Assessment of the changes induced by a wave energy farm in the nearshore wave conditions

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1. Introduction

Following the oil crises in the 1970s, the possibility of exploiting ocean waves for the production of electricity became more real. Since then, several methods are feasible and many areas of the world are shown to have the potential coastal wave energy that could be converted into useful electric power.

Ocean waves suitable for the energy extraction are a product of the surface winds. Hence the energy transferred depends on the wind speed, the wind duration and the distance over which the wind blows, known as fetch. In the coastal areas, several factors influence the wave power, such as: the type of the coastline, the nearshore bathymetry, the wave breaking type and the coastal refraction and diffraction. Deep offshore wave energy extractions are also being considered nowadays, although the accesses to the power grids and to the wave farms for maintenance are important challenges in these cases. Nevertheless, it becomes more and more obvious that waves represent a considerable renewable energy resource with great potential and relatively low environmental impact.

As regards the expected environmental impact, harvesting the wave power is less environmentally degrading than most of the other forms of power generation. Wave energy converters (WECs) produce no gaseous, liquid or solid emissions. However, their deployment, when it comes to a wave farm, may have some impact on the coastal zones (Brooke, 2003). A large WEC array has the power to alter the wave climate between the array and the coast. Large waves usually propagate from seaward and any effects of the WECs on the wave kinematics can be understood to be shoreward the devices. Most WECs extract energy from swell or low frequency wind waves, which generally corresponds to a much greater source of power than higher frequency local waves. Therefore, shoreward the WEC the energy, and implicitly the height, of the long waves will be reduced. Perhaps the most significant effect of the WECs will be on the sediment suspension and the sediment transport. This is because the longshore transport of material is dependent on the size and direction of the incoming waves (Shields et al., 2011).

In fact, even the presence of a wind farm in the coastal environment may induce some changes in the nearshore dynamics, as discussed in Ponce de Leon et al. (2011). From this perspective, the estimation of how much the wave climate will be changed and which will be the impact when an energy farm operates in the nearshore represents a problem of significant
importance. Moreover, exactly due to their possible coastal impact, floating wave energy converters can play also an important role in the coastal protection, as analyzed by Zanuttigh and Angelelli (2013).

From this perspective, estimations of the effects on the wave conditions near the shoreline due to the installation of the wave farms have been studied by several researchers. The 30 MW-rated wave farm known as “Wave Hub” was the focus of two studies, done by Millar et al. (2007) and Smith et al. (2012), where the changes in the nearshore wave climate were analyzed. Both studies use the SWAN model (Simulating Waves Nearshore, Booij et al., 1999) to evaluate the impact of the wave farm. The first one implements an obstacle and varies the energy transmission percentages from 0% to 90%, representing different scenarios corresponding to different WEC arrays. The study of Smith et al. (2012) goes further and the SWAN code was modified in order to enable frequency-dependent wave energy transmission through a barrier rather than constant wave energy transmission. Three configurations for the barrier were considered: a line, a row with a series of small 100 m width barriers and two rows of 100 m barriers. The less complex study concluded that the wave height decreases linearly at the shore line with increasing wave energy transmission, the realistic scenario of 90% wave energy transmission produces an average change in terms of \(H_t\) of 1 cm or less over the 11 months modeled and the maximum change is of about 4 cm. The second study showed that the use of the spectral sea states rather than the integral wave parameters (height, period, etc.) is essential since it was observed that if the peak of the transfer function corresponds to the spectral region between two peaks, minimal energy will be extracted. When compared with the previous studies, it is noticeable that previous assessments have over-estimated the shoreline impact.

In the northwest Iberian coastal environment, Carballo and Iglesias (2013) have also investigated the impact of a wave farm on the nearshore, but their study aimed more to quantify the interactions of the WECs with the waves using laboratory tests. The case study implemented illustrated a wave farm on the Death Coast (NW Spain). The wave energy transmitted was determined by means of a 3D physical model and based on those results the nearshore wave climate was evaluated using the SWAN model. The results indicated that the difference between a single-row and a double-row layout is negligible at a distance of 5000 m or greater down wave from the farm.

In the Portuguese continental nearshore, Palha et al. (2010) used the REFDIF model (Kirby and Dalrymple, 1994) to assess the energy extraction in one of the two Portuguese maritime pilot zones, São Pedro de Moel, which represents also the target area of the present work. Three different sinusoidal wave conditions were considered for five different wave farm configurations, varying the position and the number of the WECs as well as the width of the navigation channels at each wave farm. It was concluded that the energy extraction did not exceed 9.3%, 23% and 14% of the incident energy in the wave farms, respectively for January, July and October. In absolute terms, no major differences were found on the wave heights observed near the coast when considering each wave farm configuration and the case without wave farms. The maximum variation was of 29 cm for the month of July.

Rusu and Guedes Soares (2013a) also performed a study which was focused on the Portuguese coastal area of Peniche. The objective was to evaluate the local and coastal impact of a wave farm based on Pelamis converters. This was done not only by estimating the influence of the wave farm on the down wave conditions with the SWAN model, but also by evaluating its effect on the nearshore circulation using the ISSM modeling system (the Interface for SWAN and Surf Models, Rusu et al., 2008, Rusu and Guedes Soares, 2010), which is an easily operable tool that has been designed to simulate waves and longshore currents. The ISSM system is composed of a MATLAB GUI in the foreground, which directs the integration of the SWAN wave model with a 1D surf model (Mettlach et al., 2002) in the background. Two wave farm configurations were considered, the first consisting in a line of five Pelamis converters and the second in two lines. The wave directions assumed were 270° and 340° and for each direction average \(H_t=2.8 \text{ m}\) and high \(H_t=5.2 \text{ m}\) waves were considered, respectively. The results have shown that \(H_t\) decreases more than 10% for the first wave farm configuration and more than 20% for the second configuration, situation that also affected a sensible larger area. Then again, nearshore data demonstrate that the coastal impact is highly attenuated showing relative values of \(H_t\) not greater than 5%. In regard to the current velocities, the wave farm induced in general a decrease of about 5–8%, but also in some situations due to drastic changes in the wave directions the nearshore current velocities were also increased.

In this context, the objective of the present work is to evaluate the medium term coastal impact of a generic wave farm that would operate in the Portuguese maritime pilot zone at São Pedro de Moel, considering different scenarios by increasing gradually the conditions from zero absorption (situation without wave farm) to the hypothetic situation of the total energy absorption.

### 2. Modeling the wave climate in the Portuguese nearshore

A wave prediction system based on WAM (WAMDI group, 1988) for wave generation and SWAN for coastal transformation was considered for various evaluations of the wave patterns in the Portuguese continental coastal environment. These concerns especially the wave energy spatial distribution, as presented in Rusu and Guedes Soares (2008, 2009 and 2013b) and in Rusu and Guedes Soares (2011). Considering the same approach the wave conditions and energy in the Portuguese archipelagos Madeira and Azores, were analyzed in Rusu and Guedes Soares (2012a and 2012b).

Further wave predictions covering the entire western side of the European coast (including thus also the Portuguese continental nearshore) are based on medium term simulations with a different wave modeling system (Bento et al. 2011, Silva et al. 2012, Gonçalves et al. 2014a, 2014b) that uses Wave Watch 3 (WW3) (Tolman, 1991) for the wave generation at the scale of the entire North Atlantic Ocean forced using reanalysis wind data of NCEP/NCAR and SWAN for the coastal wave transformation forced with wind fields produced by the atmospheric model MM5 (Fifth-Generation NCAR/Penn State Mesoscale Model, Dudhia et al., 2000). More details related to the MM5 model implementation on the West Iberian coast are given in Guedes Soares et al. (2011). The computational domains defined for this modeling system, which was focused on the Portuguese maritime pilot zone (Pedro de Moel) are described in Table 1 and illustrated in Fig. 1.

The implementation of the SWAN model was made for 36 directions and 30 frequencies logarithmically spaced from 0.05 Hz to 0.6 Hz at intervals of \(\Delta f=0.1\). The model was executed without the influence of currents. The computations were performed in the non-stationary mode with a 20 min time step. The number of

<table>
<thead>
<tr>
<th>Computational domain</th>
<th>Geographical limits (lat/long)</th>
<th>(\Delta X \times \Delta Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Atlantic (WW3)</td>
<td>13 N–72 N/65 W–22 E</td>
<td>1.54 × 1.46</td>
</tr>
<tr>
<td>Portugal continental (SWAN)</td>
<td>35 N–45 N/11 W–6 W</td>
<td>0.05 × 0.1</td>
</tr>
<tr>
<td>São Pedro de Moel (SWAN)</td>
<td>39.5 N–40 N/9.5 W–8.8 W</td>
<td>0.5 × 0.5</td>
</tr>
</tbody>
</table>
iterations was set to 4 so the numerical accuracy would be increased between iterations. These specifications are presented in Table 2, along with the characteristics of the computational domain and presenting also the physical processes activated for each area.

This system was used in the present work and its results were first evaluated against the measurements coming from two directional buoys that operate in the Portuguese nearshore. The first buoy is located in the north of the Portuguese continental coast, close to the port of Leixões (41.2033°N, 9.0883°W) and operates at about 83 m water depth, and the second is located in the central part, close to the port of Sines (37.9211°N, 8.9289°W) at about 97 m. The $H_s$ classes distributed for each directional bin of 10°, as resulted from the buoy measurements (Leixões and Sines) for the entire year 2009 are illustrated in Fig. 2.

Model system simulations were performed for the entire year 2009 and both direct comparisons and statistical analyses show that in general it is a good concordance between the model data and the measurements. Thus direct comparisons, model simulations against buoy measurements for the wave parameters $H_s$ and $T_{M01}$,
are illustrated in Figs. 3 and 4 for the buoys of Leixões and Sines, respectively. As regards the error statistics this usually assumes in wave modeling the estimation of some parameters like: mean values, bias, RMSE (root-mean-square-error), SI (scatter index) and \( r \) (correlation coefficient also called Pearson’s product momentum correlation). The statistical results for the two wave parameters considered (\( H_s \) and \( T_m (TM_{01}) \)), corresponding to the comparisons against the two buoys, are presented in Table 3 while the scatter plots are illustrated in Figs. 5 and 6. As the statistical results presented in Table 3 indicate, a very good correlation exists between the model results and the buoy measurements with correlation coefficients greater than 0.9, even greater than 0.95 for the buoy of Leixões that operates in the north. Also, all the other statistical parameters indicate that the modeling system developed provides in general reliable results that can be used for further assessments related to the impact of the wave energy extraction in the coastal

Fig. 2. The \( H_s \) classes distributed for each directional bin of 10° as resulted from the buoy (Leixões and Sines) measurements for the entire year 2009.

Fig. 3. Direct comparison wave model against Leixões buoy for the wave parameters \( H_s \) and \( T_m (TM_{01}) \), on the \( x \) axis is the number of data points.

Fig. 4. Direct comparison wave model against Sines buoy for the wave parameters \( H_s \) and \( T_m (TM_{01}) \), on the \( x \) axis is the number of data points.
environment. Another observation would be that slightly better results are systematically encountered in the northern side.

Starting from the observation that various technologies for wave energy extraction can provide different efficiency in the same coastal environment, Silva et al. (2013) performed evaluations of the performance in the Portuguese continental nearshore of some different state of the art technologies for the wave energy extraction. The results of the above study show that, although they have relatively different efficiencies along the Portuguese coast, various WEC devices can produce important amounts of electric power and in order for this electricity to become cost effective large scale deployments of WEC arrays are expected in the near future in the Portuguese nearshore. Of course, these deployments will start in the Portuguese maritime pilot zones. From this perspective, such medium term assessments of the coastal impact of a generic wave farm that would operate in the target area (the pilot zone São Pedro de Moel) are performed next.

3. Assessment of the impact on the down wave conditions of the wave farm

In order to account in the SWAN model for the generic wave farm considered, the command obstacle was activated. The obstacle is assumed as a subgrid in the sense that it is narrow compared to the steps in the geographical space and its length should be at least one-step long (SWAN team, 2013a). The obstacle location is defined through a sequence of corner points of a line. Such obstacles interrupt the propagation of the waves from one grid point to the next and they will affect the wave field in three ways:

- Will reduce the wave height of the waves that propagate through or over it, will cause wave reflection, and will cause wave diffraction around its corner. For these reasons, SWAN can reasonably account for the wave propagation around an obstacle if the directional spectrum of the incoming waves is not too narrow. Several mechanisms were developed for wave transmission. In the SWAN model this is computed as transmission of waves passing over a dam with a closed surface, or alternatively as a constant transmission coefficient.

Together with the command obstacle, either specular reflection, when the angle of reflection equals the angle of incidence, or diffuse reflection, case when the incident waves are scattered over reflected direction, may be considered. In this way, the effect on the waves in front of the wave farm can be also considered.

As regards diffraction, a phase-decoupled refraction–diffraction approximation is implemented in SWAN (Holthuijsen et al., 2003). This approach is based on the mild-slope equation for refraction and diffraction, omitting phase information and for this reason it does not permit coherent wave fields in the computational domain.

The wave farm, considered to be deployed in the Portuguese maritime pilot zone, operates at about 80 m water depth and consists of 5 groups of devices, spaced between them by 1.118 km, each group is 2.5 km long and are located about 17 km distance to the shoreline. The configuration of the wave farm can be seen in Fig. 7. The length of the farm was defined to cross the entire pilot area São Pedro de Moel, geographical space where this farm is assumed to be deployed. On the other hand, starting from the fact that in order to increase the efficiency of such wave farms the

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**Table 3**

Statistical results for the wave parameters $H_s$ and $Tm01$, wave modeling system against buoys (simulations for the year 2009 with 3 h time step).

<table>
<thead>
<tr>
<th></th>
<th>$B_{med}$</th>
<th>$P_{med}$</th>
<th>Bias</th>
<th>RMSE</th>
<th>SI</th>
<th>$r$</th>
<th>$N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$ (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leixões</td>
<td>2.035</td>
<td>2.158</td>
<td>$-0.123$</td>
<td>0.418</td>
<td>0.205</td>
<td>0.951</td>
<td>3781</td>
</tr>
<tr>
<td>Sines</td>
<td>1.590</td>
<td>1.898</td>
<td>$-0.308$</td>
<td>0.549</td>
<td>0.345</td>
<td>0.911</td>
<td>2928</td>
</tr>
<tr>
<td>$Tm01$ (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leixões</td>
<td>7.390</td>
<td>7.449</td>
<td>$-0.059$</td>
<td>1.361</td>
<td>0.184</td>
<td>0.745</td>
<td>3781</td>
</tr>
<tr>
<td>Sines</td>
<td>6.848</td>
<td>6.431</td>
<td>0.418</td>
<td>1.356</td>
<td>0.198</td>
<td>0.727</td>
<td>2928</td>
</tr>
</tbody>
</table>

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**Fig. 5.** Scatter plots for the wave parameters $H_s$ and $Tm$, simulations against measurements at Leixões buoy for the entire year 2009.
trend is to consider larger WEC arrays, the wave farm defined here was considered much longer than those from the previous works. The reason behind this approach was also to assess how such long farms would affect the nearshore wave climate.

The values of the wave energy transmission factors are still not completely understood or openly disclosed by the WEC producer companies. Moreover, they depend not only on the farm geometry, but on a wider range of factors and they often seem to have a dynamic behavior in relationship with the wave conditions. Therefore, probably the best way of approaching the real scenarios would be to consider a broad range of possibilities. Following the results of the studies performed by Millar et al. (2007) and Smith et al. (2012), various transmission situations were analyzed as presented in Table 4 and denoted as CS1 (case study 1) to CS5. Thus, it was started from the situation without wave farm (zero energy absorption) and different scenarios were successively considered by increasing gradually the conditions to the hypothetical case of the total absorption. In the approach considered, no wave absorption was assumed in the gaps between the devices and the command obstacle was set for each segment individually.

For each case study, model simulations were performed covering the entire year of 2009 using the wave prediction system based on WW3 for the wave generation at the level of the entire North Atlantic Ocean and on SWAN for the coastal wave transformation that was described in the previous section. In this way, a comprehensive picture of the possible medium term impact of the wave farm is provided.

A first visual estimation of the coastal impact induced by the wave farm in each case study considered is illustrated in Fig. 8 that presents the significant wave height scalar fields and the wave vectors corresponding to three different propagation patterns that were encountered in January 2009. These are: time frame 15/01/2009/12 h waves coming from west, time frame 20/01/2009/00 h waves coming from northwest and time frame 30/01/2009/3 h waves coming from southwest. Following these three real situations, Fig. 8(a) presents the results for the case of zero energy transmission (CS5), Fig. 8(b) presents the results for the case of 40% energy transmission (CS4), Fig. 8(c) presents the results for the case of 70% energy transmission (CS3) and Fig. 8(d) presents the results for the case of 90% energy transmission (CS2).

As expected, Fig. 8 shows that the significant wave height scalar fields are diminished on large spaces behind the wave farm, although even for the hypothetic case of the zero energy transmission (total absorption of the waves by the farm) these decrease is attenuated at the level of the breaking line.

A first picture concerning the average wave energy in the target area and the impact of various transmission situations (as defined in the case studies from CS1 to CS5) is provided by Fig. 9. Thus,
corresponding to the results of the simulations performed with the wave modeling system for the entire year 2009, Fig. 9 presents the average wave power that resulted in each case study structured on winter and summer time, respectively (the summer time is the period from April to September while the winter time is the rest). As illustrated in the above figure, the average wave power over meter of wave front in the target area is between 40 kW/m and 45 kW/m for the winter time and between 10 kW/m and 12 kW/m for the summer season.

In order to assess the medium term coastal impact of the wave farm, for the five different case studies considered, the model results concerning the values of the main wave parameters were analyzed in ten reference points located close to the shoreline. The geographical positions of these points are illustrated in Fig. 10 over the bathymetric map of the target area. The depths of the reference points are between 10 m and 15 m and thus the average values of the main wave parameters are estimated in shallow water before the start of the wave breaking process. The parameters evaluated are: $H$ (significant wave height), $H_{swell}$ (significant wave height of the swell), $T_m$ ($T_{M01}$—mean wave period), $T_p$ (peak period), $\text{Dir}$ (mean wave direction), $\text{DSPR}$ (directional spreading of waves), $\text{FSPR}$ (frequency spreading of waves). All these parameters represent direct output of the SWAN model and their definitions are given in the user guide of the SWAN model (SWAN team, 2013b). For each wave parameter separately, Figs. 11–17 present the variations CS1 against CS2-5 in the ten reference points considered, corresponding to the results of the wave model simulations structured on summer and winter time, respectively.

4. Discussion

The analysis of the results was focused mainly on the variations in terms of significant wave height and significant swell height induced by the different transmission situations considered. Thus, Fig. 11 illustrates the decrease of the significant wave height (in absolute value) in the ten reference points considered from CS1 to CSK (with $K$ the number of the case study, from 2 to 5) corresponding to winter and summer time, respectively. The above significant wave height variations ($\Delta H_{sk}$) were computed as

$$\Delta H_{sk}(i) = H_{sk}(i) - H_{sk}(i),$$

where: (i) is the number of the reference point, $H_{sk}(i)$ represents the significant wave height corresponding to CS1 and $H_{sk}(i)$ represents the significant wave height corresponding to CSK. The relative variations were also evaluated and they were computed using the relationship

$$\varepsilon_{sk}(i) = 100 \frac{\Delta H_{sk}(i)}{H_{sk}(i)},$$

From the analysis of the data, it resulted that in both seasons the most affected locations by the presence of the wave farm

Fig. 8. SWAN simulations in the Portuguese maritime pilot zone. Significant wave height spatial distribution (a) Energy transmission 0% (CS5), (b) Energy transmission 40% (CS4), (c) Energy transmission 70% (CS3), and (d) Energy transmission 90% (CS2). For each situation three different cases are assumed: (1) time frame 15/01/2009/12 h waves coming from west; (2) time frame 20/01/2009/00 h waves coming from northwest; and (3) time frame 29/01/2009/3 h waves coming from southwest.
correspond to the reference points P5 to P9 with the maximum variations in P7. Thus, in comparison with the situation without wave farm (CS1) for winter time, in P7 it can be noticed a $H_s$ decrease of 7.3 cm for CS2, of 23 cm for CS3, of 49.6 cm for CS4 and of 93.6 cm for CS5. In relative terms, the corresponding values (as evaluated using the relationship 2) are: 5.1% for CS2, 10.7% for CS3, 26.5% for CS4 and 65.5% for CS5. As regards the summer period, in comparison with the situation without the wave farm (CS1), in P7 it can be noticed a $H_s$ decrease of 4.4 cm for CS2, of 13.8 cm for CS3, of 29.5 cm for CS4 and of 55.2 cm for CS5. In relative terms, the corresponding values are: 4.9% for CS2, 10.6% for CS3, 25.8% for CS4 and 62.3% for CS5, percentages that are slightly lower than in the winter time. Similar relationships with (1) and (2) were considered to evaluate the variations of the other wave parameters.

As regards the significant height of the swell, which is related to the low frequency part of the spectrum, as illustrated in Fig. 12, the same tendency is noticed in the sense that the most affected

![Wave Power](image-url)
reference points are P5 to P9. In absolute terms, the swell decreases in P7 are, in winter time, of 6.1 cm for CS2, of 19.2 cm for CS3, of 41.4 cm for CS4 and of 78.8 cm for CS5 while in summer time the corresponding values are: 2.3 cm for CS2, 7.1 cm for CS3, 15.1 cm for CS4 and 28.6 cm for CS5. It has to be highlighted that in relative terms the variations of this parameter are higher than in the case of the significant wave height. Thus in the winter time, the resulting percentages are: 5.8% for CS2, 11.7% for CS3, 29.1% for CS4 and 74.98% for CS5, while in the summer time they are: 6.25% for CS2, 12.2% for CS3, 30.1% for CS4 77.7% for CS5. Looking at these values it can be also noticed that unlike in the case of the significant wave height, for the swell in the summer time the relative decays are slightly more pronounced than in the winter time.

As it can be seen from the results presented in Figs. 13 and 14 in terms of mean and peak periods the variations are less relevant, with the exception of the last case study that is associated to total absorption. Nevertheless, an interesting feature is that while in the points more affected from the point of view of the wave height (P5 to P9) a slight decrease of the period is induced by the wave farm, in the other points (which are in fact the points closer to the extremities) an enhancement of the wave period can be noticed.

In terms of mean wave direction, the variations from one case study to another are illustrated in Fig. 15. Variations of only a few degrees are usually encountered, with the exception of the last case study when considerably greater variations occur, which may reach 6 degrees in the winter time and almost 8 degrees in the summer time. Another particularity related to the variation of this parameter along the reference points is that in the southern points a decrease of the wave direction is encountered (positive variations) while in the northern points an increase in terms of wave direction occurs (negative variations). The inflection point is near to the reference point number 7 in the winter time while in the summer time is moved to the south between the reference points number 6 and 7.

![Fig. 10.](image1.png)

**Fig. 10.** The bathymetric map of the target area and the geographical positions of the ten reference points.

![Fig. 11.](image2.png)

**Fig. 11.** $H_s$ variations for CS1 against CS2-5 in the ten reference points considered corresponding to the results of the wave model simulations structured on summer and winter time, respectively.

![Fig. 12.](image3.png)

**Fig. 12.** $H_{swell}$ variations for CS1 against CS2-5 in the ten reference points considered corresponding to the results of the wave model simulations structured on summer and winter time, respectively.
The other two wave parameters evaluated are illustrated in Figs. 16 and 17, respectively. They are $DSPR$, which represents the directional spreading of the waves and is in fact the one-sided directional width of the spectrum or the directional standard deviation, and $FSPR$, representing the frequency spreading of the waves or the normalized frequency width of the spectrum. From the analysis of the data it results that the variations of these quantities for the ten reference points and corresponding to the case studies considered do not reflect any significant tendency with the exception of the last situation considered that corresponds to the total absorption.

Since it is expected that for a real wave farm, the transmission conditions will be in fact those between the case studies CS2 and CS3, the conclusion of this section is that in terms of significant
wave height the average coastal impact in the target area would be a decrease of this parameter between 7 cm and 23 cm for the winter season and between 5 cm and 14 cm for the summer season. In relative terms, these values indicate a decrease of the significant wave height between 4% and about 14%. Another conclusion of the analysis performed in this section would be that, although the absolute values of the significant wave height decays are greater than those of the significant height of the swell, in relative terms the significant height of the swell appears to be a more sensitive parameter to the presence of the wave farm, with an expected decay in percentage between 5.8% and 11.7% for the winter time and between 6.25% and 12.2% for the summer time. As the results also show, for a greater absorption rate the decay in relative terms of the significant height of the swell becomes even more noticeable in relationship with the significant wave height.

5. Conclusions

Starting from the fact that large marine farms are expected to operate in the near future in many coastal environments, a fundamental aspect relates the correct evaluation of the nearshore impact induced by such large marine power plants. From this perspective, evaluations of the main wave parameters were carried out in the present work for one entire year (2009) considering various case studies related to the energy absorption produced by a generic wave farm that is assumed to be deployed in the the Portuguese maritime pilot zone, São Pedro de Moel. The results show that, while immediately behind the farm drastic changes occur in the wave fields, they are gradually attenuated at the level of the shoreline. This is also due to the relatively large distance between the location of the wave farm and the shoreline. Nevertheless, for the coastal environment considered, decays in terms of significant wave height of up to 23 cm can be expected before the surf zone. Moreover, it has to be also highlighted that according to the results presented in the present work, the low frequency part of the spectrum (the swell) is more sensitive to the presence of the wave farm than the high frequency part (the wind seas).

On the other hand, it has to be underlined that the coastal impact of the wave farms should not be expected as necessarily negative. This is because, by reducing the down wave energy, the farms can be used also for coastal protection (Norgaard et al., 2011). Nevertheless, besides a general decrease of the significant wave height, changes might also appear in relationship with some other wave parameters, as the mean wave direction or the directional and frequency spreading. This might lead locally to unexpected modifications in the shoreline dynamics, as for example the enhancement of the longshore current velocity (as shown in Rusu and Guedes Soares, 2013a).

Finally, the medium to long term environmental impact of the marine energy farms represents a very important issue, which is
yet insufficiently studied, and it becomes obvious that a lot of studies are still required in this direction, studies that should be focused on the characteristics of each particular case considered.

Acknowledgment

This work has been performed with the project MAREN—Marine Renewable Energy—Energy Extraction and Hydro-environmental sustainability, which is partially funded by the Atlantic Area Program.

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