Wave energy farms as coastal defence elements under global warming

Rafael J. Bergillos*[1], Cristóbal Rodríguez-Delgado[2] and Gregorio Iglesias[3]

*Corresponding author: rafael.bergillos@uco.es
[1]Hydraulic Engineering Area, Department of Agronomy, University of Córdoba, Campus Rabanales, Leonardo Da Vinci Building, 14071, Córdoba, Spain
[2]PROES Consultores, Calle San Germán 39, 28020, Madrid, Spain
[3]MaREI, Environmental Research Institute & School of Engineering, University College Cork, College Road, Cork, Ireland

Keywords: Wave energy, Sea level rise, Coastal protection, Erosion, Flooding

Introduction

The development of renewable energy is one of the most relevant targets confronting society in the coming decades, due to the finite nature of fossil fuels, their high costs and, last but not least, the environmental impacts of their exploration and use, including climate change and the subsequent sea-level rise. Wave energy is, among the renewable energy sources, one of the most promising due to its comparatively huge potential and low impacts on the environment.

This work analyzes the efficiency of wave energy farms as coastal protection elements against erosion and flooding under sea-level rise. The study site (Playa Granada, southern Spain, Figure 1) is a deltaic beach which has been experiencing strong erosion and flooding issues in the past two decades, mainly induced by human interventions in the Guadalfeo River basin.

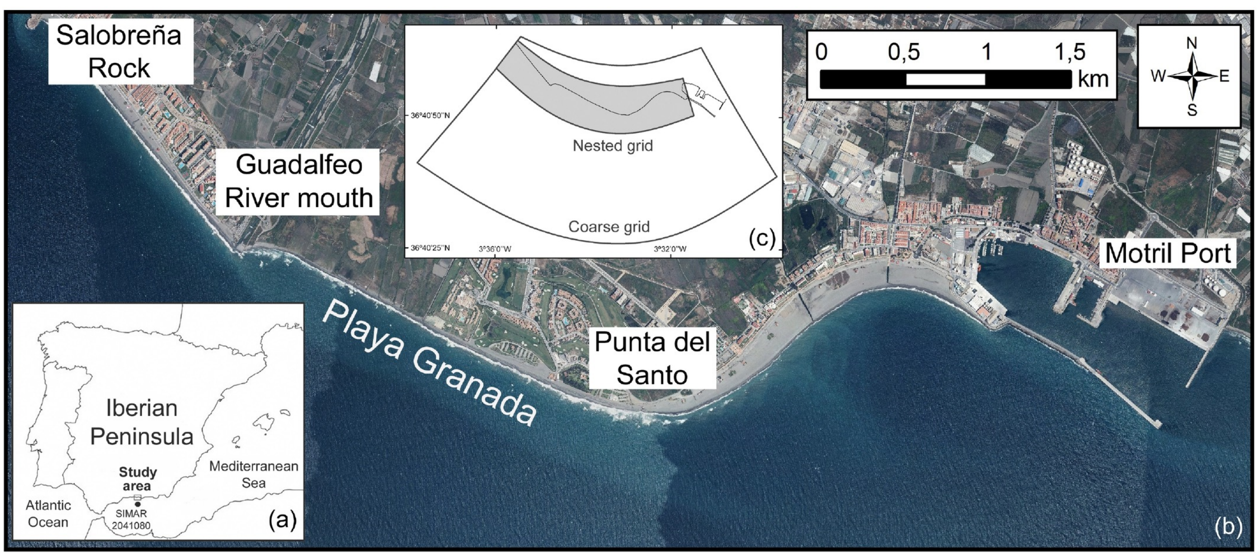

Figure 1: (a) Location of the study area in southern Spain, (b) plan view of the deltaic coast, indicating the studied stretch of beach (Playa Granada), (c) contours of the numerical grids used in the SWAN model. [Source: Bergillos et al. (2019). Reproduced with permission of Elsevier].

Methodology

In order to analyze the effects of a wave farm on wave propagation and coastal flooding, we selected the wave farm location indicated in Figure 1, with the geometrical center situated at 30 m water depth. This position was found to be optimum in terms of both wave energy availability (Rodriguez-Delgado et al., 2018b) and coastline protection (Rodriguez-Delgado et al., 2018a). The wave farm layout consisted of eleven WaveCat devices, distributed in two rows and with an inter-device spacing equal to 180 m (Figure 2).

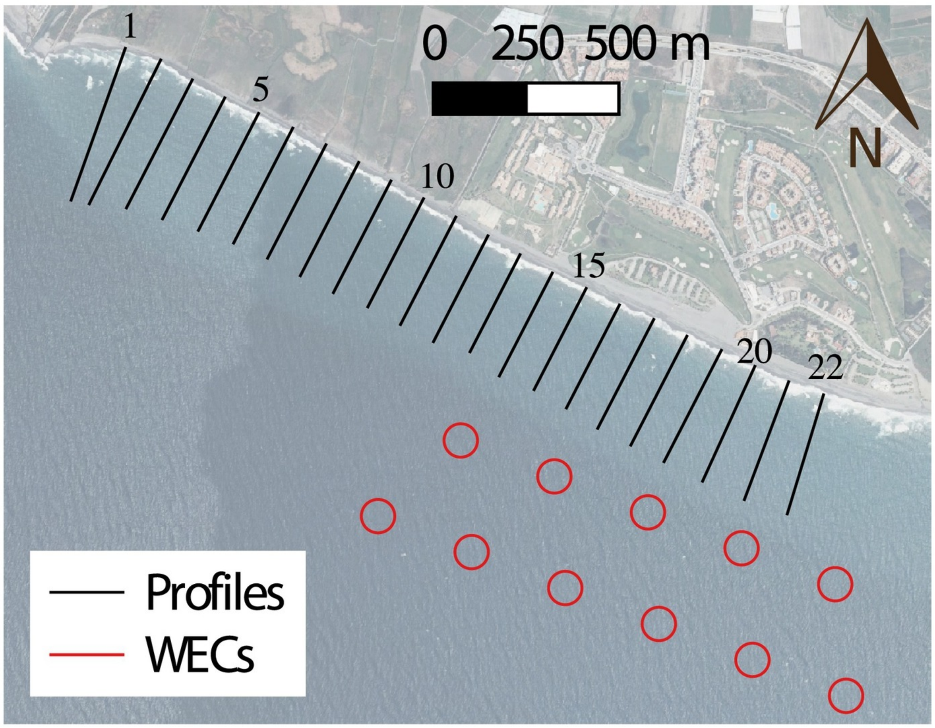

Figure 2: Location of the studied beach profiles (1–22, in black) and wave energy converter farm (in red). [Source: Bergillos et al. (2019). Reproduced with permission of Elsevier].

WaveCat is a type of overtopping WEC composed by two hulls connected by the stern, with a distance between them commonly equal to 90 m. The efficiency of WaveCat and the wave farm layout selected for coastal defence purposes has been widely demonstrated in previous works (Rodriguez-Delgado et al., 2019).

The performance of wave farms for coastal defense against erosion was evaluated through the joint application of a wave propagation model (Delft3D-Wave), a LST formulation and a one-line model under three sea-level rise scenarios: the present situation (SLR0), and the optimistic (SLR1) and pessimistic (SLR2) projections proposed by the Intergovernmental Panel on Climate Change in 2014. This allowed computing the final position of the shoreline and final dry beach areas for the three scenarios under storm conditions for the prevailing wave directions at the study site (southwest and southeast).

On the other hand, to evaluate the efficiency of the farm for coastal protection against flooding, the Delft3D-Wave and XBeach-G models, previously validated for the study site, were coupled and applied to 22 beach profiles in order to assess wave propagation patterns, total run-up values (including water level), flooded cross-shore distances and total flooded area for the prevailing storm directions and the three SLR scenarios. In both cases (protection against erosion and flooding), the results were compared to the baseline (no farm) case study to properly quantify the effects of the wave energy farm.

Results and conclusions

The results indicate that the absorption of wave power by the wave farm affects wave propagation in its lee and, in particular, wave heights, with alongshore-averaged reductions in breaking wave heights about 10% (25%) under westerly (easterly) storms. These lower significant wave heights, in turn, induce variations in the shoreline evolution and flooded dry beach area.

In the case of protection against shoreline erosion, under westerly waves the wave farm reverses the behavior of the coast from an erosive to an accretionary response in every sea-level rise scenario. Whereas the subaerial beach area differences without the wave farm are 90.15 m^2, -42.83 m^2 and -51.66 m^2 for scenarios SLR0, SLR1 and SLR2, respectively; with the wave farm these differences are 2.31 m^2, 28.76 m^2 and 8.14 m^2, respectively. Under the easterly storm, the coastal response is accretionary, and this behavior is strengthened by the wave farm.

On the other hand, in terms of coastal flooding mitigation, the presence of the farm leads to alongshore-averaged run-up reductions for the three sea-level rise scenarios and for both wave directions. The flooded cross-shore distances are also reduced by the farm along the studied coastline section for both wave directions and the three sea-level rise scenarios. Importantly, the dry beach area flooded under westerly (easterly) storms is reduced by 5.7% (3.2%), 3.3% (4.9%) and 1.99% (4.5%) in scenarios SLR0, SLR1 and SLR2, respectively.

Thus, the results indicate that the wave farm reduces erosion and promotes accretion regardless of the sea-level rise scenario considered. The run-up and flooded dry beach area are also reduced by the wave farm for the three scenarios. In general, sea- level rise strengthens the effectiveness of the wave farm as a coastal protection mechanism. This fact enhances the competitiveness of wave farms as coastal defense elements compared to traditional hard engineering solutions such as groynes or detached breakwaters, whose effectiveness tends to weaken under sea-level rise.

Acknowledgments

This work was supported by the research grants WAVEIMPACT (PCIG-13-GA-2013-618556, European Commission, Marie Curie fellowship, fellow GI) and ICE (Intelligent Community Energy, European Commision, Contract no. 5025). RB was partly funded by the University of Granada (*Programa Contratos Puente 2017*) and the Spanish Ministry of Science, Innovation and Universities (*Programa Juan de la Cierva 2017*, FJCI-2017-31781). Wave, sea-level rise, bathymetric and DEM data were provided by *Puertos del Estado* (Spain), *Universität Hamburg* (Germany), *Ministerio de Agricultura, Pesca y Alimentación* (Spain) and *Instituto Geográfico Nacional* (Spain), respectively.

References

Bergillos, R.J., Rodriguez-Delgado, C., Iglesias, G., 2019. Wave farm impacts on coastal flooding under sea-level rise: a case study in southern Spain. Science of the Total Environment 653, 1522–1531. doi:10.1016/j.scitotenv.2018.10.422.

López-Ruiz, A., Bergillos, R.J., Ortega-Sánchez, M., 2016. The importance of wave climate forecasting on the decision-making process for nearshore wave energy exploitation. Applied Energy 182, 191–203. doi:10.1016/j.apenergy.2016.08.088.

Rodriguez-Delgado, C., Bergillos, R.J., Iglesias, G., 2019. Dual wave farms for energy production and coastal protection under sea level rise. Journal of Cleaner Production 222, 364–372. doi:10.1016/j.jclepro.2019.03.058.

Rodriguez-Delgado, C., Bergillos, R.J., Ortega-Sánchez, M., Iglesias, G., 2018a. Protection of gravel-dominated coasts through wave farms: Layout and shoreline evolution. Science of the Total Environment 636, 1541–1552. doi:10.1016/j.scitotenv.2018.04.333.

Rodriguez-Delgado, C., Bergillos, R.J., Ortega-Sánchez, M., Iglesias, G., 2018b. Wave farm effects on the coast: The alongshore position. Science of the Total Environment 640, 1176–1186. doi:10.1016/j.scitotenv.2018.05.281.