WAVE FARM LAYOUT AND COASTAL IMPACTS

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Understanding the impacts of wave energy exploitation is crucial if it is to develop as a fully-fledged renewable. The objective of this work is to investigate whether the impacts of a wave farm on the nearshore wave conditions change significantly depending on its layout, and if so, in which manner. This investigation is carried out through a wave farm project proposed for NW Spain. The impact resulting from one- and two-row layouts of the farm is compared under different wave conditions representative of the area, leading to twelve case studies. We find that the different layouts do produce substantially different wave conditions immediately behind the farm. The differences in the nearshore for the cases studied are, however, not so large, but could increase if the farm is placed closer to the shoreline.

Keywords: wave energy; ocean energy; marine renewable energy; coastal processes; nearshore impacts; coastal defence.

INTRODUCTION

Wave energy is one of the renewables with the greatest potential for development. Indeed, the global wave resource is vast, and important advances are being made to develop the technology for harnessing this resource. Understanding the impacts of wave energy exploitation is therefore crucial, and in this context, the objective of this work is to investigate the coastal impacts of an array of wave energy converters (WECs), also known as a wave farm. More specifically, we focus on the following research question: does the layout of the wave farm play a role in its coastal impacts?

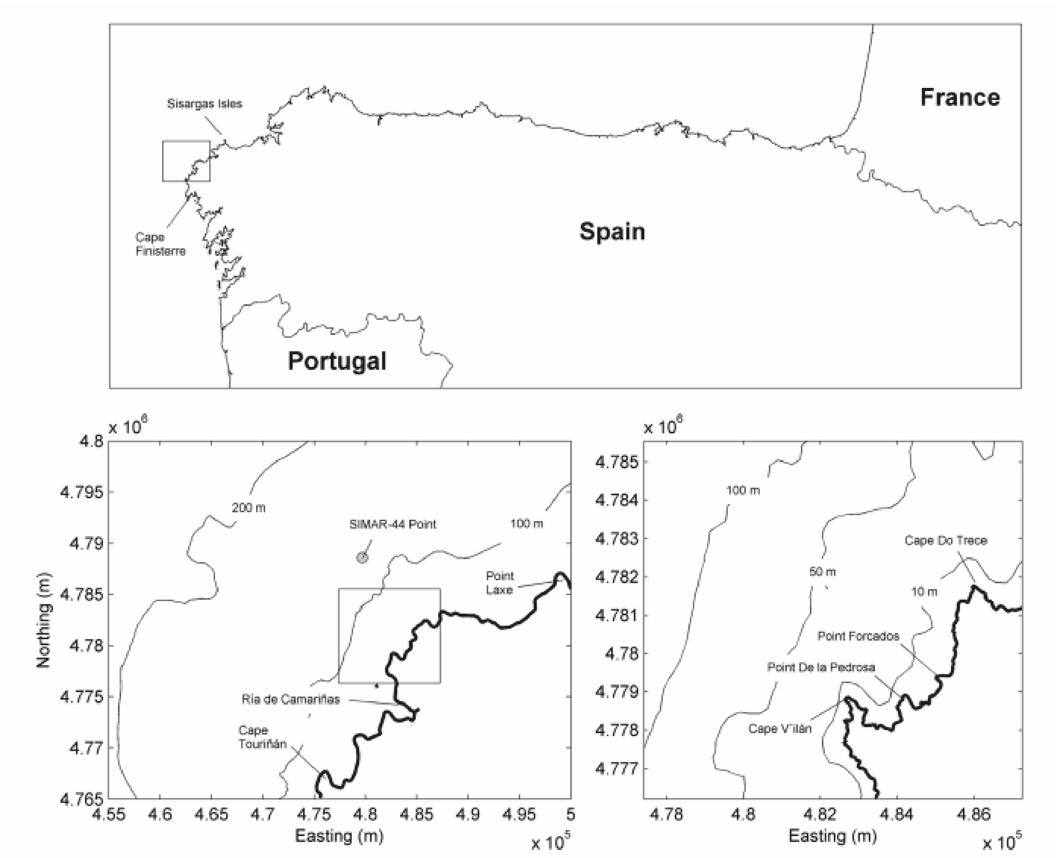

Figure 1. Study area: Spain's Costa da Morte (Death Coast), one of the areas with the largest wave resource in Europe.

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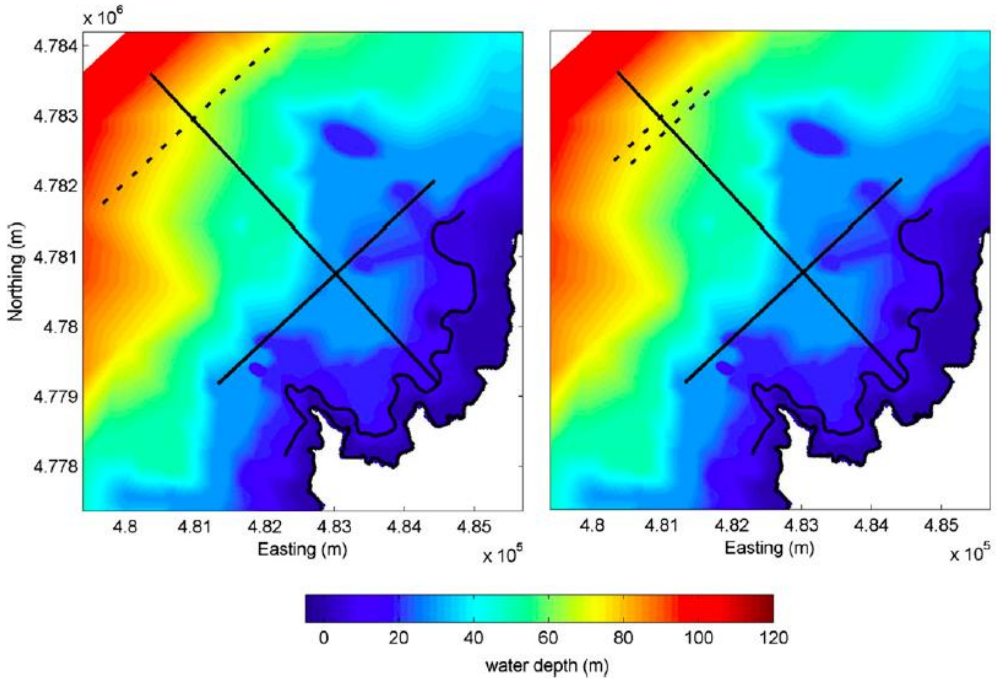

Figure 2. Wave farm layouts with one (left) and two (right) rows of WECs and bathymetry of the study area. The 10 m contour and reference lines perpendicular and parallel to the farm are also depicted.

MATERIAL AND METHODS

Study area

To ascertain whether the farm layout plays a significant role in its coastal impacts, we consider a wave farm project offshore Spain's *Costa da Morte*, the stretch of coastline extending between Cape Finisterre and the Sisargas Islas, in Galicia (NW Spain) (Figure 1). Its name translates literally as 'Death Coast', a reference to the many wrecks induced by its energetic wave climate). With an average power of 50 kWm-1, the Death Coast has, alongside the Cape Ortegal - Estaca de Bares area, the largest wave resource of the Iberian Peninsula, and one of the largest in Europe. A detailed analysis of the resource in the area was carried out by Iglesias and Carballo (2009).

Case studies

For this wave farm project we consider twelve case studies, formed as the combinations of two wave farm layouts plus a baseline (no farm) case with four wave conditions. The two layouts have the same number of WECs distributed in either one or two rows (Figure 2). The layout is described in more detail in Carballo and Iglesias (2013) The four wave conditions are obtained in turn as a result of combining two pairs of significant wave height and peak period representative of summer and winter scenarios with two mean directions typical of the wave climate in the area (Table 1).

Numerical modelling

The coastal wave propagation model (SWAN) (Booij *et al.* 1999), calibrated and validated for the study area as part of an assessment of the vast wave resource in the area (Iglesias and Carballo 2009), is implemented on a computational grid with two levels of refinement. The area of the wave farm and that in its lee (between the farm and the coastline) were covered by a high-resolution grid, with a spacing of 18 m in both directions (approximately one tenth of the wavelength) so as to delineate the individual WECs of the farm and accurately resolve their wakes, and hence that of the wave farm as a whole. For the remainder of the computational area a coarser grid was used so as not to be burdened with too large computational times.

The interaction between the individual WECs of the farm and the wave field was accounted for through the wave transmission coefficient, itself obtained through laboratory tests of WaveCat, an overtopping WEC whose patent is conjointly owned by the University of Santiago de Compostela (Spain) and Plymouth University (UK). The laboratory tests were conducted in a large wave tank at a

1:30 scale, as reported by Fernandez *et al.* (2012). The tests provided useful information on the performance of the WEC and its interaction with the wave field.

RESULTS AND DISCUSSION

The wave power distribution in the baseline (no farm) scenario under winter wave conditions from NW (case study CS1, Table 1) is presented in Figure 3. Fairly smooth in deep water, the distribution becomes more irregular as waves approach the coastline and interact with the bathymetry, giving rise to so-called nearshore hotspots (Iglesias and Carballo 2010)

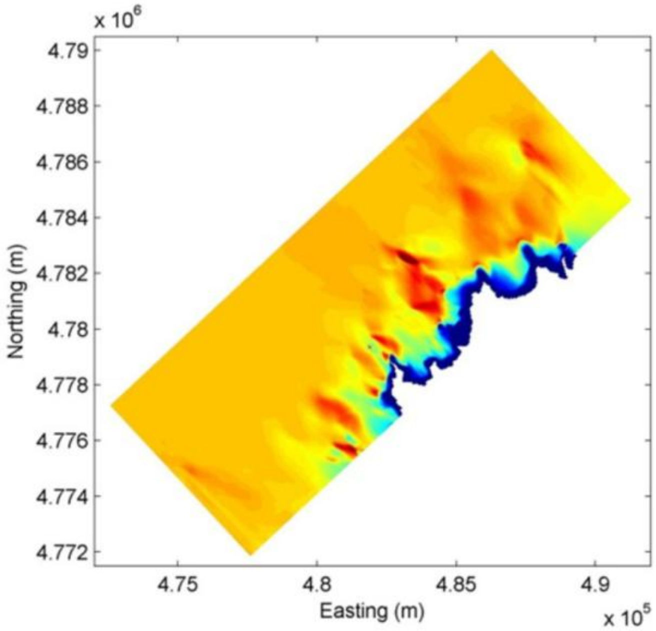

Figure 3. Wave power distribution in the baseline situation under typical wave conditions (case study CS1, Table 1) [*J* = wave power].

The results corresponding to the one-row and two-row layouts under the same wave conditions, or case studies CS2 and CS3 (Table 1), are presented in Figures 4 and 5, respectively. The "shadow" of the farm is apparent - as is its lack of uniformity, which is due as before to the interaction of the wave field with the highly irregular bathymetry of the area. A detail of the wave farm area is also included in the figures, so that the resolution of the individual wakes of the WECs can be appreciated.

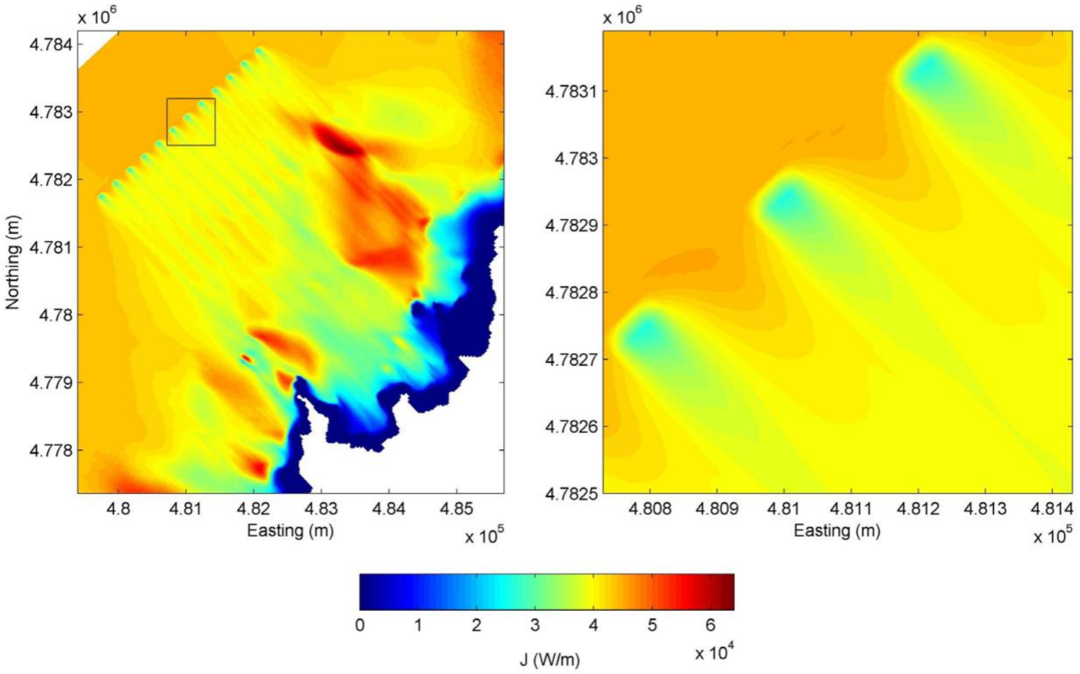

Figure 4. Wave power distribution with the one-row layout (case study CS2, Table 1) [*J* = wave power].

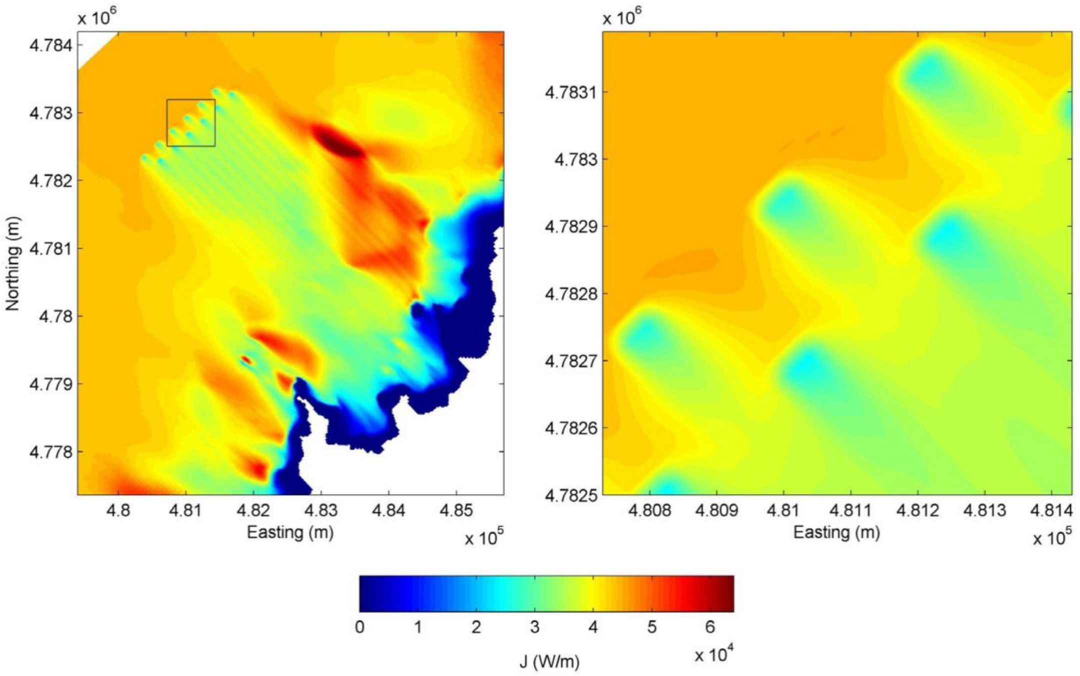

Figure 5. Wave power distribution with the two-row layout (case study CS3, Table 1) [*J* = wave power].

The reduction in wave power and significant wave height along a line passing through the centre of the farm in the incident wave direction is presented in Figure 6. The maximum impact is a reduction of approximately 18 kW/m in wave power, of the order of 30% of the baseline value. Advancing towards the coastline this impact is progressively offset by the energy diffracted from both sides of the farm. Significant differences exist between the one- and two-row farms immediately behind the farm.

Importantly, however, these differences decrease towards the coast, so much so that at approximately 4 km they are very minor.

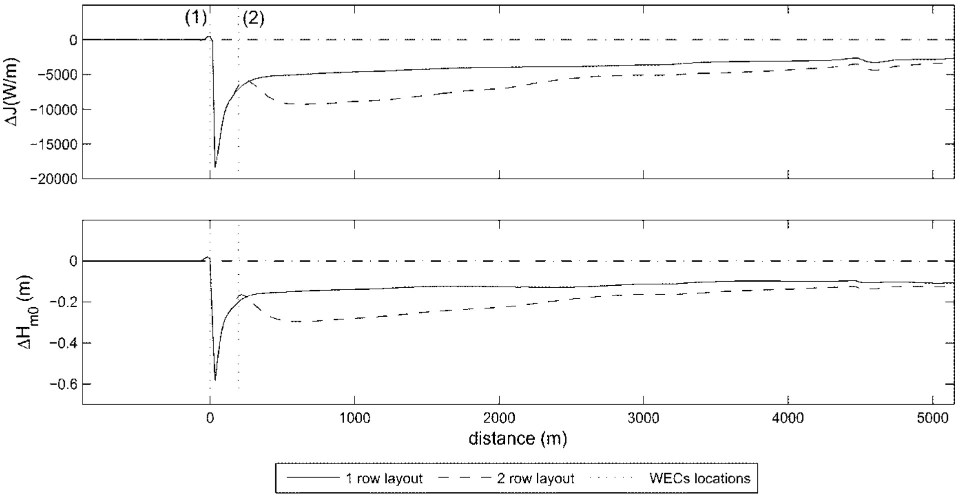

Figure 6. Reduction in wave power (ΔJ) and significant wave height (*ΔH_{m0}*) as a result of the operation of the wave farm along a line passing through the centre of the wave farm in the incident wave direction.

The impacts of the wave farm on the nearshore wave conditions of the one- and two-row layouts are presented in Figure 7 in terms of the deficit of wave power and significant wave height relative to the baseline scenario along the 10 m contour. A more detailed analysis can be undertaken, in particular using the *ad hoc* indicators developed by (Abanades *et al.* 2014; Abanades *et al.* 2014), but for the present purposes the aforementioned deficits are sufficient. The maximum impact in terms of reduction of wave power is approximately 5 kW/m, or 20% of the baseline values. The main aspect to be retained for the purposes of this work is that the differences between both layouts in terms of wave conditions along the coast are not very substantial. Thus, on the grounds of these case studies, the answer to the research question seems to be that the wave farm layout does not play a significant role. Notwithstanding, these results need not hold in the case of a radically different layout, e.g., with WECs very close to, or very far from, each other (the distances between adjacent WECs and between rows in the two layouts considered were similar).

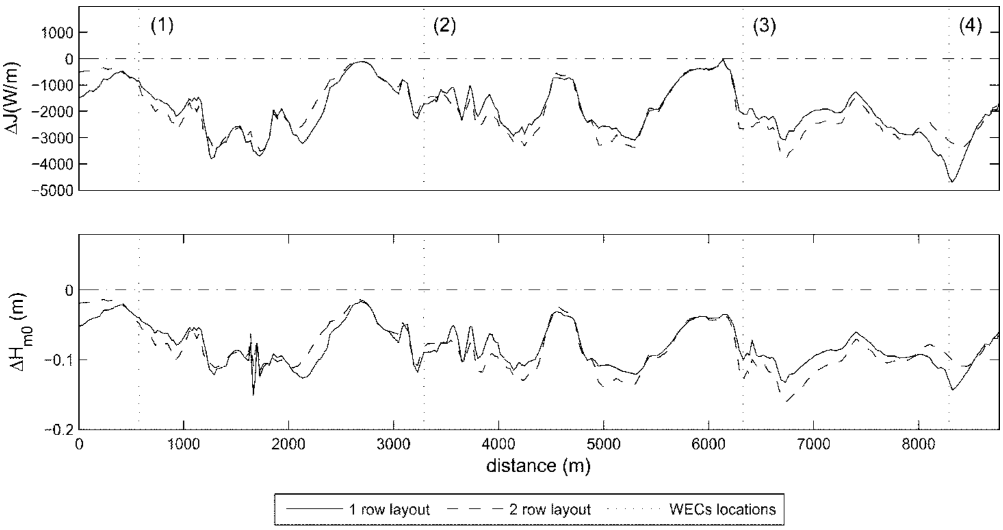

Figure 7. Reduction in wave power (ΔJ) and significant wave height (*ΔH_{m0}*) as a result of the operation of the wave farm along the reference nearshore contour (10 m water depth).

CONCLUSIONS

Overall, the wave farm, whatever its layout, produces a deficit in the wave energy flux (relative to the baseline situation) in its lee – a direct consequence of the energy absorbed by the WECs. This deficit is translated directly into the nearshore wave height and hence the wave power.

As regards the question of whether the impacts of the wave farm on the nearshore wave conditions depend on the wave farm layout, it was found that the layouts compared in this work did not lead to significant differences in wave height or power in the nearshore. Immediately behind the farm, however, relevant differences were found. For this reason, if the wave farm is located closer to the shoreline the differences in the nearshore between the different layouts can be expected to be more marked. It goes without saying that these conclusions hold as long as the layout is not changed radically. In particular, if the WECs are placed very close to each other the results may be expected to differ from those found here.

The bathymetry played an important role in the wave power distribution in the lee of the farm. Thus, the coastal area to the southeast of the farm experienced a completely different impact from that to its south, and this impact also varied in a different manner when the farm layout was modified – differences caused by a shoal close to the eastern end of the farm. It follows that the impacts of different layouts must be analysed for each specific case.

ACKNOWLEDGMENTS

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