SAFE WAVE

STREAMLIING THE ASSESSMENT
OF ENVIRONMENTAL EFFECTS
OF WAVE ENERGY

DELIVERABLE 2.2
Monitoring of Electromagnetic fields

This Project is co-funded by the European Climate, Infrastructure and Environment Executive Agency (CINEA)

WP 2
Deliverable 2.2 Monitoring of Electromagnetic fields

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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 development of the sector. 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 that may delay the permitting of the projects.

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 were addressed by the WESE project funded by EMFF in 2018. The present project builds on the results of the WESE project and aims to move forward through the following specific objectives:

1. Development of an **Environmental Research Demonstration Strategy** based on the collection, processing, modelling, analysis and sharing of environmental data collected in WE sites from different European countries where WECs are currently operating (Mutriku power plant and BIMEP in Spain, Aguçadoura in Portugal and SEMREV 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, broaden 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

tools (i.e. WEC-ERA[1] by Galparsoro et al., 2021[2] and VAPEM[3] tools) 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.

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.

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[1] https://aztidata.es/wec-era/;

[2] Galparsoro, I., M. Korta, I. Subirana, Á. Borja, I. Menchaca, O. Solaun, I. Muxika, G. Iglesias, J. Bald, 2021. A new framework and tool for ecological risk assessment of wave energy converters projects. Renewable and Sustainable Energy Reviews, 151: 111539. https://doi.org/10.1016/j.scitotenv.2022.156037

[3] https://aztidata.es/vapem/

2. Glossary

μT	Microtesla
A	Ampere
BiMEP	Biscay Marine Energy Platform
CPO	CorPower Ocean
EMF	Electromagnetic field(s)
Hz	Hertz
h	hour(s)
kg	Kilogram(s)
kV	Kilovolt(s)
kW	Kilowatt(s)
m	Metre(s)
μm	Microtesla(s)
mm	Millimetre(s)
MRE	Marine Renewable Energy
ms	Millisecond(s)
MW	Megawatt(s)
MVA	Megavolt-ampere(s)
nT	Nanotesla(s)
V	Volt(s)
WE	Wave Energy
WEC(s)	Wave Energy Converter(s)
Wh	Watt-hour(s)

3. Executive summary

The SafeWAVE project aims to improve the knowledge on the potential environmental impacts from Wave Energy (WE) projects. In the project scope, Work Package 2 aims to collect, process, analyse, and share environmental data related to four priority areas of research: i) Electromagnetic Fields (EMF), ii) Acoustics (noise), iii) Seafloor integrity, and iv) Fish communities.

The Deliverable 2.1 (Vinagre et al., 2021) represented the first phase for the fulfilment of the objectives above, namely developing the planification of the monitoring plans for each area of research, to be implemented at three marine renewable energy (MRE) test sites where different types of wave energy converters (WECs) are installed: in Portugal, HiWave-5; in Spain, Penguin II; and in France, WAVEGEM.

The aim of Task 2.2 and the present deliverable (D2.2) is to present the main findings from EMF monitoring surveys conducted. At present, none of the WECs considered initially for the EMF surveys could be monitored due to different reasons (delays in the installation of HiWave-5 device in Aguçadoura, Portugal, unexpected removal of Penguin II due to maintenance and repair operations in BiMEP, Spain, and no connection of WAVEGEM device to the grid in SEMREV, France). Instead, and as a mitigation measure, the EMF generated by a floating wind turbine prototype – FLOATGEN – which was operational at one of the test sites (SEMREV) was monitored. Although it is a floating wind technology, aspects such as EMF could be studied around this technology and be comparable to the EMF produced by wave energy devices. This prototype is connected by an umbilical cable to an offshore collection hub which is then connected by an export cable to an onshore substation. Overall, results indicate low power production by the device during the 2-day EMF survey, leading to low EMF values which, according to the literature, should not represent significant impact to marine life.

This report will be updated with the results obtained for the monitoring of the HiWave-5 device in Portugal, which should provide further insight on EMF levels generated by WECs. All monitoring results will then be used in Task 3.1 for the modelling of EMF considering greater power production and the installation of large arrays of devices.

4. Devices under study

Three devices at three sites, representing different conditions both in terms of the technology installed and of the geographical and hydrographical conditions were intended to be monitored within the SAFEWAVE project (Figure 1, Table 1). The devices and test sites are thoroughly described in Deliverable 2.1 of the SafeWAVE project (*Development of Environmental Monitoring Plans*) (Vinagre et al., 2021).

Figure 1. Devices under monitoring of EMF. Left: HiWave-5 (CPO). Centre: Penguin II (Wello). Right: WAVEGEM (GEPS Techno).

Table 1. Devices foreseen for EMF monitoring.

WEC	Characteristics	Test site
HiWave-5	Point absorber type with a 300 kW power capacity	CPO test site, Portugal
Penguin II	Vessel shaped attenuator device with a nominal power of 600 kW	BiMEP test site, Spain
WAVEGEM	It is an hybrid autonomous energy production platform of 150 kW	SEM-REV test site, France

However, during the SafeWAVE EMF monitoring timeline any of the WECS were operational or connected to the grid. Hence, as a mitigation measure, the FLOATGEN

(BW-IDEOL) wind turbine prototype operational at the SEM-REV test site was monitored instead.

FLOATGEN is a 2 MW floating wind turbine installed in 2018 off the coast of Le Croisic, at the SEM-REV test site. It is connected to an offshore collection hub with a 20 kV umbilical cable with a capacity of 5 MVA. The hub is then connected to the onshore substation with a 24 km long 8 MVA cable (Reynaud et al., 2021). The umbilical cable is partially floating in the water column and laid on the seafloor. Since it was installed in 2012, natural burial could be expected, but this was not verified. On the other hand, the export cable is mainly buried in the seafloor (1-1.5 m depth).

At a water depth of 40 m, the turbine is supported by a concrete barge platform and moored with 6 nylon mooring lines, two in the front and four in the back of the platform, each one anchored to the seabed with a drag-embedded anchor (see Figure 1).

5. Monitoring activities

5.1 CPO test site EMF survey

At the time of writing this report, the CPO HiWave-5 device had not yet been installed at the Aguçadoura test site in Portugal, currently being used by CPO. The installation of this device is expected in May 2023. Therefore, no EMF survey was performed. The current report will be updated with the operational EMF measured along the submarine cable and onshore near the substation.

5.2 BiMEP test site EMF survey

The Wello Penguin device was deployed in BiMEP test site in August 2021. In December 2021 the device was decommissioned for inspection, maintenance, and repairs due to an alarm of leakage which was detected in November. Although the plan was to repair Penguin II and re-deploy it at BiMEP, this did not happen. Therefore, at the time of writing this report, no EMF survey was performed around the Wello Penguin II.

5.3 SEM-REV test site EMF survey

The EMF survey at the SEM-REV site was undertaken by RTSYS (https://rtsys.eu). This company is specialized in autonomous underwater vehicles and has developed the Autonomous Underwater Vehicle (AUV) COMET-300 used to perform the EMF measurements.

5.3.1 Equipment used

The COMET-300 is a two-man portable AUV which can be deployed and recovered with ease from low freeboard vessels (Figure 2), designed to cover large underwater areas in a limited time. It has several embedded sensors to track its position with a limited drift independently of the covered distance (Table 2).

Figure 2. Deployment of the RTSYS AUV COMET-300 at the SEM-REV test site. (Source: ECN)

Table 2. Summary of AUV COMET-300 specifications[4].

Weight	38 kg
Length	2 360 mm
External diameter	150 mm
Maximal speed	10 knots
Type of battery	Li-ion battery
Capacity	1000 Wh
Autonomy	20 h
Propulsion	Electrical
Embedded sensors	Navigation sensor (INS, GPS)[5] Pressure and temperature sensors Speed and elevation sensor (DVL)[6] Imaging sensors (SSS)[7]
Software	Owned software by RTSYS
Communication	ASM and UHF/WIFI (on the surface)[8]
AIS transmission	No

To measure EMF the field sensor Bartington GRAD-13 was used (Table 3, Figure 3). The Bartington GRAD-13 is a digital three-axis gradiometer that provides high resolution vector measurements of the strength and direction of magnetic fields. The sampling frequency of the sensor is 10 Hz, therefore, every 100 ms a sample is logged.

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[4] https://rtsys.eu/comet-300-auv.

[5] INS: Inertial Navigation System, GPS: Global Positioning System.

[6] DVL: Doppler Velocity Logger.

[7] SSS: SideScan Sonar

[8] ASM: Submarine Acoustic, UHF: Ultrahigh Frequency, WIFI: Wireless Fidelity.

Figure 3. Bartington GRAD-13 Digital three-axis magnetometer[9]

Table 3. Summary of the Bartington GRAD-13 sensor specifications[10].

Number of axes	Three
Bandwidth (at -3dB)	>1kHz
Measuring range	± 70 μT or ±100 μT
Maximum gradient	2x Measuring range
Offset error	<10 nT in zero field
Orthogonality error	< 1° (<0.03° after balancing)
Linearity error	< 0.0015%
Data conversion	24 bit oversampled
Extension cable	5 m

5.3.2 Survey details

The EMF survey was conducted in two days in May 2022, and led by the RTSYS members Yann Gregoire and Florian Tanguy.

For safety reasons, a first SSS survey was carried out to detect any obstacles close to the seafloor before towing the gradiometer.

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[9] https://bartingtondownloads.com/wp-content/uploads/DS3100.pdf.

[10] https://bartingtondownloads.com/wp-content/uploads/DS3100.pdf.

During the navigation, the COMET-300 travelled at 3 m above the seabed (at an average depth of -31 m) and a speed of 3 knots. The Bartington GRAD-13 sensor was towed by the AUV with a 5 m cable approximately at the same distance to the seabed as the AUV (the difference in distance to the seabed between the AUV and the sensor was around 0.1 m).

Two missions were performed, totalling 8 monitoring transects (Figure 4):

- First mission tracing the transects J1, J3, J5, J7 from North-West to South-East;
- Second mission tracing the transects J2, J4, J6, J8 from South-East to North-West.

The transects distanced by 20 m from each other, and each corresponded to a distance of approximately 350 m.

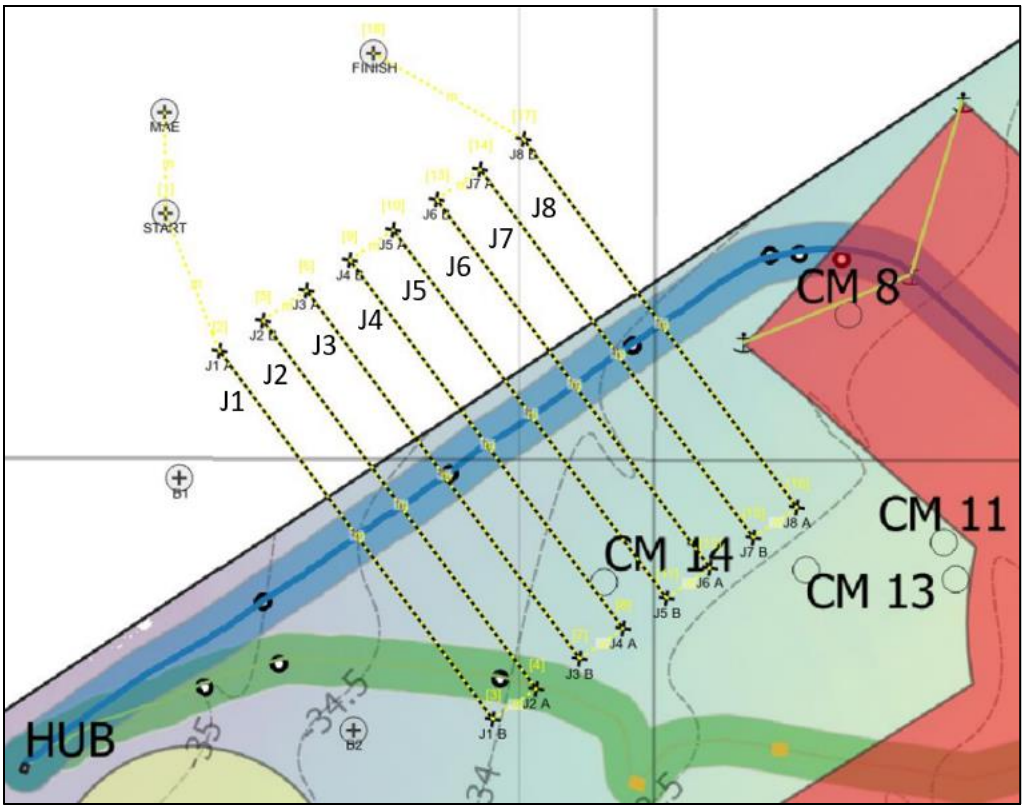

Figure 4. Transects traced by the AUV COMET-300 at SEM-REV test site. In blue the layout of the umbilical cable connecting the floating wind prototype to the connection Hub. In green, the layout of the export cable connecting the test site Hub to the onshore grid. (Source: RTSYS)

6. Monitoring results

6.1 Device operation

Energized power cables produce a magnetic field proportional to the cable current. It is therefore important to know the voltage and the current output of the 2 MW wind turbine, connected to the cable under study which was producing energy at the time of the survey (Table 4).

Table 4. Voltage (U) and current (I) of the submarine cable at the time of the survey. (Source: ECN)

	Average	Median	Standard deviation	Min	Max
U (V)	11885.90	11877.05	29.70	11829.33	11966.33
I (A)	1.82	1.74	1.79	0	7.22

Based on the rated power of the wind turbine (2 MW) and the rated power of the submarine cable (5 MVA), at the time of the campaign the power output was low, resulting in low EMF emissions. The average output power can be calculated using the formula $P = \sqrt{3}.V.I.\cos(\varphi)$, with the assumption of a power factor ($\cos(\varphi)$) of 1, returning approximately 37.5 kW.

6.2 EMF measured

The colormap in Figure 5 shows the EMF detected by the field sensor. In particular, the magnetometer spots the umbilical cable, which is the main cable under study (shown in the centre of the map), going from the wind turbine to the collection hub, and the export cable (shown in the lower-left angle of the map) that evacuates the energy from the hub to shore (the collection hub is not part of the area covered during the survey).

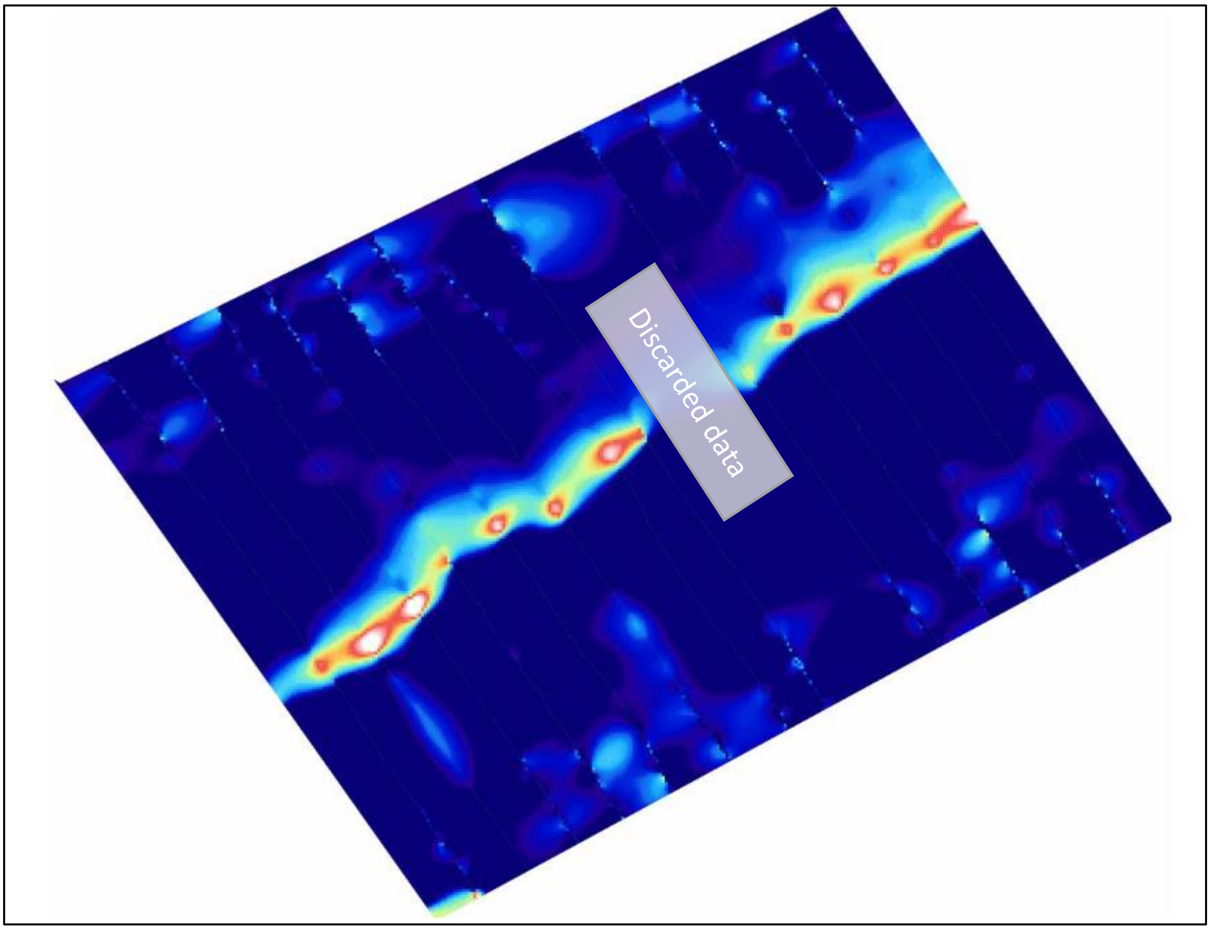

Figure 5. Colormap of the EMF detected by the Bartington GARD-13 sensor at the SEM-REV test site. (Source: RTSYS)

Figure 5 presents a part (at the middle) with missing data due to positioning issues of the AUV during transect J5. As shown in Figure 6, there is a position jump during which the data collected could be unreliable and, therefore, disregarded to avoid using uncertain data.

During the survey the magnetometer sensed the geomagnetic field, the field generated by the submarine cable and some noise due to its proximity with the AUV (5 m of proximity). The data were analysed with the software Sonarwiz (https://chesapeaketech.com/products/sonarwiz-sidescan/) which automatically removed the geomagnetic contribution. The following graphs are, therefore, plotting the EMF measured without the geomagnetic field.

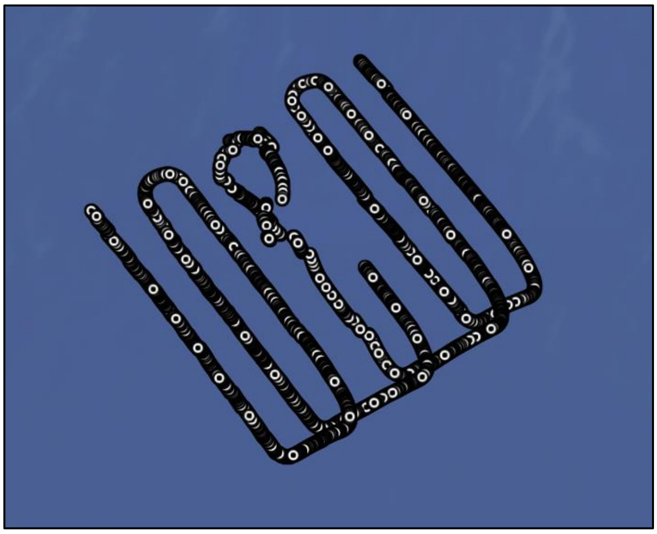

Figure 6. EMF sampling along the 8 transects.

The overall EMF measured (including the geomagnetic and the cable contribution) across the eight transects returned a magnitude of the magnetic field close to the geomagnetic field – equal to 47.5 μT (Vinagre et al., 2021) and 45,4 5 μT (Reynaud et al, 2021). After the geomagnetic field was subtracted to the total EMF by Sonarwiz, the EMF being generated in the umbilical cable were in the order of nT.

Figure 7 presents the EMF of the umbilical cable detected during transect J7 moving from South-East to North-West, and corresponding to a window of samples from 11660 to 12680 (x-axis). Knowing that the EMF decays with the distance, the plot shows that the AUV gets closer to the cable, passes above it (peaks) and then moves away from it. At first, the EMF detected is between 1 and -1 nT, probably due to noise created by the AUV itself, and at the time in which the sensor is above the cable the EMF shifts from a negative value to a positive one reaching a peak of around 12.8 nT. After the peak, the EMF returns to the initial low values as the AUV gets further from the cable. The same trend was observed for data acquired during transects J1, J3, and J5.

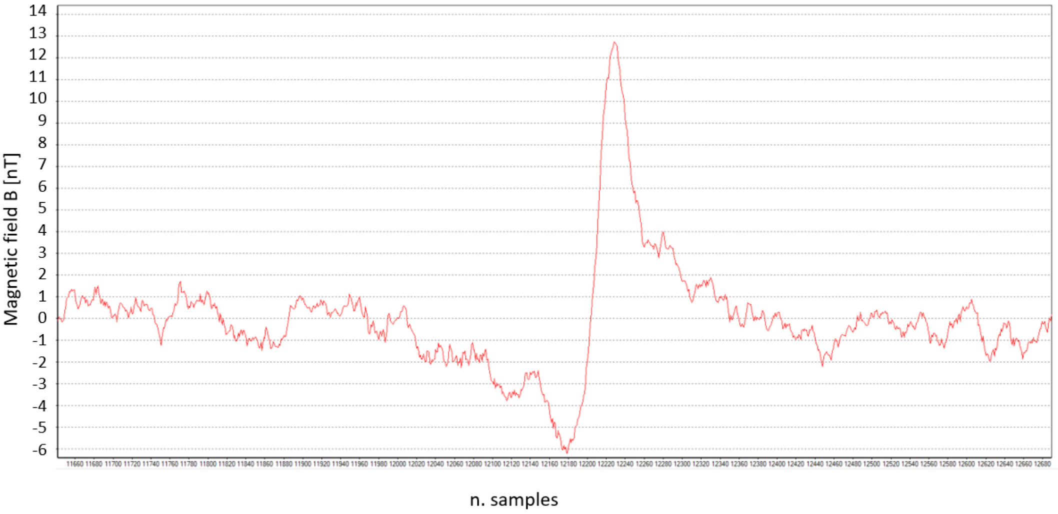

Figure 7. Magnetic detection of the cable, transect J7 from South-East to North-West. (Source: RTSYS)

Figure 8 presents the EMF detected along the transect J4, moving from North-West to South-East. It should be noted that since the magnetic field is proportional to the electric current, its sign will be dependent on the direction in which the electric current is flowing. Therefore, since the electric current flows always in the same direction, but in transect J4 the AUV is moving in the opposite direction compared to transect J7, the sensor first detects positive values of the field and then negative values. The peak value is around 9.4 nT which is close to the one measured in the previous transect and in the expected order of magnitude. The same trend is expected for data acquired during transects J2, J6, and J8.

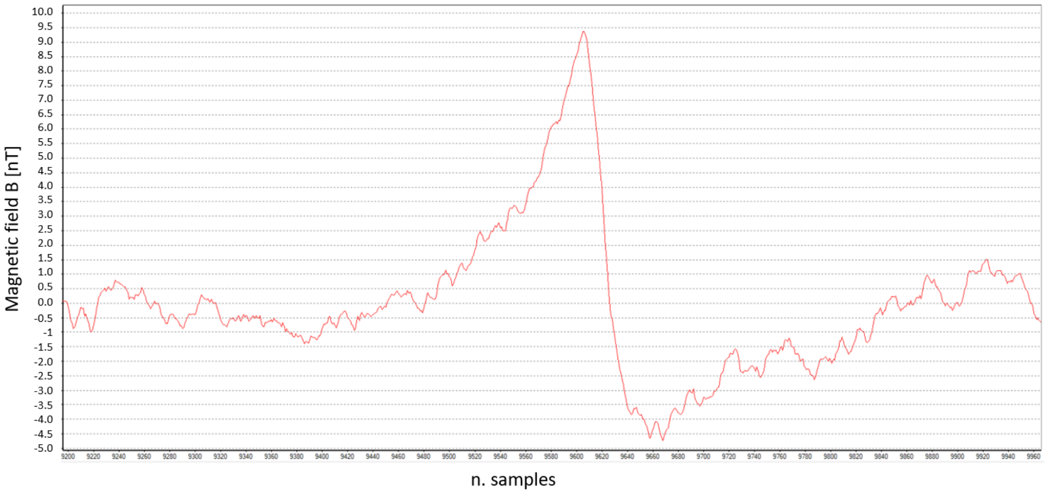

Figure 8. Magnetic detection of the cable, transect from North-West to South-East. (Source: RTSYS)

As shown in the colormap (see Figure 5), during the campaign besides the EMF generated by the umbilical cable, the EMF generated by the export cable was also monitored. Figure 9 presents the EMF detected in the South path between transect J1 and transect J2 where the export cable is laid.

At the time of the survey, the only device connected to the collection hub was the FLOATGEN wind turbine, hence, the umbilical and export cables were transporting the same amount of power (considering potential losses as negligible for the purpose of the study). The EMF shown in Figure 9 is in the same order of magnitude as the previous ones presented in Figure 7 and Figure 8 but it shows a slightly higher peak, around 20 nT (still significantly lower than the value of the geomagnetic field). Although the difference in peaks is not significantly high, it could be associated with the export cable (i) having overall smaller diameter than the umbilical one, and (ii) being a single armour cable, different from the umbilical cable which is double armoured. The armouring layer is composed by steel, which has a magnetic permeability of 300 (CMACS, 2003), able to contain the magnetic field within the cable and therefore reducing the emissions. Consequently, the peak of magnetic field can be slightly higher in the export cable because of the single armour layer.

In Figure 9 it can also be noticed that the magnetic field curve looks smoother and wider than the curves in Figure 7 and Figure 8, due to the fact that AUV is moving horizontally from one transect to the other, crossing the export cable for a longer time.

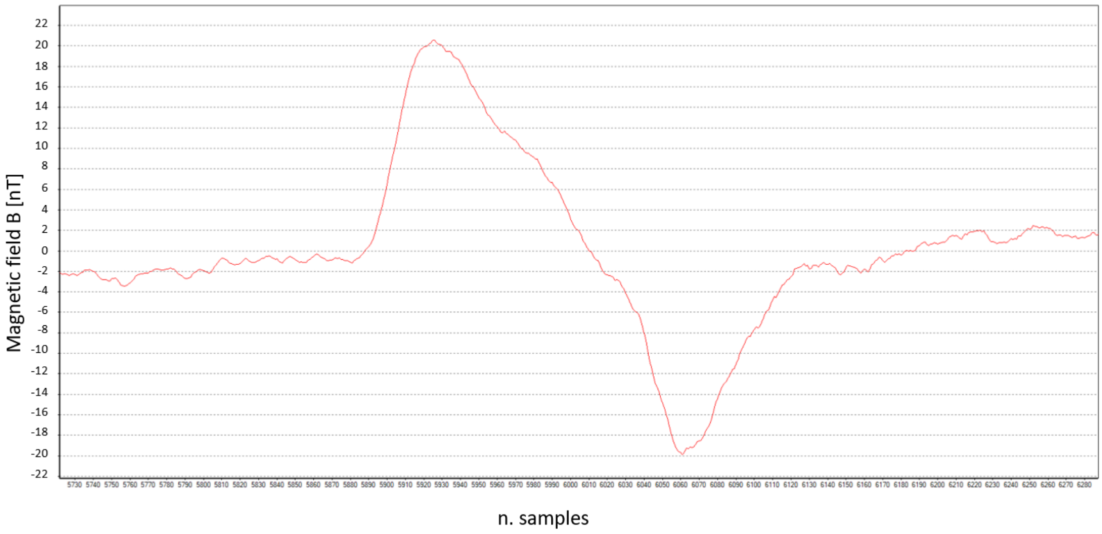

Figure 9. Magnetic detection of the export cable, South transect. (Source: RTSYS)

6.2.1 Other EMF monitoring at SEM-REV

The results from the present monitoring campaign at SEM-REV can be further compared and verified with previous surveys performed in August 2017 and in October 2019 within the scope of the SPECIES project (https://www.france-energies-marines.org/en/projects/species/).

The first survey was carried out without any device being connected to the grid (namely to the hub). It was conducted by MAPPEM GEOPHYSICS (https://www.mappem-geophysics.com/) using the PASSEM mobile system towed by a vessel at an approximate distance of 6-7 m from the seabed (Figure 10).

The magnetic fields measured, corresponding only to the geomagnetic field, ranged between 45.1 μT and 45.7 μT (Reynaud et al., 2021). The range of measurements is explained by the fact that besides some natural variation the geomagnetic field varies based on waves, current, movement of the field sensor in the water, and potential influence of land electrical equipment.

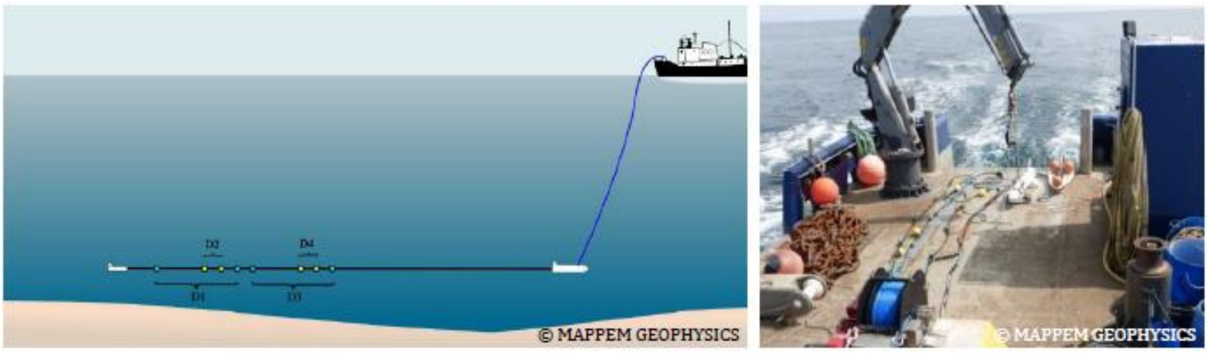

Figure 10. Diagram and picture of the PASSEM© system (Source: Reynaud et al., 2021).

The second survey was performed with both export and umbilical cables energized by the FLOATGEN device. The survey was done using the STATEM static system to measure the EMF (Figure 10). The STATEM system is an autonomous seafloor electromagnetic measurement station for long term monitoring. STATEM is equipped with a state-of-the-art 3-axis fluxgate magnetic sensor and two perpendicular electric dipoles. This instrument records 5 components of the EMF at 512 Hz for up to about 1 month. The STATEM system was placed at 2 m from the hub, 5 m from the export cable, and approximately 10 m from the umbilical cable.

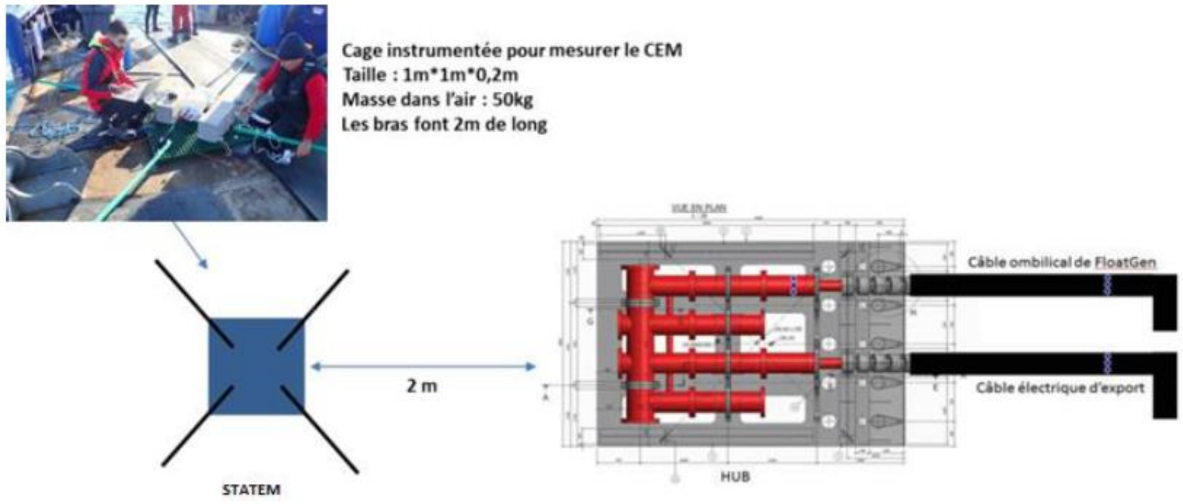

Figure 11. Diagram and picture of the STATEM© system. (Source: Reynaud et al., 2021).

During the survey, at a distance of 5 m from the seabed and with a phase current of 55 A, the maximum magnetic field measured was 6 nT.

7. Discussion and conclusions

In WE and other marine energy sectors (tidal energy, wind energy), EMF are produced in submarine cables throughout their extension from the device (or between devices) to an offshore substation (either fixed or floating) or a submarine hub, or to a substation onshore.

Such EMF have the potential to affect different marine animals by different means and levels, for example:

- the ability of animals (e.g., cetaceans, migratory fish, turtles, and some crustaceans) to use Earth’s natural geomagnetic fields for large-scale migrations (e.g., Keller et al., 2021; Klimley et al., 2021);
- the ability of elasmobranch fish to detect and respond to very low frequency bioelectric fields emitted by prey or mates and for orientation (Collin & Whitehead, 2004);
- the development, physiology, and/or behaviour of sensitive fish and invertebrate species (Hutchison et al., 2018, 2020; Scott et al., 2021).

However, to date, there is not enough evidence to determine if there are significant negative impacts, especially long-term physiological or behavioural effects, as a consequence of interaction between organisms and EMF generated by WEC installations (Hutchison et al., 2018; Gill & Desender, 2020), especially when considering the installation of large-scale, commercial farms in the near future.

The SafeWAVE project tackles the monitoring of EMF produced in submarine cables. To that, the project implemented a novel methodology, i.e. using an AUV (instead of a vessel) to tow a magnetometer allowing to acquire EMF data (namely magnetic field data) close to and covering a large extend of a submarine cable.

Unfortunately, for different reasons mentioned earlier (delays in the installation of HiWAve-5 device, unexpected removals of Penguin II due to maintenance and repair operations and the no connection of WAVEWGEM device to the grid), it was not possible to monitor the EMF produced by WECs. Instead, a floating wind turbine prototype was monitored, FLOATGEN. The prototype was connected by a 5 MVA umbilical cable to a collection hub at the SEM-REV test site in France.

As mentioned in the results section, the EMF are proportional to the levels of currents and voltages at which the power cable operates. It is therefore important to underline that at the time of the survey the power produced by FLOATGEN (37.5 kW) suggests that the umbilical cable, sized for a rated power of 5 MVA, was being used quite below its capacity, justifying the low values of magnetic field detected. In fact, the survey returned results in the order of nT (highest peak of 13 nT) having an expected geomagnetic field in the site of around 47 $\mu\mathrm{T}$. For the purpose of this study, it would be important to understand the level of EMF emissions at the rated conditions of the wind turbine and at the rated current of the cable. Nevertheless, performing a campaign when wind turbines or WECs are producing the maximum power can be challenging from a logistics viewpoint. Although the AUV can be operated in rough sea states, the low freeboard vessel from which the AUV is deployed and retrieved is not designed for facing such conditions safely. This means that this part of the project can be implemented with important limitations and that it would be better to implement autonomous systems capable of monitoring over long periods of time and different sea conditions to overcome these limitations and obtain better results.

Despite the limitations mentioned above, a previous EMF monitoring conducted in the SPECIES project acquired data while the FLOATGEN was operating at rated conditions. Namely maximum 6 nT magnetic fields (significantly lower than the geomagnetic field) were measured at 5 m from the export cable, which is aligned with the Ampére Law of EMF decay with distance. Once again, the surveys show that even with significantly higher current values the magnetic field is in the order of the nT at a distance of 5 m from the cable. Similar results were found by Chainho & Bald (2020) for the monitoring of the Marmok-A-5 WEC in the BiMEP test site, although the magnetic field values were quite below (maximum 0.15 nT) than the present ones (13 nT and 20 nT for the umbilical and export cables, respectively), mostly owed to low power production during calm sea state.

Empirical research about the effects of EMF on marine animals have been mostly dedicated to fish and invertebrates. Detrimental effects to different species have been reported (e.g., Fisher & Slater, 2010; Albert et al., 2020), seeming that their probability and magnitude depend on the species, development stage, environmental conditions, and type of field (static vs alternating). A few examples for magnetic fields are provided below:

- Levin & Ernst (1995) reported delayed or abnormal embryonic development in sea urchins (*Strongylocentrotus purpuratus*) by 10 mT static magnetic fields.

- Nishi et al. (2004) showed a significantly slowed heartbeat by the Japanese eel (*Anguilla japonica*) exposed to 10 to 40 conditioning runs of $\sim$12.7 μT to 192.5 μT magnetic fields.
- Bochert & Zettler (2004) reported no differences in survival rates in blue mussel (*Mytilus edulis*), North Sea prawn (*Crangon crangon*), round crab (*Rhithropanopeus harrisii*), glacial relict isopod (*Saduria entomon*), and flounder (*Plathichthys flesus*) between "control" subjects and those exposed to 3.7 mT magnetic field for several weeks.
- Hutchison et al. (2020) reported increased exploratory and/or area restricted foraging behaviour by the electro-sensitive little skate, (*Leucoraja erinacea*) and the presumed magneto-sensitive American lobster (*Homarus americanus*). That was indicated by increased distance travelled, large turns, and time spent closer to the seabed, in areas were maximum 18.7 μT to 20.7 μT magnetic fields emitted by HVDC cables were measured.
- Scott et al. (2021) reported minimal physiological and behavioural changes on edible crab (*Cancer pagurus*) exposed to 250 μT magnetic fields. Crabs were attracted to fields of 500 μT and 1000 μT, with a significant reduction in time spent roaming. Furthermore, 500 μT and 1000 μT increased stress-related parameters.

As it can be seen from the examples above, effects of magnetic fields on animals, namely fish and invertebrates, were originated by exposure to magnetic levels considerably higher (three to six orders of magnitude) than those found in the present monitoring (13 nT and 20 nT for the umbilical and export cables, respectively). Therefore, it is most likely that the EMF, namely the magnetic fields, measured at the umbilical or export cables at SEM-REV have no significant impact, if any impact, on such animals.

The comparison of the present results with those obtained in the EMF monitoring expected for the HiWave-5 device in Portugal should provide further insight on EMF levels generated by WECs. Furthermore, SafeWAVE Task 3.1 (EMF modelling) will provide additional understanding of the potential EMF (both magnetic and electric fields) generated by the WECs under study and FLOATGEN. The task will focus on modelling the EMF considering different levels of power production and especially addressing the installation of large arrays of devices.

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