborn A., Tøffner-Clausen L., Thébault E., Thomson A.W., Wardinski I., Wei Z., Zvereva T.I., 2010. International Geomagnetic Reference Field: the eleventh generation. Geophysical Journal International 183(3), p. 1216-1230.

HD – Habitats Directive, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Union, L206, p. 7-50.

Merchant N., Fristrup K., Johnson M., Tyack P., Witt M., Blondel P., Parks S., 2015. Measuring acoustic habitats. Methods in ecology and evolution 6(3), p. 257-265.

MSFD – Marine Strategy Framework Directive, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community actions in the field of marine environmental policy. Official Journal of the European Union, L164, p. 19-40.

Robinson S.P., Lepper P.A., Hazelwood R.A., 2014. Good Practice Guide for Underwater Noise Measurement (NPL Good Practice Guide No. 133). Teddington, England, National Measurement Office, Marine Scotland, The Crown Estate, 95 pp.

Slater M., Schultz A., Jones R., 2010. Estimated ambient electromagnetic field strength in Oregon's coastal environment. Report prepared to Oregon Wave Energy Trust, 26 pp.

Walsh J., Bashir I., Garrett J., Thies P., Blondel P., Johanning L., 2017. Monitoring condition of Marine Renewable Energy Devices through underwater Acoustic Emissions: case study of a Wave Energy Converter in Falmouth Bay, UK. Renewable Energy 102(Part A), p. 205-213.

9. Annex I. 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)	Latitude	Longitude	Water column depth (m)	Hydrophone Depth (m)	Wind speed (knots)	Sea-state (Beaufort scale)	Other sources of noise

10. Annex II. ROV sampling dive log sheet.

Mission name			
ROV Operator(s)			
Date		Location	
Purpose of dive			
Conditions			
Weather		Waves	
Bottom type		Current speed	
Additional notes			
No. of Dives		Video(s) ID(s)	
GoPro videos ID(s)			
Start time		End time	
Total time:		Max tether used	
Sensors/manipulators used		Max Depth	
Comments			

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