SAFE WAVE
STREAMLINING THE ASSESSMENT OF ENVIRONMENTAL EFFECTS OF WAVE ENERGY

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

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1. SafeWAVE project synopsis

The European Atlantic Ocean offers a high potential for marine renewable energy (MRE), which is targeted to be at least 32% of the EU's gross final consumption by 2030 (European Commission, 2020). The European Commission is supporting the development of the ocean energy sector through an array of activities and policies: the Green Deal, the Energy Union, the Strategic Energy Technology Plan (SET-Plan) and the Sustainable Blue Economy Strategy. As part of the Green Deal, the Commission adopted the EU Offshore Renewable Energy Strategy (European Commission, 2020) which estimates to have an installed capacity of at least 60 GW of offshore wind and at least 1 GW of ocean energy by 2030, reaching 300 GW and 40 GW of installed capacity, respectively, moving the EU towards climate neutrality by 2050.

Another important policy initiative is the REPowerEU plan (European Commission, 2022) which the European Commission launched in response to Russia's invasion of Ukraine. REPowerEU plan aims to reduce the European dependence amongst Member States on Russian energy sources, substituting fossil fuels by accelerating Europe's clean energy transition to a more resilient energy system and a true Energy Union. In this context, higher renewable energy targets and additional investment, as well as introducing mechanisms to shorten and simplify the consenting processes (i.e., 'go-to' areas or suitable areas designated by a Member State for renewable energy production) will enable the EU to fully meet the REPowerEU objectives.

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

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

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

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

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

2. Development of a **Consenting and Planning Strategy** through providing guidance to ocean energy developers and to public authorities tasked with consenting and licensing of WE projects in France and Ireland; this strategy will build on country-specific licensing guidance and on the application of the MSP decision support tool developed for Spain and Portugal in the framework of the WESE project; the results will complete guidance to ocean energy developers and public authorities for most of the EU countries in the Atlantic Arch.
3. Development of a **Public Education and Engagement Strategy** to work collaboratively with coastal communities in France, Ireland, Portugal and Spain, to co-develop and demonstrate a framework for education and public engagement (EPE) of MRE enhancing ocean literacy and improving the quality of public debates.

2. Executive summary

In this report, the conclusions drawn from the modelling performed in WP3, as well as the main GAPs encountered, are presented.

- Electromagnetic fields (EMF): No significative EMF disturbances related to the device's operation are found from the simulations. This suggests a low likelihood of EMF interference with marine life or navigational systems. However, while modelling has provided valuable insights, there is a need to correlate these findings with long-term field data to validate the models and ensure their predictive accuracy.
- Underwater noise: In terms of underwater noise, extensive acoustic modelling was carried out at three test sites and showed that the highest noise emissions were typically in the lower frequency bands. Acoustic nuisance distances varied between 0.5 km and 2.5 km from the equipment, depending on the specific site and conditions. The main gaps in the knowledge of underwater noise were the lack of high quality input data, the lack of validation of the models and the absence of consideration of the many noise-generating systems of the WECs.
- Marine dynamics: Marine dynamics modelling at the Aguçadoura test site showed a significant shadowing effect on wave energy, with significant energy reduction within 250 m of the device. Beyond this range, the effect diminished significantly, with less than a 2% reduction in wave energy reaching the shore. The main gap identified is that relying solely on theoretical wave spectra for modelling may not accurately represent real ocean conditions, potentially leading to errors in the assessment of WEC system performance. Criteria are needed to determine when actual measured wave data should be used to improve model accuracy. In addition, data should be collected in all seasons to allow for comparison.

3. Introduction

This deliverable is part of Work Package 3 (WP3), which tackles modelling of potential impacts from WEC technologies, namely by electromagnetic fields (EMF) and underwater acoustics (noise) and on marine dynamics. WP3 is technically complex and has encountered execution challenges and limitations, leading to gaps in achieving precise and reliable results. Consequently, a gap analysis, typically a business tool for comparing actual performance with potential or desired performance, has been integrated to benefit future environmental impact assessments of WEC technologies. The gap analysis helps identify and address barriers to enhance modelling activities.

The SafeWAVE project incorporates four WECs: Penguin II in Spain, the onshore Mutriku power plant in Spain, HiWave-5 in Portugal, and WAVEGEM in France. The modelling focuses on the significant impacts anticipated in the prior WP2, from which data was collected to inform current models. These modelling tasks utilize open-source software and leading-edge models, with a comprehensive synthesis of the knowledge presented. For detailed methodologies, references to deliverables D3.1 EMF (Imperadore et al. 2024), D3.2 Underwater noise (Garcia et al., 2024), and D3.3 Marine Dynamics (De Santiago et al., 2023)[1] are provided.

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[1] https://www.safewave-project.eu/wp-content/uploads/2023/08/D3.3_Marine_dynamics_modelling.pdf

4. Electromagnetic fields modelling

Here we examine the main results, problems, and gaps identified from the work carried out in Task 3.1 EMF Modelling. The main EMF 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 Penguin II, HiWAVE-5, and WAVEGEM devices.

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 (Imperadore et al., 2023)) except for the SEM-REV test site.

4.1 Synthesis of acquired knowledge

4.1.1 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 Finite Element Method Magnetics (pyFEMM) version library were employed (Meeker, 2018). 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.

4.1.2 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 the export cables in BiMEP, Aguçadoura, and SEM-REV.

4.1.3 Acquired knowledge

Overall, effects from EMF modelled at maximum capacity should be negligible, as evidenced in the results that follow. For a reference value, typical values of Earth's average magnetic and electric fields on its surface are 25-65 μT (Finlay et al., 2010) and 100 V/m (Feynman et al., 2011), respectively.

- Aguçadoura – CPO
    - At 10 cm from the cable the flux density $|B|$ reaches the value of 98.85 $\mu\mathrm{T}$ and it reduces to 0.22 $\mu\mathrm{T}$ at 3 m parallel to the cable. The electric field follows the same trend, it reaches its maximum values of 3232.10 $\mu\mathrm{V/m}$ and decays to 174.84 $\mu\mathrm{V/m}$ at 3 m distance.
- BiMEP
    - At 10 cm from the cable the flux density $|\mathrm{B}|$ reaches a value of 152.37 $\mu\mathrm{T}$ and it reduces to 0.40 $\mu\mathrm{T}$ at a distance of 3 m from the cable. The electric field follows the same trend, reaching maximum values of 5500.57 $\mu\mathrm{V/m}$ and decaying to 334.33 $\mu\mathrm{V/m}$ at 3 m distance.
- SEM-REV
    - For the dynamical umbilical cable connecting the energy device to a collection hub: At 10 cm from the cable the flux density $|\mathrm{B}|$ reaches a value of about 94.46 $\mu\mathrm{T}$ and it reduces to 0.23 $\mu\mathrm{T}$ at a distance of 3 m from the cable. The electric field follows the same trend, it reaches its maximum values of around 3230.32 $\mu\mathrm{V/m}$ and decays to 187.65 $\mu\mathrm{V/m}$ at 3 m distance. For this study, the FLOATGEN wind turbine is considered as power device because it was the device energizing the cable. See Imperadore et al., (2023).

- For the export cable: At 10 cm from the seabed surface and parallel to the cable there was a peak flux density of 98.22 µT, while at 3 m it reduced to 0.21 µT. For what it concerns the electrical field, at 10 cm distance the value found was 3084 µV/m and reduced to 175 µV/m at 3m.

4.2 Gap analysis

The main gap, as can be seen in Table 1, relates to the lack of validation of the results. Only at the SEM-REV test site it was possible to conduct the survey to obtain the EMF data. Moreover, the only real data obtained was an average of the electric current from the SEM-REV test site, so it was not possible to understand to which current the peaks of EMF were related in order to simulate and validate.

Table 1. Gap analysis of EMF modelling.

Focus area	Current state	Future state	Identified gaps	Actions
Validation of results and calibration of parameters	Only one test site was validated with an average current	Results are properly validated and compared against field measurements.	No confirmation of the validity of the results is established. Also, model parameters are not calibrated	Take field measurements and compare with simulated data

5. Underwater acoustics modelling

5.1 Synthesis of acquired knowledge

5.1.1 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).

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 (Garcia et al., 2024) or specialized books (Jensen et al., 2001). 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 (Smith, 2001).

In order to understand how the sound emitted by the source under study would propagate, it is necessary to obtain the Sound Pressure Level (**SPL**), which is a logarithmic measure of the acoustic intensity obtained as **SL** – **TL,** where **SL** is the Source Level (SPL at 1 m distance from the source) and is obtained in Deliverable 2.3 (Madrid et al., 2024).

5.1.2 What has been done?

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

- Three frequencies: 62.5, 125 (which were specified in MSFD guidelines) and 100' Hz.
- Eleven depth slices: 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 metres.

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 (Madrid et al., 2024), for the following sets of parameters:

- Three frequencies: 62.5, 125, and 1000 Hz.
- Three significant wave height ranges: [0,0.75), [0.75,1.5), [1.5,2.5), [2.5,4) and [4,8) metres.

Finally, **SPL** polar maps have been developed from the corresponding **TL** maps and **SLs** (simply subtracting TL from SL) for every WEC (except for Aguçadoura at the day of writing this deliverable, as no acoustic data is available) (Figure 1).

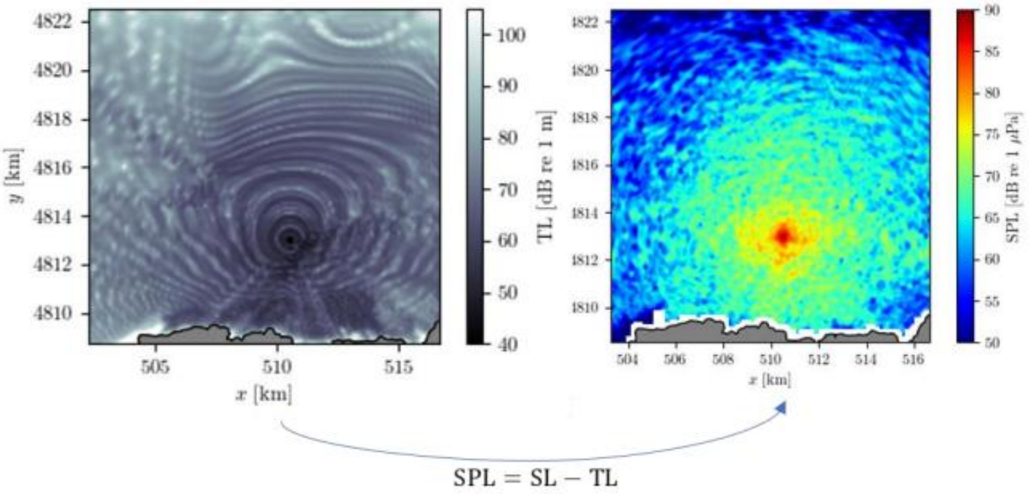

Figure 1. Schematic of the followed methodology to obtain SPL distributions.

After the modelling of the WEC devices, two WEC farms (PENGUIN II and WAVEGEM devices) were simulated using the same methodology described before and adding the individual contributions of every WEC, thus assuming a 100% coherent and additive phase relationship (worst case scenario). The number of devices was selected for a fixed arbitrary output power of 1200 kW, which was obtained by two PENGUIN II devices and by eight WAVEGEM devices. It should be noted that a low output power was selected in order to avoid falling into less reliable models. Also, as the worst case scenario was studied, a very high number of devices would return highly overestimated and unreal metrics, which would lead to confusion.

5.1.3 Acquired knowledge

The 'area of perturbance' is selected as a metric for reporting due to its ability to quantify the impact with scalar values relative to ambient conditions. It is characterized as the region where the **SPL** with the device in operation exceeds the **SPL** of the background noise. Similarly, 'perturbance distance' is utilized to gauge the acoustic influence of the devices, defined as the radial extent over which the spatially averaged SPL (across concentric annuli) surpasses the background noise **SPL**. To simplify the results further, **SPL** readings are averaged in the vertical dimension (depth). These perturbance radial distances, expressed in meters, are presented in subsequent Table 2, Table 3 and Table 4 for BiMEP, Mutriku and SEM-REV test sites respectively, delineated as a function of significant wave height and frequency.

It should be noted that for some devices some wave heights are not reported in the table. This is due to the absence of waves of these heights during the monitoring campaign.

It should also be noted how the acoustic disturbance distance is always higher at 1 kHz, as the acoustic shallow waters low frequency filter doesn't take part.

5.2 Gap analysis

Among the problems and detected gaps faced in the modelling phase of the acoustics characterization Table 5 describes the most relevant issues the team has identified.

Three main gaps are identified for underwater acoustics modelling. First one being the characterization of the source, which does not take into account the directivity of the device as the many noise-generating mechanisms that the source has are not considered.

- **BiMEP**

Table 2. Acoustic disturbance distances (km) for the PENGUIN II WEC, in BiMEP.

	***H* [m]**	[1.5, 2.5)			[2.5, 4)			[4, 8)		
Season	**f [Hz]**	62.5	125	1k	62.5	125	1k	62.5	125	1k
Winter		0.17	0.44	0.31	0.18	0.47	0.44	0	0.35	0.40
Spring		0.17	0.44	0.31	0.18	0.47	0.44	0	0.35	0.40
Summer		0.17	0.44	0.31	0.18	0.47	0.44	0	0.35	0.40
Autumn		0.17	0.44	0.31	0.18	0.47	0.44	0	0.35	0.35

- **Mutriku**

Table 3. Acoustic disturbance distances (km) for the Mutriku power plant WEC, in Mutriku.

	***H* [m]**	[0, 0.75)			[0.75,1.5)			[1.5, 2.5)			[2.5, 4)		
Season	**f [Hz]**	62.5	125	1k	62.5	125	1k	62.5	125	1k	62.5	125	1k
Winter		0.18	0.40	0.56	0.25	0.53	0.53	0.47	1.26	0.64	0.56	1.44	0.71
Spring		0.18	0.40	0.56	0.25	0.53	0.53	0.47	1.26	0.64	0.56	1.44	0.71
Summer		0.18	0.40	0.56	0.25	0.56	0.53	0.50	1.26	0.64	0.56	1.44	0.69
Autumn		0.18	0.40	0.56	0.25	0.53	0.53	0.50	1.26	0.62	0.56	1.44	0.69

- **SEM-REV**

Table 4. Acoustic disturbance distances (km) for the WAVEGEM WEC, in SEM-REV.

	H [m]	[0, 0.75)			[0.75,1.5)			[1.5, 2.5)		
Season	**f [Hz]**	62.5	125	1k	62.5	125	1k	62.5	125	1k
Winter		0.25	0.44	1.18	0.25	0.53	1.46	0.35	0.71	2.03
Spring		0.25	0.40	1.07	0.25	0.47	1.31	0.31	0.62	1.80
Summer		0.2	0.35	1	0.25	0.44	1.22	0.31	0.53	1.68
Autumn		0.25	0.40	1.08	0.25	0.47	1.32	0.31	0.59	1.82

Table 5. Gap analysis of underwater acoustics modelling.

Focus area	Current state	Future state	Gaps	Actions
Source acoustic characterization	WEC is characterized as point source with SL obtained through backpropagation of SPL measured at three locations (different angles from source).	WECs directivity is full characterized	The many noise-generating mechanisms of the source are not considered.	Use modelling software (e.g., COMSOL) to simulate the many noise-generating mechanisms of the source.
Spatial data resolution	Spatial resolution of ~100 m for some test sites	Increased spatial resolution	Lack of high resolution data to feed the models and obtain high quality maps	Use interpolation ML models and integrate different datasets. Also, use self-acquired data
Validation of results	No validation of the models is obtained	Results are properly validated and compared against field measurements.	No confirmation of validity of the models Model parameters are not calibrated for every test site	Use field measurements obtained with mobile campaigns to assess the validation

In this regard, the acoustic monitoring was conducted at a single fixed point, which limits the ability to evaluate the direction from which sounds originate, leaving only theoretical reasoning for directionality assessments. Furthermore, WECs are intricate structures that may not be precisely represented as simple point sources, especially at closer proximities. To bridge this gap, several measures are suggested: expanding the volume of noise recordings during monitoring, positioning hydrophones near enough to ensure that noises from the WECs are dominant (or alternatively, applying source separation algorithms), conducting monitoring in various directions relative to the source to include directionality, and improving the modelling of the source with more sophisticated Finite Element Method (FEM) software like COMSOL.

Another gap found is the scarcity of input data to the model, especially bathymetry, most of which has a rather low resolution, which does not allow obtaining good quality maps with greater detail. It is proposed to use ML models to interpolate and extend the bathymetries, as well as to try to obtain self-acquired data in future projects.

The last gap identified is shared with the EMF modeling, and is the lack of validation data for the models. 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.

6. Marine dynamics modelling

6.1 Synthesis of acquired knowledge

6.1.1 Introduction

The coastal regions along the Atlantic hold a substantial yet underutilized MRE resource. This sector promises a significant contribution to diversifying energy supplies, cutting down on greenhouse gas emissions, and boosting the economic prospects of seaside towns. Ocean energy advancement is a key component of the EU's Blue Growth strategy. Although there is rapid progress in the technology of WEC, there's limited knowledge about their environmental impacts. It's essential to conduct in-depth research into these impacts before WECs are widely deployed.

For the BiMEP test site, the methodology followed in Deliverable 3.3 (De Santiago, 2023) was validated and also, different downscaling strategies for this kind of studies were tested/consolidated.

For the Aguçadoura test site, SNL-SWAN model was used in order to assess the impact of a WEC farm. The results achieved with these simulations showed that a WEC farm located at the Aguçadoura site would not influence the sediment transport at the shore or any other processes.

6.1.2 What has been done?

- **BiMEP**

The validation process involved a sensitivity test concerning the model grid cell size, which is crucial in computational modelling for balancing detail against computational cost. The findings showed that while computational cost is directly related to the grid cell size, the variations in cell size did not significantly alter the model's output. This indicates the model's stability and robustness, suggesting that the model can deliver reliable predictions of wave propagation without requiring extremely fine grid resolutions, which would otherwise increase computational costs. Moreover, when comparing downscaling methods, the study found that the Hybrid Statistical Downscaling approach was particularly suitable for probabilistic studies of coastal impacts of wave farms. This method, when compared to Dynamic Downscaling, showed minor differences that were within acceptable ranges for the study's purposes (with a Root Mean Square Error - RMSE - below 0.28 m for significant wave height (Hs), 1.52 s for peak period (Tp), and 13.14° for peak direction (θp)), suggesting that this downscaling method can reliably predict changes in wave conditions due to the presence of WECs.

- **Aguçadoura**

The methodology was centred around using the SNL-SWAN model to simulate the interaction between WECs and the marine environment. The simulation aimed to estimate the energy extraction by the WECs and assess its effect on coastal processes, with a particular focus on sediment transport. Virtual monitoring stations were set up within the simulation environment to measure the impact of the WEC farm on wave height, wave power, and wave direction, which are factors that influence sediment transport and other coastal processes.

6.1.3 Acquired knowledge

- **BiMEP**

The findings showed that while computational cost is directly related to the grid cell size, the variations in cell size did not significantly alter the model's output. This indicates the model's stability and robustness, suggesting that the model can deliver reliable predictions of wave propagation without requiring extremely fine grid resolutions, which would otherwise increase computational costs.

Moreover, when comparing downscaling methods, the study found that the Hybrid Statistical Downscaling approach was particularly suitable for probabilistic studies of coastal impacts of wave farms. This method, when compared to Dynamic Downscaling, showed minor differences that were within acceptable ranges for the study's purposes (with a Root Mean Square Error - RMSE - below 0.28 m for significant wave height (Hs), 1.52 s for peak period (Tp), and 13.14° for peak direction (θp)), suggesting that this downscaling method can reliably predict changes in wave conditions due to the presence of WECs.

- **Aguçadoura**

The simulations used the SNL-SWAN model to determine the interaction between the WEC device and the waves, and the expected energy extraction by the WEC. The results showed a significant energy reduction of 68% to the lee of a single WEC unit over a 15-day period. This reduction was observed to dissipate as it approached the shore, with less than 2% reduction nearshore.

The WEC farm's impact was further analysed by setting up virtual monitoring stations, which helped quantify the changes in wave height and wave energy due to the WEC farm. Stations closer to the WEC showed some reductions in significant wave height and wave energy, while stations more than 4.5 km away from the WEC farm showed a decrease in energy reduction ranging from 4% to 1%. The timeseries data from nearshore locations indicated that the changes in wave energy with and without the WEC array are negligible.

6.2 Gap analysis

Among the problems and detected gaps faced in the modelling phase of the marine dynamics modelling, Table 6 describes the most relevant issues the team has identified.

One gap related with temporal data resolution was found, since comparisons were carried out during specific period, Consequently, data should be taken for all relevant seasons in order to compare. Also gaps relating to grid resolution generating high computational costs, lack of local validation data and need to improve knowledge on real versus theoretical wave spectra were detected.

Table 6. Gap analysis of marine dynamics modelling.

Focus area	Current state	Future state	Gaps	Actions
Data temporal resolution	Data acquisition during limited period time	Deployment of wave buoys during longer period	Comparisons carried out during specific period	Data acquisition performed in all relevant seasons
Spatial data resolution	Spatial resolution of 9 m at Aguçadoura (width of the WEC)	Increased grid size for larger WEC Arrays	High computational costs reducing the number of simulated scenarios	Use HPC or supercomputers; try different numerical models; use a statistical downscaling approach based on integral wave parameters
Validation of results	No validation of the model in Aguçadoura was obtained	Results are properly validated and compared against field measurements.	No confirmation of validity of the marine dynamics model	Use field measurements obtained to assess the validation
Real versus theoretical wave spectra	The use of theoretical wave spectra simplifies the analysis of marine dynamics but may have errors	Real or theoretical wave spectra are used in the appropriate conditions	WEC are usually more efficient for intermediate sea states where remote swell may be as important as local generation	Development of criteria for the need to use real or theoretical wave spectra

7. Conclusions

In this document, we present a comprehensive summary of key insights from various modelling activities, including EMF, underwater acoustics, and marine dynamics. Additionally, we perform a gap analysis of these areas. This section offers a more succinct overview of these findings, organized by the type of WEC and specific modelling activity.

7.1 Acquired knowledge

CorPower Ocean HiWAVE-5 (Aguçadoura test site – Portugal)

- **EMF:** Values found immediately close to the cable were 99 µT for the flux density and 3232 µV/m for the electric field at cable maximum capacity.
- **Underwater acoustics:** A campaign was conducted during the commissioning phase, but due to the low representativeness of this data, no conclusions could be drawn. More deployment time should be considered to understand the real impact of the device.
- **Marine dynamics:** WEC farm impact was further analysed. One station close to the WEC showed reductions in significant wave height and wave energy. However, the WEC farm showed a decrease of wave energy ranging from 4% to 1% near the shore.

WELLO Penguin II (BiMEP test site – Spain)

- **EMF:** Slightly superior values than the ones obtained in WESE were obtained due to the fact that the model used within SafeWAVE considers also a separation layer within the two armouring layers, in which is reasonable to consider some water infiltration that leads to higher EMF emissions. The maximum EMF obtained close to the cable was 152 µT for the flux density and 5500 µV/m for the electric field.
- **Underwater acoustics:** Although obtained SPL levels are higher 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 0.47 km is found for the 125 Hz band and significant wave heights between 2.5 and 4 meter. Thus, noise level contribution from WEC can be considered as very limited. A 2 device simulation was carried out, obtaining a maximum increase of 8 km in the worst case.

Mutriku Power Plant (Mutriku test site – Spain)

- **Underwater acoustics:** Maximum disturbance distance obtained was 1.44 km for wave heights ranging between 2.5 and 4 m at the 125 Hz component. Thus, a limited propagation of the noise is observed.

SEM-REV (Le Croisic test site – France)

- **EMF:** Two cables were studied: For the dynamical umbilical cable, at 10 cm from the cable, the flux density reaches a value of about 94 μT and the electric field reaches its maximum values of around 3230 $\mu V/m$. For the export cable, similar values are found, with 98 μT for the flux density and 3084 $\mu V/m$ for the electric field.
- **Underwater acoustics:** Biggest acoustic disturbance distance found is 1.5 km for the 125 Hz component for wave heights ranging from 0.75 to 1.5 meters. Thus, a reduced and no significant contribution is found. A simulation with 8 devices was carried out and a maximum increase of 11 km in the worst case.

7.2 Gap analysis

Although the objective proposed in WP3 to model the levels of certain parameters in the fields of acoustics, EMF, and marine dynamics in order to then infer and theorise on the impacts caused by this type of devices has been met, certain interesting gaps have been identified which may serve for the development of future projects related to marine renewable energy devices.

- **EMF:** The main gap related with EMF modelling was the lack of validation data for further calibration of the models due to the lack of surveys.
- **Underwater acoustics:** Three main gaps were identified. The first one was related to the acoustic characterization of the source, as the many noise-generating mechanisms of the source are not fully taken into account. The second was related to the quality of the input data for the models, as it is difficult to find high-resolution bathymetry, which is a problem especially in small study areas such as those involved in this project. Last one was shared with EMF modelling, as no validation of the models could be performed.
- **Marine dynamics:** One gap related with temporal data resolution was found, as data should be taken for all relevant seasons in order to compare. Also gaps relating to grid resolution generating high computational costs, lack of local validation data and need to improve knowledge on real versus theoretical wave spectra were detected.

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