WESE

WAVE ENERGY IN SOUTHERN EUROPE

DELIVERABLE 3.4 (Synthesis of knowledge acquired and gap analysis)

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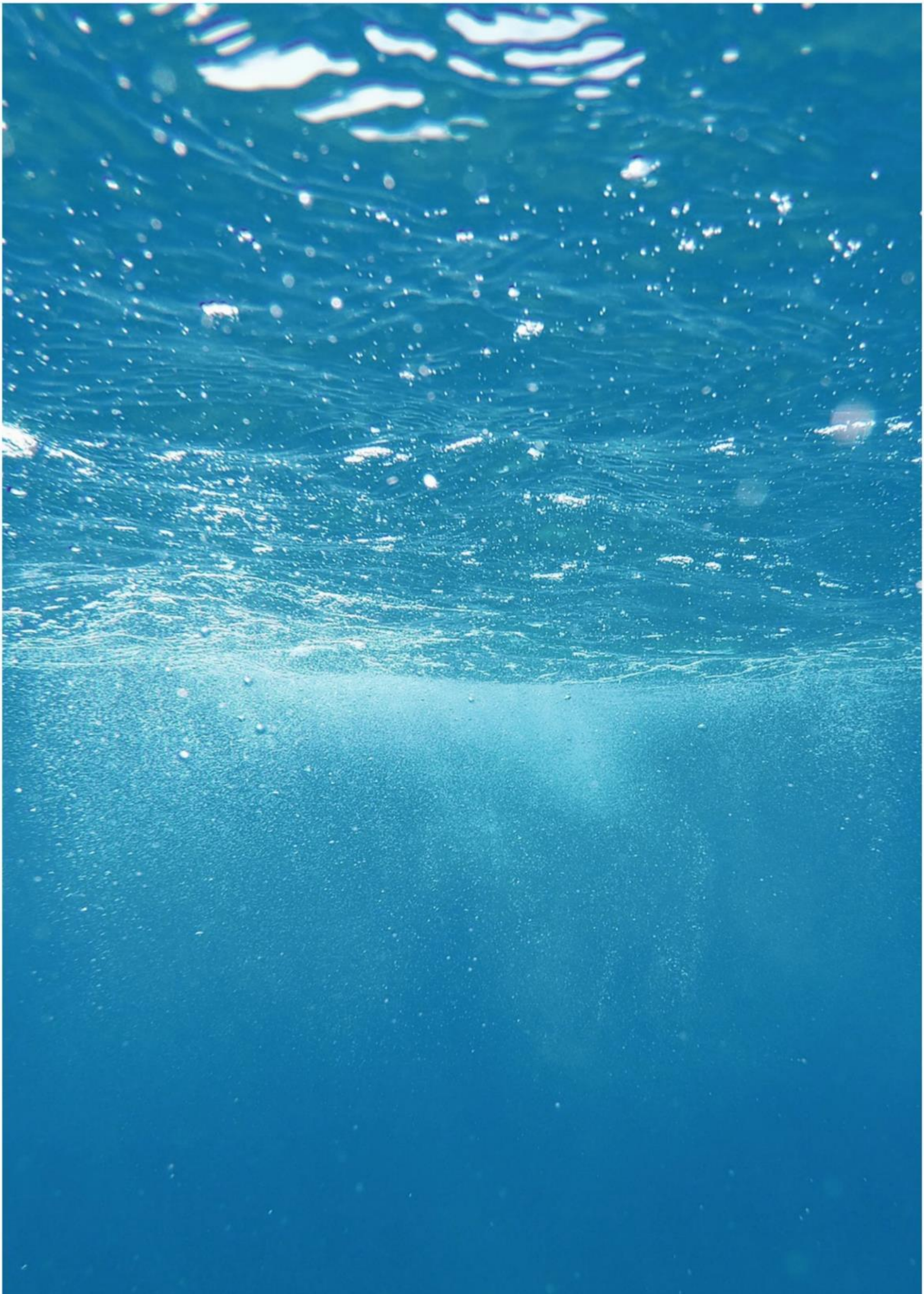

WP 3

Deliverable 3.4 (Synthesis of knowledge acquired and gap analysis)

PROJECT COORDINATOR

AZTI

TASK LEADER

CTN

AUTHORS

Eduardo Madrid Navarro (CTN)

Iñaki de Santiago (AZTI)

Theo Moura (HIDROMOD)

Paulo Chainho (WAVEC)

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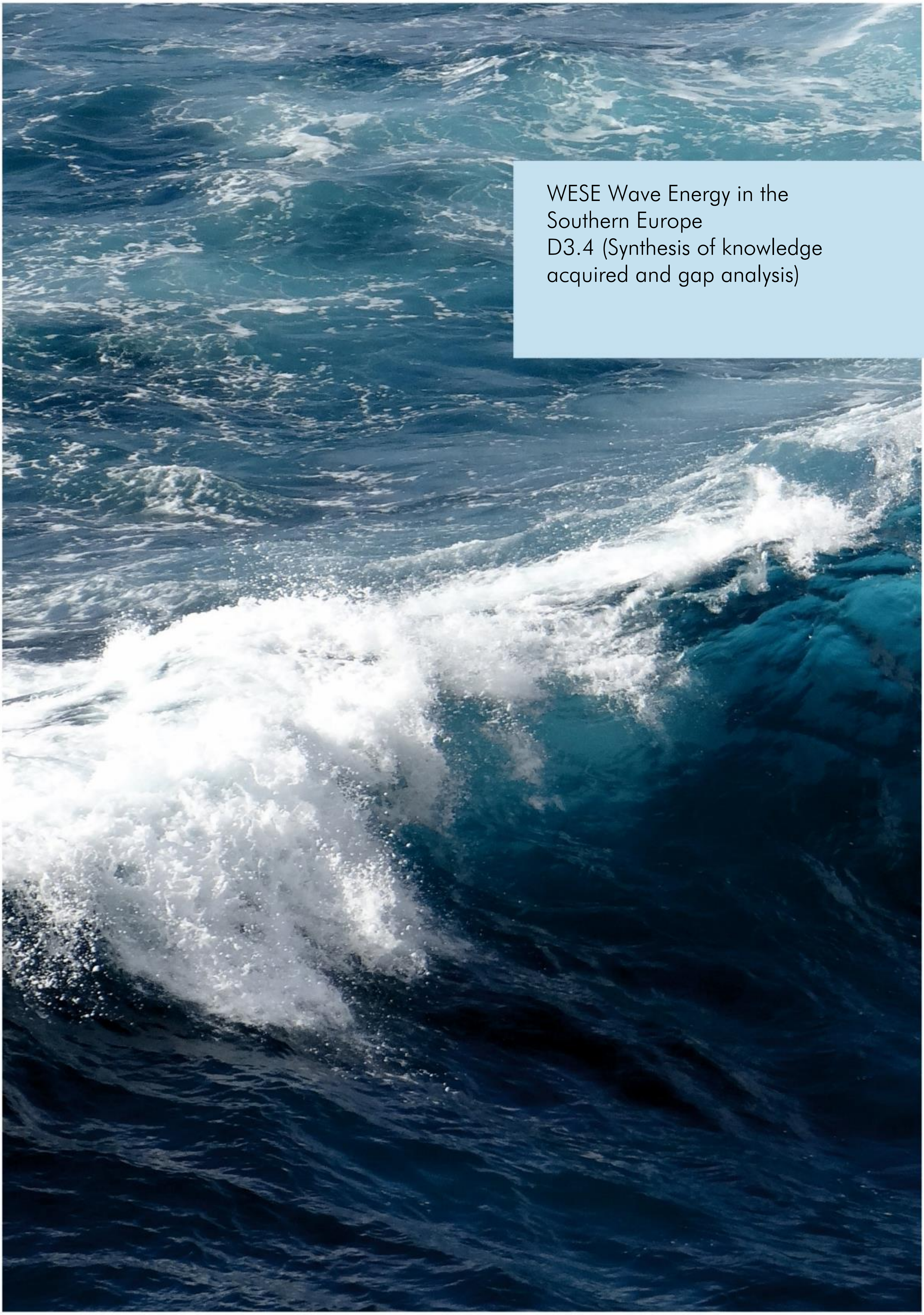

WESE Wave Energy in the Southern Europe
D3.4 (Synthesis of knowledge acquired and gap analysis)

CONTENTS

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 still 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 of overcoming these non-technological barriers through the following specific objectives:

- 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.
- 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.

- 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;
- 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 iii);
- 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 this report, the works carried out in Task 3.4, in which the main conclusions derived from the modelling of electromagnetic fields, underwater noise, and marine dynamics, as well as the identified problems encountered during their implementation, are presented.

- Electromagnetic fields
    - No significative EM disturbances related to MARMOK-A-5 and WaveRoller operation are found from the simulations, due to the low current (and coating) of the cables.

- Underwater noise
    - For MARMOK-A-5, low acoustics perturbances could be observed (compared to background noise levels) in the 62.5 Hz band, up to around 200 meters distance from the device for low wave heights; for other conditions this disturbance distance is even lower.
    - For Mutriku power plant, no significative noise could be detected, and thus no SPL distributions could be computed.

- Marine dynamics
    - For a series of arrays of up to 80 MARMOK-A-5 devices, limited impact due to its operation can be observed in both shoreline and energy loss, mostly due to the long distance between such arrays and the coast.
    - The addition of an array of 17 WaveRoller devices (Peniche) seem to imply no significant sediment exchange between long-shore areas, neither effect on wave direction nor its spreading. Presenting seasonal variability, significant wave height is reduced in the shaded zone around 10% (winter) and 20% (summer).

3. Introduction

The work package (WP) within which this deliverable is framed (WP3) consists of modelling tasks in three of the main possible impacts of WEC technology: electromagnetic fields, underwater acoustics, and marine dynamics. Thus, it could be seen as the most technical WP of the project, and as such, it is no surprise that some problems may arise in the execution of these tasks, as well as gaps that prevent from obtaining more precise, realiable results. For this reason, adding a gap analysis was was considered to be useful to future projects related to assessment of WEC-related pressures in the environment.

The term gap analysis comes from the business context and could be defined in the scope of this WP as an examination and assessment of the current state of some component of a modelling activity in relation to its desired state (to be achieved) in further research. It allows to identify and separate distinct barriers identified, and subsequently pinpoint the needed measures to overcome them.

As a remainder, WESE project involves three different WECs: MARMOK-A-5 (installed in BiMEP test site, Spain), Mutriku power plant (Mutriku, Spain), and WaveRoller (Peniche, Portugal). Both MARMOK-A-5 and Mutriku power plant could be considered oscillating water column (OWC) converters, off-shore and onshore, respectively. The modelling activities therefore concern the most significant impacts of such devices, as was foreshadowed in the work undertaken in the previous work package (WP2).

In this sense, this WP builds on the knowledge gained in the implementation of WP2, which allowed to gather input data to some of the applied models in these tasks. The modelling activities were carried out using open-source programs and state-of-the-art models.

Furthermore, a synthesis of the acquired knowledge in every activity is presented. For more specific information about this and the methodology used in every case, please refer to deliverables D3.1 [1], D3.2 [2], and D3.3 [3].

4. Electromagnetic field modelling

In this first section, we examine the main results, problems, and gaps identified from the work carried out in Task 3.1 EMF Modelling. The main electromagnetic fields (i.e. relatively strongest) produced by the WECs appear in the submarine power cables that transmit current between the devices and the (on-land) electric grid. Thus, as Mutriku Power Plant does not have cables of these characteristics, the modelling was done for MARMOK-A-5 and WaveRoller device.

In addition, although data gathered from field monitoring (T2.2) was planned to validate and inform these modelling activities, no actual data of enough quality could be obtained for several reasons (described in Deliverable 2.2 [4]). For this reason, the validation of the simulations will be assessed using data from another similar project: the Oregon Wave Energy Trust [5], henceforth referenced as Oregon study.

4.1 Synthesis of acquired knowledge

Introduction

As with most work done in modelling in this project, EMF modelling was performed by means of open-source software: for EMF specifically, Python and its version of the Finite Element Method Magnetics (pyFEMM [6]) version library were employed.

In few words, EMF modelling consists in solving (some of) the Maxwell Equations with more or less complicated boundary conditions, in this case by means of the finite element method.

What has been done?

By using the actual cables characteristics and the phase currents produced at rated power of the devices, intensities of electric and magnetic fields have been computed for both MARMOK-A-5 and WaveRoller scenarios. Moreover, as these magnitudes are linearly dependent on the current, they can be expressed as

Acquired knowledge

Overall, EMF impact is very low, as evidenced in the results that follow. For a reference value, typical values of Earth's average electric and magnetic fields on its surface are 100 V/m [7] and 25-65 μT [8], respectively.

The rather small EMF impact can be attributed to the small cable currents, or in other words, to the cables being oversized for the power capacity of the devices studied.

- MARMOK-A-5
  - At rated power and assuming power factor equal to one (equivalent to a current equal to 1.3 A), magnetic flux density ranges from 0.40 μT (close to the surface of the cable) to 0.008 μT (1 meter away- perpendicularly), decaying in an exponential fashion. In a similar way, the electric field ranges from 13 μV/m to 2 μV/m, respectively.
  - This cable maximum current capacity[1] (422 A) would imply EMF levels around 127 μT and 4.2 mV/m near cable surface and 2.74 μT and 675 μV/m when (perpendicularly) distanced 1 meter away from the cables.
  - Comparison between normalized (per current unit) magnetic/electric fields results of this study and that of Oregon study indicates correlation that decreases with proximity to the cable.

- WaveRoller
  - At rated power and assuming power factor equal to one (equivalent to a current equal to 24.2 A, one order of magnitude higher than for MARMOK-A-5), magnetic flux density ranges from 7 μT (close to the surface of the cable) to 0.11 μT (1 meter away- perpendicularly), decaying in an exponential fashion. In a similar way, the electric field ranges from 215 μV/m to 29 μV/m.
  - This cable maximum current capacity (125 A) would imply EMF levels around 37.5 μT and 1.1 mV/m near cable surface and 0.63 μT and 150 μV/m when (perpendicularly) distanced 1 meter away from the cables.
  - Comparison between normalized (per current unit) magnetic/electric fields results of this study and that of Oregon study indicates correlation that decreases with proximity to the cable.

[1] Of course, this value could not be ever produced by this WEC operation.

4.2 Gap analysis

Admittedly, not many gaps have been identified in this modelling activity, as it employed a widely used and validated numerical method. In any case, a list of the most significant can consulted in Table 1.

Table 1. Gap analysis of EMF modelling.

Focus area	Current state	Future state	Identified gaps	Actions
Validation of results and calibration of parameters	No validation of the results obtained from the simulations, except comparison with previous study.	Results are properly validated and compared against field measurements.	• No confirmation of the validity of the results is established. • Model parameters are not calibrated.	• Take field measurements and compare with simulated data. • Depending on this comparison, assess validity of input data.
Uncertainty of results	No available error assessments.	Uncertainty in EM fields is properly considered in the simulations.	• Uncertainty due to numerical computation. • Uncertainty due to input data.	• Use an ensemble of models. • Simulate for varying input data.

One gap that is shared between these modelling activities is the validation of results. In the case of EMF, the validation was more about validating the methodology (comparison with the Oregon study) than the actual results, as no in-situ data could be obtained from the field monitoring campaings. As off-shore logistics are complex, it is proposed to use new technologies (e.g., ROVs) to ensure that proper data can be collected without high costs and risks.

Another common gap issued here is the lack of uncertainty metrics in the simulations. Even though the simulated EMF magnitudes were extremely low due to low currents and the high quality of coatings of the submerged cables, associating uncertainty to results provides a more comprehensive study.

5. Underwater acoustics modelling

5.1 Synthesis of acquired knowledge

Introduction

Underwater acoustic propagation modelling consists in simulating the transmission losses (TL) from a given source, usually for a certain frequency. This variable expresses the amount of acoustic energy lost along the propagation of the sound waves, and is generally expressed in logarithmic units (i.e. dB re 1 m[2]).

There are quite a variety of acoustic propagation models, most of them coming from assuming different approximations to the linear acoustic wave equation, as can be consulted in deliverable 3.2 from this project [2] or specialized books [9]. In the case of this project, the chosen model was a Parabolic Equation model, in particular, the Monterey-Miami Parabolic Equation, a full range dependent (bathymetry, sound speed profile and seabed elastic properties) underwater transmission loss model based on the parabolic equation approximation, as its name suggests [10].

Note that although the TL field provide useful information (e.g., directivity and frequency dependence), to know the absolute measure of noise in the surrounding area of the devices studied in this project the magnitude of interest is the Sound Pressure Level (SPL), which is a logarithmic measure of the acoustic intensity. To obtain the SPL from the TL it is necessary to use the source level[3] (SL), by subtracting the latter from the former. Thus, by knowing the SL (from the analysis of the acoustic recordings [11]) and the TL, it is possible to infer the SPL fields around the WECs. This methodology was carried out in deliverable 3.2, and the interested reader is referenced to such document for more further information.

What has been done?

With respect to sound transmission modelling, TL polar[4] maps have been made for every WEC and for the following sets of parameters:

- Three frequencies: 62.5, 125, and 1000 Hz.
- Eleven depth slices: 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 metres.

[2] dB with respect to 1 metre (from the source).
[3] Defined as the Sound Pressure Level at one metre from the source (dB re 1 m).
[4] That is, 2-dimensional TL fields, or horizontal planes, as if observed from above.

SLs have been obtained for every WEC by backpropagating the SPL values resulting from the processing done on the hydrophone recordings from the acoustics temporal monitoring [11], for the following sets of parameters:

- Three frequencies: 62.5, 125, and 1000 Hz.
- Three significant wave height ranges: [0,1), [1,2), and [2,5) metres.

Finally, SPL polar maps have been developed from the corresponding TL maps and SLs (simply subtracting TL from SL) for combinations of the following selection of parameters:

- Three frequencies: 62.5, 125, and 1000 Hz.
- Eleven depth slices: 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 metres.
- Three significant wave heights ranges: [0,1), [1,2), and [2,5) metres.

This methodology has been accordingly applied to every WEC, ending up with a total of 297 SPL maps. This methodology is illustrated in Figure 1.

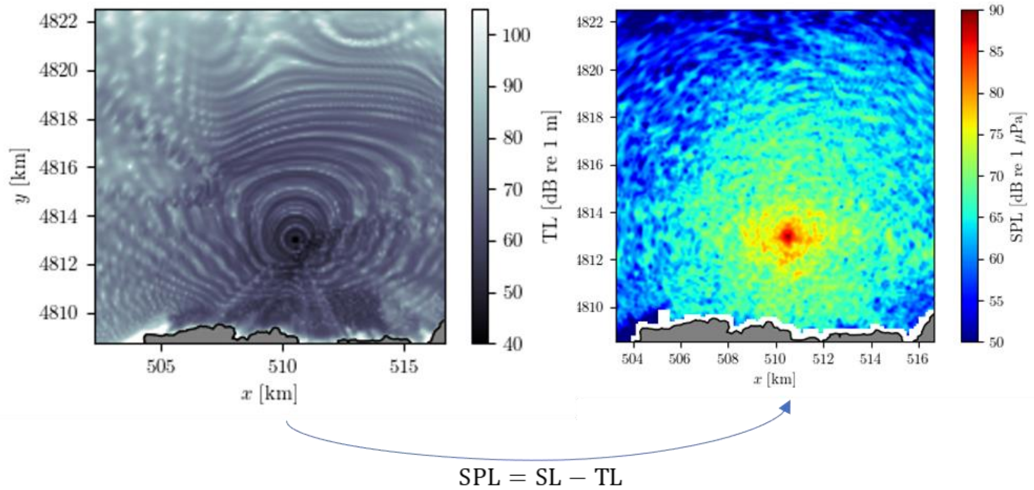

Figure 1. Schematic of the followed methodology to obtain SPL distributions.

Acquired knowledge

One of the chosen metrics for reporting is the area of perturbance, because it manages to express the impact relative to the background with scalar values. It is defined as the area in which the SPL when the device is operating is higher than the SPL corresponding to the background noise. Equivalently, a perturbance distance from the source can be defined to assess the acoustic impact of the devices, as the radial distance in which the spatially averaged (in concentric annuli) SPL is greater than the SPL corresponding to the background noise. In addition, we average the SPL maps in the vertical dimension (depth) to further reduce the dimensionality of the results.

This perturbance radial distance (in meters) is gathered in the following tables, in function of significant wave height and frequency:

- MARMOK-A-5

Table 2. Radial distance of acoustic perturbance (in meters) from MARMOK-A-5 WEC.

	f [Hz]		
H_w	62.5	125	1000
[0,1)	240.6	103.2	82.1
[1,2)	216.1	81.7	73.8
[2,5)	152.3	64.7	89.2

- Mutriku

Table 3. Radial distance of acoustic perturbance (in meters) from Mutriku.

	f [Hz]		
H_w	62.5	125	1000
[0,1)	659.6	1001.6	1261.4
[1,2)	644.4	467.6	2244.3
[2,5)	664.0	969.7	2593.7

For completeness, results from Mutriku have also been added, although it must be remarked that these are undoubtedly overestimated, as uncertainty in the SL calculation was high enough to reject a valid assessment of its value. In fact, and as explained in D2.3, when considering uncertainty, it could not be possible to distinguish between background SPL values and background+device SPL values.

Also, as no long-term acoustic monitoring campaign could be undertaken in Peniche due to reasons explained in the same deliverable, it was not possible to associate an equivalent point source SL to the WaveRoller WEC; therefore, only transmission losses maps could be produced in this case. However, if a proper estimation of the SL of this device is achieved, the calculation of SPL fields is as straightforward as subtracting the absolute value of the TL fields from the SL. Since these TL fields can be found in the MARENDATA platform, they are readily usable in further investigations.

5.2 Gap analysis

Among the problems and detected gaps faced in the modelling phase of the acoustics characterization, Table 4 describes the most relevant issues the team has identified.

Table 4. Gap analysis of the underwater acoustic propagation modelling.

Focus area	Current state	Future state	Identified gaps	Actions
Source acoustic characterization	WEC is characterized as point source with SL obtained through backpropagation of SPL measured at one location.	WEC is characterized considering its many noise-generating mechanisms and taking into account directionality.	• Devices are complex structures that may not generate noise omnidirectionally. • No spatial resolution in SPL data distribution.	• Use modelling software (e.g., COMSOL). • Acoustic monitoring performed at more locations (different angles from source).
Data spatial resolution	Spatial resolution of ~100 metres.	Increased spatial resolution.	No public datasets for input parameters at lower resolutions	Interpolation ML algorithms, integration of different datasets, or self-acquired input data.
Data temporal resolution	Simulations only for one season.	Seasonality accounted in the simulations.	• Computation time increases four-fold. • Acoustic monitoring performed in each season.	• Use parallelization methods. • Acoustic monitoring performed in all relevant seasons.
Uncertainty in the simulations	There is no uncertainty metric associated to the results of the simulations.	Uncertainty in SPL fields is properly considered.	• Uncertainty due to model selection. • Uncertainty due to computed SL. • Uncertainty due to other inputs.	• Use an ensemble of models. • Assess combined uncertainty of SL. • Simulate with randomized variations of inputs.

Validation of results and calibration of parameters	No validation of the results obtained from the simulations.	Results are properly validated and compared against field measurements.	• No confirmation of the validity of the results is established. • Model parameters are not calibrated.	• Take field measurements and compare with simulated data. • Depending on this comparison, assess validity of input data.

In more detail, the four main problems that have been identified and pointed out in the previous table are:

- Source acoustic characterization

  One of the key steps in calculation of the SPL fields is the Source Level value; in fact, any error on it will directly propagate to the resulting value of SPL. While working on the acoustic data in deliverable 2.3 of this project, the uncertainty in the resulting SPL distribution was considerable so that only for those cases in which there was a clear increase in noise with respect to the background soundscape we could infer the Source Level with confidence. What is more, to find the Source Level one must backpropagate the Sound Pressure Level value to its source by means of acoustic propagation modelling, and by doing so it is inherently assumed that there is no other noise signature than the one directly corresponding to the WEC operation (e.g., there is no other sound contribution to the signal apart from the WEC). This means that the actual value of SL will most likely be lower than the reported one, and it would be more correctly viewed as an upper bound, as was stated in deliverable D3.2.
  Another point of consideration is the directionality of the sources. In this regard, as the acoustic temporal monitoring was performed in one fixed location, there is no way to assess directionality apart from theoretical arguments (which sometimes may be enough, as for the case of MARMOK-A-5).
  To add to this, the WECs themselves are complex structures that may not be adequately modelled as point sources, in particular for close ranges. The actions required to close this gap are: increasing the amount of noise recordings acquired in the monitoring; placing the hydrophones close enough so that WEC-related noise is predominant (alternatively, implementation of source separation algorithms could be advised); monitoring in different directions from the source so directionality is accounted for; and lastly, modelling the source in a more detailed way using modelling FEM software (e.g., COMSOL), respectively.

- Spatial resolution

  Another gap identified has to do with the spatial resolution of the model, which is constrained by the resolution of the input data. Especially considering that the effects of the WECs in this project are at most minor, the extension of the assessed area does not need to be greater than distances of the order of 1 km (radius from the source), and thus a greater resolution in data should be used to take into account the spatial dependence in the transmission. To improve such resolution, it could be interesting to try up-sampling algorithms, such as those based on Machine Learning methods, to integrate different datasets or even to obtain new data through field monitoring.

- Temporal resolution

  Similar to the previous point, there is the concern of the temporal resolution used in the simulations. From D3.2, simulations have no temporal resolution in the sense that different seasons are not explicitly considered, as the simulations were performed with the input data corresponding to the months of monitoring (May-June 2019). As the sound speed profile changes through the year, the acoustic channel is correspondingly modified, thus possibly changing the possible Sound Pressure Level values in the monitoring location. In this sense, it would be interesting to monitor during different seasons of the year, replicating the methodology of modelling for every one of them. While this obviously implies larger computational times for the modelling, this may be countered by code optimization and parallelization techniques.

- Uncertainty in the simulations

  There are three main components of the uncertainty in the SPL: that of the model itself, that of the SL and that of the remaining input data. To assess the first one, a possible method is by using more underwater acoustic propagation models (ensemble); of course, this comes with a huge cost in computational resources. The second one is related to the first identified gap, point discussed previously. Finally, the third one relates to uncertainty in input data such as bathymetry, sound speed profile and the acoustic properties of seabed substrate. To assess these uncertainties, a run of simulations (Monte Carlo) in which these parameters are randomly varied (within reasonable limits) may be carried out.

- Validation of results and calibration of parameters

To increase confidence in the results of the simulations, it is appropriate to compare these with (processed) data obtained from field measurements. Although this is an expensive action to undertake, it is mandatory to assess the validity of the simulations and the input parameters. For example, seabed morphology, which dataset is usually quite sparse, could be inferred from the comparison between the simulations and measurements.

All these proposed solutions imply, if taken together, a great increase in computational load, so it may not be possible for the modeller to tackle all of them, in which case, the modeller should detect what are the most critical among them and use the respective solutions. Also, some of these imply a considerable time and effort investment, such as those related to field measurements, a logistically challenging activity in the open sea environment.

6. Marine dynamics modelling

6.1 Synthesis of acquired knowledge

Introduction

The Atlantic seaboard offers a vast marine renewable energy (MRE) resource which is still far from being exploited. 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 Wave Energy Converters (WEC) is growing fast, their potential environmental effects are not well-known and therefore these must be thoroughly investigated prior to WEC implementation.

Here, two case studies related to the impact of WECs on coastal morphodynamics are presented. The first case has the objective of investigating the long-term impacts of a WEC farm composed by a series of point absorber OWC (Oscillating Water Column) devices on nearshore wave climate and the consequences on the shoreline response; and the second case is focused on evaluating the changes in the wave spectrum caused by the frequency dependent' energy absorption of bottom mounted energy converters and their impacts in the short-term morphological evolution.

What has been done?

- MARMOK-A-5 (BiMEP):

A hybrid downscaling methodology is used to provide the wave characteristics at the nearshore. Five indicators are used to characterize the nearshore impact.

The propagated wave climate is used to combine with the MVAR model generating a series of synthetic wave time series at the beach. A shoreline evolution model is used to analyse the morphodynamic impact.

- WaveRoller (Peniche):

A dynamic downscaling methodology is used to provide full wave spectrum as boundary condition allowing the evaluation of the WEC array impact on nearshore wave spectrum.

Four morphodynamic simulations have been performed taking as boundary condition the yearly-mean wave climate; summer and winter mean wave climate; and an extreme wave condition.

Acquired knowledge

- MARMOK-A-5 (BiMEP):
    - MARMOK-A-5 arrays produce a maximum decrease of wave power (P) and significant wave height (Hs) of 41kW/m and 0.45m, respectively. Decrease of P and Hs greater than 10% are only recorded during 40% and 4% of the time, respectively.
    - The impact extension (Hs/P decrease larger than 2.5%) is of 5.5 km for P and 3 km for Hs and only affects a rocky cliff area.
    - WEC farm effect, in terms of P and Hs buffering, at the coastline is limited due to the long distance from to the coast, which seems far enough to significantly reduce the wave shadowing effect at the lee of the WEC farm.
    - The morphodynamic impact is low (less than 3m) and not homogeneous along the beach. While the western part of the beach undergoes a slight accretion (+2m), the central area is hardly modified, and it is only on the eastern contour of the beach where erosion (-1.5m) occurs.
- WaveRoller (Peniche):
    - WEC array not only removes energy from the system but can also change the shape of the transmitted wave spectrum. For the typical Portuguese west coast wave climate, the array of WECs tend to work more efficiently during summer periods, where wave spectral energy is located at higher frequencies.
    - The WEC array offers little protection to extreme wave conditions due to the frequency operation limits of the WaveRoller converter.
    - The simulated initial sediment transport tendencies show that most of the changes occur in the orientation of rip channels, mostly in the cross-shore direction, which is expected due to the nature of the simulations. No significant sediment exchange between long-shore areas have been observed.

6.2 Gap analysis

Among the problems and detected gaps faced in the task of marine dynamics modelling, describes the most relevant issues the team has identified.

Table 5. Gap analysis in the marine dynamics modelling.

Focus area	Current state	Future state	Identified gaps	Actions
WEC technology	The WEC impact is analysed based on a given technology	The WEC impact is analysed considering MARMOK-A-5 and WaveRoller updates and/or different WEC technologies.	• Update technology advances • Test different technologies suitable for being implemented on the studied locations.	• Include MARMOK-A-5 and WaveRoller technology updates (if any). • Test different technologies.
Morphodynamic model	The beach morphodynamic response is analysed based on shoreline evolution and process-based models.	The beach morphodynamic response is analysed based on shoreline evolution and process-based models and contrasted against field measurements.	• No historical shoreline data was able to be obtained. • Limited sediment transport information. • No information regarding sediment distribution.	• Collect field data from direct measures (RTK-GPS) or indirect measures (coastal video monitoring, satellite). • Compare measurements with model output.
Hydrodynamic model	The wave characteristics at the nearshore are analysed based on well-known methodologies and models.	The modelled wave characteristics at the nearshore are contrasted against field measurements.	Lack of hydrodynamic in-situ measurements: waves and currents.	• Collect field data from wave buoys and ADCPs • Calibrate and validate models using in-situ measurements.

In more detail, the three main problems that have been identified and pointed out in the previous table are:

- **WEC technology**
  Currently, there are a wide range of WEC technologies under development or/and already developed. Each technology captures the wave energy differently. As a result, they usually have a varying energy capture efficiency depending on

the wave conditions (wave energy distribution throughout the frequency spectrum) which is represented by the power matrix. In the current study, tailored power matrixes have been used. However, the impact of other kind of WEC technologies that might be installed at the studied sites or future technological advances/updates that might be carried out in MARMOK-A-5 and WaveRoller were not considered.

- Morphodynamic model (validation)

Although this study has used a wave propagation model that is widely accepted and used by the scientific community, a comparison of the results with real measurements is needed to ensure that the model performs well. This will require the installation of wave sensors close to the study area and the collection of data under sufficiently variable wave conditions to characterise the marine climate of the area.

- Hydrodynamic model (validation)

The beach response is modelled by means of robust and widely used models. However, a comparison of the results with real measurements is needed to ensure that the model performs well. This will require the collection of in situ data by means of direct techniques (RTK-GPS) or indirect techniques (videometry, satellite).

7. Conclusions

In this deliverable, a synthesis of the most significant acquired knowledge in all modelling activities (EMF, underwater acoustics, and marine dynamics) is presented, as well as a gap analysis regarding all these activities. Here, a more concise presentation of these results is given, classifying by prototype of WEC and modelling activity.

7.1 Acquired knowledge

MARMOK-A-5 (BiMEP test site - Spain)

- EMF:

  EMF impact is mostly undistinguishable, being the electric and magnetic fields magnitudes quite low, with maximum values at rated power of 13 μV/m and 0.40 μT, respectively (immediately close to the cable).

- Underwater acoustics:

  Although obtained SPL levels are highest for low frequencies (compared to background levels), acoustic transmission in these frequencies is limited due to the shallow water environment. A maximum radial distance of (acoustic) perturbance around the WEC of 0.24 km is found for the 62.5 Hz band and significant wave heights between 0 and 1 meter. Thus, noise level contribution from WEC can be considered as very limited.

- Marine dynamics:

  The addition of a series of array of devices (up to 80) does not imply much impact in marine dynamics, given the distance from the shore at which the devices would be placed. In particular, a decrease of power and significant wave height greater than 10% are recorded during 40% and 4% of the time, respectively, while morphodynamic maximum impact is less than 3 m and stretched along a 5.5 km of rocky cliffs.

Mutriku power plant (Mutriku - Spain)

- Underwater acoustics

  Acoustic transmission in this case is even more inefficient in low frequencies. No statistically significative SPL fields could be obtained in this scenario, as background noise overlaps operating device noise when considering uncertainty.

WaveRoller (Peniche – Portugal)

- EMF

  With a rated current one order of magnitude higher than MARMOK-A-5, the electric and magnetic field magnitudes are correspondingly higher, yet still low compared to common EMF intensities: 215 μV/m and 7 μT, respectively.

- Underwater acoustics

  Because no Source Level could be established (for different reasons explained in D2.3 [11]), no SPL distributions could be inferred. With respect to transmission losses, as Peniche waters are very shallow, transmission is very inefficient for low frequencies.

- Marine dynamics

  The addition of an array of 17 WaveRoller devices in Peniche waters imply no significant sediment exchange between long-shore areas as observed from the simulations. Also, no effects on wave direction and directional spreading are observed. Lastly, the extraction of energy in some wave frequencies carries a decrease of significant wave height in the shaded zone of about 10% during winter and 20% in summer compared to when no WEC is present.

7.2 Gap analysis

Although some gaps have been identified, we consider that the objective of the WP has been achieved, and the WEC-related impacts have been assessed for most proposed cases. The definition and identification of these gaps will help to circumvent them in future and already planned works of the very same partners of this project.

EMF

For the EMF modelling, only two gaps were identified: a lack of uncertainty metrics associated with the results of the simulations and also the lack of proper validation of these results with real in-situ data of EM fields.

Underwater acoustics

A total of six gaps were detected in this modelling activity (see Table 4), mostly concerning uncertainty and lack of resolution of input data; from these, the most significant may be the Source Level characterization problem, as any error in SL propagate directly to the SPL distribution and therefore alter them significantly.

Marine dynamics

Three gaps were identified in this modelling activity, mostly concerning validation of model results, as no long-term real data on shoreline and wave energy was possibly obtained.

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