A Computational Platform to assess the Coastal Impact of the Marine Energy Farms

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Abstract. The aim of the present work is to describe a computational platform (CSIAM - Computational System for Impact Assessment of the Marine energy farms) that can easily be implemented to identify the expected coastal impact of a particular marine energy farm. Several case studies are discussed in order to present the versatility of this tool, including coastal areas from Portugal (central part), Italy (Sardinia) or Romania (the Danube Delta), respectively. Various spatial configurations were considered, starting from individual wave energy converters, such as the Wave Dragon and ending with generic marine farms defined by particular absorption properties and distances from the shore. Furthermore, considering the ERA5 wave data (from 2012 to 2021), some extreme sea states were identified for each target area, the significant wave heights reaching maximum values of 8 m in the case of Iberian Peninsula. Based on these results, we can conclude that the CSIAM interface can be efficiently used in the early development of a particular project, being possible to identify the best correlation between the spatial layout and the far-fields effects.

Keywords: Renewable Energy, Marine Environment, Coastal Impact, CSIAM.

1 Introduction

The human evolution is driven by the accessibility to a water source, starting from basic needs (ex: domestic use) to more advanced levels involving transportation or energy production, respectively. Almost 71% of the earth surface is covered by water, from which a significant part is found in the oceans, which represent in fact the biggest ecosystem of the planet [1]. The coastal areas are considered to be very dynamic environments, being shaped by the natural forces and by anthropogenic activities, being estimated that almost 40% of the global population lives in these areas [2].

In terms of renewable energy, the marine areas seem to present some advantages compared to the onshore ones, the European offshore wind market being considered a successful one with an installed capacity of 28.4 GW. Nevertheless, in the European Union (EU) there are plans to increase this capacity up to 160 GW (by 2030), that will involve the use of floating platforms, as in the case of Hywind Tampen from Norway. Also the inclusion of new areas will make a difference, starting with the ones from France (ex: project Saint-Nazaire, 480 MW) and gradually extending to coastal areas from the Mediterranean or the Black seas [3, 4]. Among the marine resources, the tidal and wave energy is expected to make a significant contribution to the EU's future, although at this moment there are 13 MW of devices tested on various levels. On an European level, during 2007 and 2019 a total of €3.84 billion was allocated to this sector, being expected a capacity production of 3 GW by the end of 2030 and 60 GW, in 2050 [5].

The recent progress related to the evolution of the marine renewable sector brings new possibilities, such as the development of combined wind-wave projects [6, 7], or the use of an array of energy convertors to provide a suitable coastal protection [8–10]. As a consequence, besides the analysis of the natural resources or the performances of a particular energy convertor, another important aspect is related to the expected impact of a particular farm layout onto the surf area of a particular coastal sector. These are very sensitive areas, the balance between accretion and erosion being influenced by multiple factors, such as the attenuation of the wave height, sediment transport rate or even the type of breaking waves.

2 Materials and Methods

The proposed computational model involves the CSIAM and ISSM interface (Interface for SWAN and Surf Models), that was extensively used by the authors for various case studies [11, 12]. The ISSM system combines the SWAN (Simulating Waves Nearshore) wave model with the NSSM (Navy Standard Surf Model) model [13, 14]. In this way, it is possible to provide a more complete picture of the wave transformation in the coastal areas, including the transformations associated to the surf area and the evolution of the longshore currents. In Figure 1 the workflow associated to this computational platform is illustrated, from which we can noticed that the CSIAM section is used in the early stages of analysis.

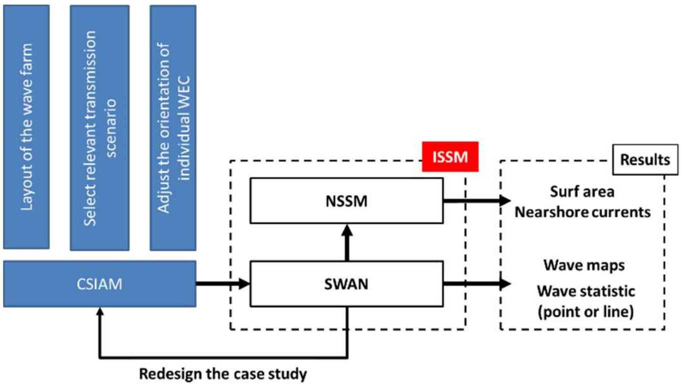

Fig. 1. Workflow presenting the CSIAM computational platforms.

Based on the configuration of the target area, a preliminary marine farm is proposed for evaluation and based on the preliminary results obtained throughout the

ISSM interface; the scenarios can be refined or completed redesigned. A library of scenarios is available, ranging from the transmission indexes available on the market, throughout the general orientation of the farms according to the shoreline, or eventually the layout (and orientation) of individual systems.

Several geographical areas were considered for assessment, as it can be noticed from Figure 2. This includes a coastal area facing the ocean environment (Sines, Portugal), and island sector (Porto Ferro, Sardinia) and an enclosed sea region associated to the Saint George coastal sector, Romania.

Fig. 2. Coastal environments considered for evaluation.

Furthermore, in order to highlight the versatility of this system, several scenarios were developed as presented in Figure 3. These involves different spatial layouts (CS1) based on the characteristics of the Wave Dragon system [15, 16], or the absorption properties of the Wave Cat system (CS2) [17] grouped in different wave farm configurations. Finally, a generic wave farm defined by either moderate (20%) or high absorption (40%) properties was proposed for the Saint George area (CS3). The N-points will be used to process the wave parameters, while the associated lines will be considered for the evaluation of the nearshore currents.

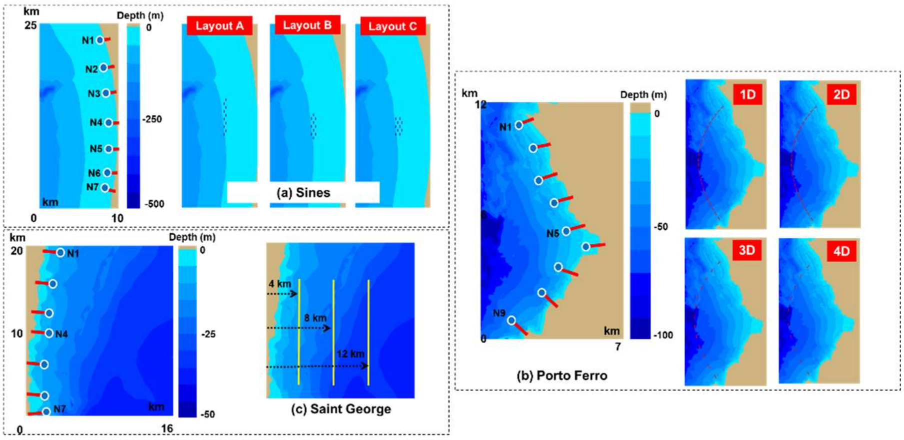

Fig. 3. Set-up of the SWAN computational domains, where: (a) Sines, Portugal; (b) Porto Ferro, Sardinia; (c) Saint George, Romania.

The wave conditions in the vicinity of these coastal areas were identified by using the ERA5 data [18] that were processed for the 10-year time interval from January 2012 to December 2021. Table 1 presents the relevant statistics for the main wave parameters, namely: significant wave height (*Hs*), wave energy period (*Te*) and mean wave direction (*Dir*). Only the extreme values were considered for evaluation, since this will better reflect the expected impact of a particular case study.

Table 1. Identification of the extreme sea states for each target area, based on the 10-year time interval of ERA5 data (from 2012 to 2021).

Reference area	Time frame	*Hs* (m)	*Tm* (s)	*Dir* (º)
Pinheiro da Cruz (PT)	2014.02.10-h00	8.02	11.56	300
Saint George (RO)	2012.02.07-h18	5.83	8.75	60
Porto Ferro (IT)	2017.12.28-h06	6.84	9.93	300

3 Results

Figure 4 illustrates the wave distribution from the Sines target area. Although the proposed layouts cover a small percentage from this target area, the shielding effect is visible, being directly related to the direction of the waves heights that are occurring usually from the north-west sector. The expected changes near the shoreline, are better reflected by the N-points (see Figure 5), where besides the well-known wave parameters, the orbital velocity at the bottom (*Vbot*) that is directly related to the sediment transport was included. The presence of the farms starts to become visible near the point N3, which is located above the Wave Dragon systems, presenting maximum values near the site N4. In this case, the waves are decreasing from 6.18 m (no farm) to a minimum of 5.62 m (layout A).

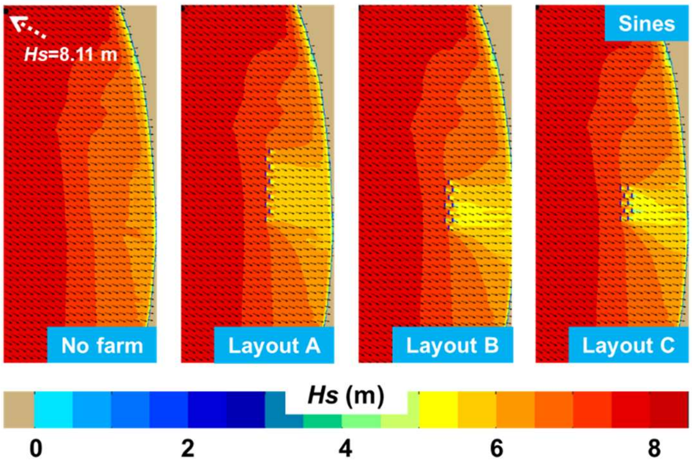

Fig. 4. Spatial distribution of the wave conditions (*Hs* scalar fields and wave vectors) related to the Sines area.

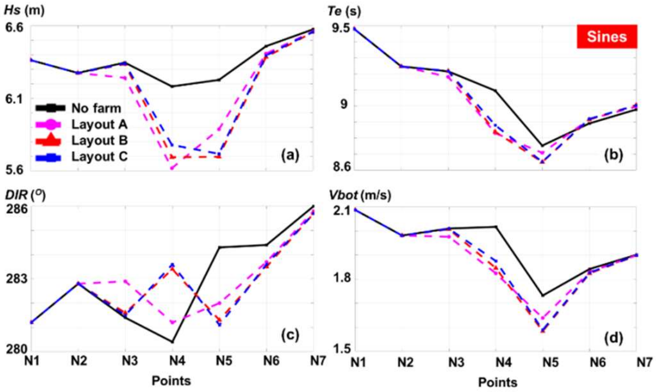

Fig. 5. Sines area - evolution of the main wave parameters associated to the N-points, where: (a) *Hs*; (b) *Te*; (c) *Dir*; (c) *Vbot*.

A similar analysis is performed in Figure 6 for the Porto Ferro coastal sector, from which it can be noticed that a 1D layout can provide a better coastal protection compared to a 4D scenario that indicates values close to a no farm situation. Finally, related to the Saint George coastal area, Figure 7 presents the evolution of the wave fields in the presence of the generic wave farm, and as expected a high absorption wave farm (40%) will provide a significant impact. The sheltering effect is visible regardless of the distance from the coast taken into account (4, 8 or 12 km), the wave heights decreasing near the shoreline from 3 m (no farm) to minimum 2.4 m (L4-40%), depending on the location.

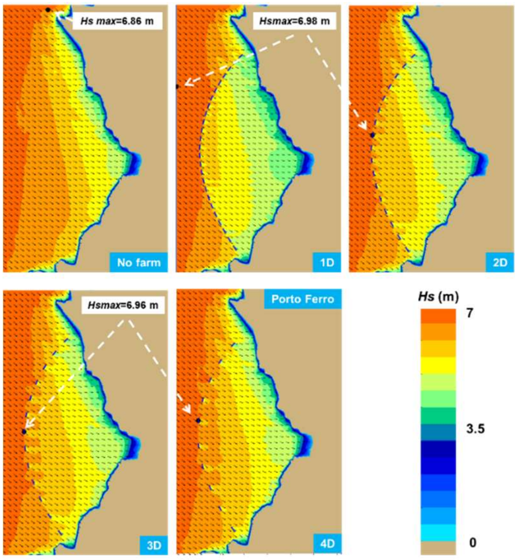

Fig. 6. Spatial distribution of the wave conditions (*Hs* scalar fields and wave vectors) related to the Porto Ferro coastal area.

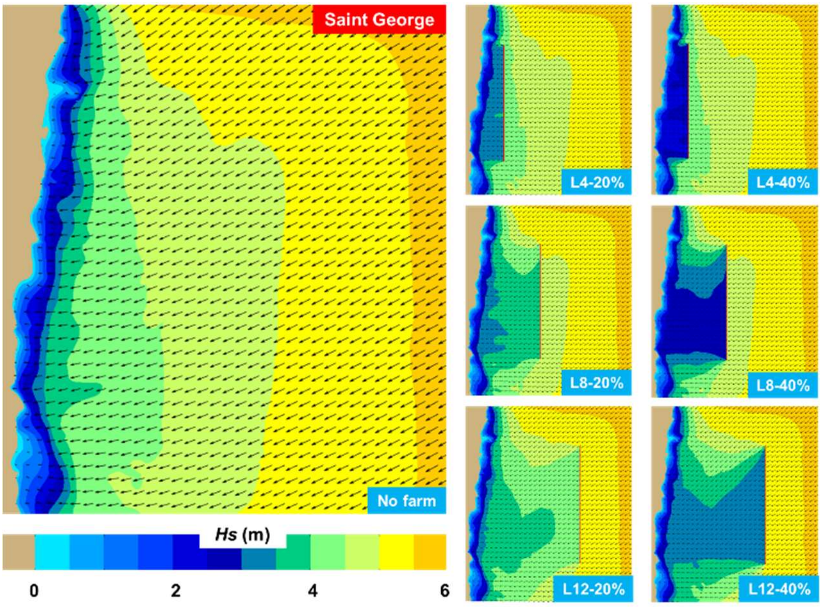

Fig. 7. Spatial distribution of the wave conditions (*Hs* scalar fields and wave vectors) related to the Saint George area.

The nearshore currents (maximum velocities) in the three target areas are provided in Figure 8, for some of the case studies considered.

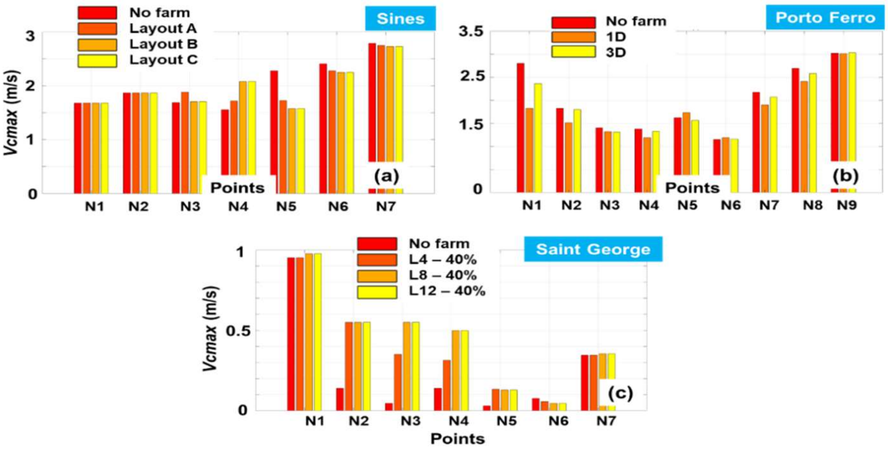

Fig. 8. Maximum velocity of the nearshore currents in the presence of the wave farms, where: (a) Sines; (b) Porto Ferro; (c) Saint George.

For example, in the case of the Sines region the velocity can increase in the presence of the wave farm near the points N3 and N4, while a decrease is expected for the sites N5 and N6 (ex: 1.56 m/s). For the Porto Ferro, the wave farm will decrease the velocity in most of the cases, while for the Saint George an increase it is expected.

4 Conclusions

The nearshore areas are very sensitive environments and any intervention can trigger domino effects that may significantly influence the coastal stability. A sustainable energy future it is possible to be obtained through the use of the renewable sources, in particular those from the marine areas. The paper presents an interactive computational platform denoted as CSIAM, which is associated with the assessment of the down wave effects of the marine energy farms. This includes SWAN model for the waves and Surf model for the nearshore currents. By using this computational platform a more complete picture of the expected transformation induced by a marine energy farm can be obtained, being possible to analyze in a short period of time various configurations that can be tailored to particular shoreline environments. As an example, three case studies have been considered. The first is Sines area in the Atlantic Ocean on the continental Portuguese nearshore, south of Lisbon, the second is Porto Ferro in Sardinia the Mediterranean Island and the third close to the Saint George arm at the Danube River outflow in the Black Sea. Taking into account that at this moment there is interest to accelerate the development of marine energy sector, the proposed system can be considered to be opportune. Further development of this computational platform, should include the design of a graphical user interface and also a post-processing routine that could simplify the processing of results.

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References

1. Fava, M.F.: 2022: How much of the Ocean have we explored to date, https://oceanliteracy.unesco.org/ocean-exploration/, last accessed 2023/01/04.
2. Baztan, J., Chouinard, O., Jorgensen, B., Tett, P., Vanderlinden, J.-P., Vasseur, L.: Introduction. In: Baztan, J., Chouinard, O., Jorgensen, B., Tett, P., Vanderlinden, J.-P., and Vasseur, L. (eds.) Coastal Zones. pp. xxi–xxiii. Elsevier (2015). https://doi.org/10.1016/B978-0-12-802748-6.02001-5.
3. Offshore wind energy 2022 mid-year statistics, https://windeurope.org/data-and-analysis/product/offshore-wind-energy-2022-mid-year-statistics, last accessed 2023/01/04.
4. Onea, F., Rusu, L.: A Study on the Wind Energy Potential in the Romanian Coastal Environment. Journal of Marine Science and Engineering. 7, 142 (2019). https://doi.org/10.3390/jmse7050142.

5. Simon, F.: EU aims for “massive change of scale” on tidal, wave energy, https://www.euractiv.com/section/energy/news/eu-aims-for-massive-change-of-scale-on-tidal-wave-energy/, last accessed 2023/01/04.
6. Saenz-Aguirre, A., Saenz, J., Ulazia, A., Ibarra-Berastegui, G.: Optimal strategies of deployment of far offshore co-located wind-wave energy farms. Energy Conversion and Management. 251, 114914 (2022). https://doi.org/10.1016/j.enconman.2021.114914.
7. Rusu, E., Onea, F.: Joint Evaluation of the Wave and Offshore Wind Energy Resources in the Developing Countries. Energies. 10, 1866 (2017). https://doi.org/10.3390/en10111866.
8. Onea, F., Rusu, L.: Coastal Impact of a Hybrid Marine Farm Operating Close to the Sardinia Island. Ieee, New York (2015).
9. Abanades, J., Greaves, D., Iglesias, G.: Coastal defence through wave farms. Coast. Eng. 91, 299–307 (2014). https://doi.org/10.1016/j.coastaleng.2014.06.009.
10. Bento, A.R., Rusu, E., Martinho, P., Guedes Soares, C.: Assessment of the changes induced by a wave energy farm in the nearshore wave conditions. Computers & Geosciences. 71, 50–61 (2014). https://doi.org/10.1016/j.cageo.2014.03.006.
11. Conley, D.C., Rusu, E.: The middle way of surf modeling. Presented at the Proceedings of the Coastal Engineering Conference (2007).
12. Raileanu, A., Onea, F., Rusu, E.: An Overview of the Expected Shoreline Impact of the Marine Energy Farms Operating in Different Coastal Environments. JMSE. 8, 228 (2020). https://doi.org/10.3390/jmse8030228.
13. Booij, N., Ris, R.C., Holthuijsen, L.H.: A third-generation wave model for coastal regions: 1. Model description and validation. J. Geophys. Res. 104, 7649–7666 (1999). https://doi.org/10.1029/98JC02622.
14. Mettlach, T.R., Earle, M.D., Hsu, Y.L.: Software Design Document for the Navy Standard Surf Model Version 3.2: Defense Technical Information Center, Fort Belvoir, VA (2002). https://doi.org/10.21236/ADA411576.
15. David, D.R., Rijnsdorp, D.P., Hansen, J.E., Lowe, R.J., Buckley, M.L.: Predicting coastal impacts by wave farms: A comparison of wave-averaged and wave-resolving models. Renewable Energy. 183, 764–780 (2022). https://doi.org/10.1016/j.renene.2021.11.048.
16. Onea, F., Rusu, L., Carp, G.B., Rusu, E.: Wave Farms Impact on the Coastal Processes—A Case Study Area in the Portuguese Nearshore. JMSE. 9, 262 (2021). https://doi.org/10.3390/jmse9030262.
17. Rusu, L., Onea, F., Rusu, E.: The Expected Impact of Marine Energy Farms Operating in Island Environments with Mild Wave Energy Resources—A Case Study in the Mediterranean Sea. Inventions. 6, 33 (2021). https://doi.org/10.3390/inventions6020033.
18. Guillory, A.: ERA5, https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5, last accessed 2019/05/31.