Journal of
*Marine Science
and Engineering*

Editorial

Hybrid Systems for Marine Energy Harvesting

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The marine renewable energy (MRE) industry is being stimulated by the growing world energy demand, climate change mitigation policies, and land-use conflicts. The ocean is our largest primary global renewable energy resource. Moreover, it offers large free areas to harvest its potential. However, the harsh and variable marine environment challenges the survivability, resilience and reliability of current harvesting technologies and, consequently, impacts the cost and the affordability of electricity generation. Exhaustive research is being conducted to reduce the levelized cost of energy (LCoE) of MRE by reducing cost drivers and increasing generation. In this context, the use of hybrid systems appears to be a promising solution.

Wind and waves are concentrated forms of solar energy, comprising vast and underexploited offshore resources with different degrees of technological maturity. A large number of wave energy converters (WECs) have been proposed—from the pioneer concept of Salter to the innovative concept CECO—but a fully commercial WEC has not been reached yet. Offshore wind turbines (OWTs) fixed to the seabed in shallow waters have been generating electricity for decades. Harvesting the full potential of offshore wind requires moving to deeper waters, where reliable floating foundations are required. Similar to WECs, although a wide variety of floating OWT technologies have been proposed, no particular kind stands out above the others yet.

Another promising MRE is offshore floating photovoltaics (FPV). The deployment of FPV systems in continental bodies of freshwater has grown exponentially in recent years, and is still unexploited in many world regions with a high potential. In the meantime, the transition of FPV technology to the marine environment has already started, and different ad hoc solutions are being developed.

In addition to the challenge of developing cost-effective technologies (affordability), MRE faces key issues in contributing to the decarbonization (sustainability) of the energy sector: its intermittent nature (reliability), and location/marine environmental constraints (resilience). These aspects result in an inadequate energy generation, i.e., the ability of an existing generation portfolio to match power demand at all times. In fact, as renewable shares increase, scheduling power generation becomes more challenging. Conventional operational and technical solutions to integrate higher penetrations include forecasting, demand response, flexible generation, larger balancing areas, balancing area cooperation, and fast scheduling and dispatch, among others. Hybridization also contributes to mitigate the excessive production costs and the intermittent nature of MRE.

Citation: Rosa-Santos, P.; Taveira-Pinto, F.; López, M.; Rodríguez, C.A. Hybrid Systems for Marine Energy Harvesting. *J. Mar. Sci. Eng.* **2022**, *10*, 633. https://doi.org/10.3390/jmse10050633

Received: 8 March 2022
Accepted: 27 April 2022
Published: 6 May 2022

In the scope of this Special Issue, hybridization should be understood in three different manners:

(i) The combination of technologies to harvest different MREs (e.g., WECs integrated into OWTs);
(ii) The combination of different working principles to harvest the same resource (e.g., oscillating water columns with overtopping devices to harvest wave energy);
(iii) The integration of harvesting technologies in multifunctional platforms and structures (e.g., the integration of WECs in breakwaters, oil and gas platforms, or aquaculture platforms);
(iv) The co-location of different harvesting technologies and multi-resource systems, for example, combining wind turbines, tidal turbines, diesel generators, and pumped hydroelectric storage.

Hybridization also fosters synergies among the different MRE resources and harvesting technologies. Possible synergies might be related to opportunities for cost reduction in the technology itself—including deployment, operation, maintenance, and decommissioning costs—but also to improvements in the quantity and quality of energy generation. Technological synergies include:

- Common grid infrastructure. Access to the power grid is assured when a MRE technology is deployed in an existing coastal infrastructure, which reduces deployment costs. In cases of hybrid conversion technologies, these costs would be shared;
- Shared logistics during the lifetime of the project;
- Common substructure, mooring or foundation systems. The mooring system can represent about 10% of the capital expenditure for a WEC and may reach higher values for an OWT. In cases of integration with other coastal structures, such as breakwaters, this may be shared. Furthermore, breakwaters offer a reliable foundation for WECs and OWTs. Therefore, shared foundation systems would significantly reduce the total deployment costs;
- Shadow effects. A wave energy farm may significantly reduce the energy of incident sea states, and therefore dampen wave forces on other structures. Combining WECs with other MRE technologies in the same farm and with an appropriate layout may reduce structure requirements, as well as the corresponding manufacturing, operational and maintenance (O&M) costs.

As for the generation synergies of hybridization, these include:

- Enhanced energy yield. Relative to a traditional MRE farm, a hybrid farm would increase the total energy production per unit surface area. For example, if OWTs are combined with offshore FPVs, the production per surface area can increase by a factor of ten;
- Better predictability. Wave resources are easier to predict and more constant in time than wind resources. Therefore, the combination of both will reduce the system balancing costs;
- Smoothed power output. Co-located technologies have been proven as a solution to smooth the power output and reduce the disadvantages of MRE when penetrating the energy mix. Some examples include combined wind–wave farms, wind–solar farms and wave–solar farms.
- In the same weather systems, wave climate peaks trail behind wind peaks. Consequently, a combined exploitation will result in a reduction in sudden disconnections from the electric grid, an increase in availability (reducing the number of hours of non-activity), and a more accurate output forecast.

The minimization of negative impacts of MRE applications on biodiversity and ecosystems is considered an essential condition for the environmental permission of such projects and for social acceptance. Hybrid installations are expected to cause less environmental impacts compared to independent installations. Since, in some areas of MRE production, industrial fishing operations or intense navigation may not be allowed, these areas may potentially become shelters of marine life or artificial reefs.

This Special Issue presents a set of works on hybrid systems for marine energy conversion which focus on innovative numerical and/or experimental research, and demonstrate projects on the development of technologies to harness MREs. Seven articles have been compiled addressing the following hybrid systems:

- The integration of WECs in port breakwaters;
- The combination of offshore wind and solar-power harvesting technologies;
- The combination of WECs and offshore wind turbines.

As evidenced in this Special Issue, at present, there is significant interest in the integration of WECs into port breakwaters or the areas nearby these structures. Given their exposure to ocean waves and the high energy consumption of port facilities, this is considered an excellent combination that could also increase the sustainability of seaports.

For instance, a novel hybrid WEC (HWEC), which combines an overtopping device with an oscillating water column system on a breakwater, is proposed and assessed for proof of concept in the first study of the Special Issue [1]. The study of this HWEC, which uses air and water turbines, is performed using a composite modelling approach, i.e., combining physical and CFD numerical modelling. The preliminary research findings demonstrate that the HWEC is viable in both rubble-mound and vertical breakwaters, without detrimental effects to their hydraulic performance and structural response/stability. A succeeding experiment assessment reports significant reductions in overtopping discharges in a case study of rubble-mound breakwater, which is considered a highly beneficial contribution of the hybrid concept to the functional performance of the structure. However, the authors recommended a careful analysis of its structural stability and damage potential, in order to maintain safety levels [2]. This study also points out that traditional damage assessment parameters should be applied with care when non-conventional structures are analysed, for example, rubble-mound breakwaters with integrated WECs.

Another study proposes taking advantage of the Bragg reflection induced by multiple submerged breakwaters (partial standing wave field) in nearshore areas, in combination with a fully standing wave field generated by wave reflection on a vertical wall, in order to enhance the performance of an oscillating buoy WEC [3]. The flume experiments conducted in the study demonstrate that the standing wave field created could enhance the energy conversion performance of the WEC. Furthermore, the Special Issue also presents a research study that deals with the numerical determination of hydrodynamic loads on arrays of floaters in front of a vertical breakwater [4]. In the study, different arrays and shapes of vertical axisymmetric floaters are numerically investigated. The image method is applied to simulate the effect of the breakwater on the array, and the multiple scattering approach is used to evaluate the interaction phenomena among the WECs. The geometrical characteristics of the floater had a greater influence on the values of its hydrodynamic forces and coefficients than both the existence of the breakwater and the arrangement of the array with respect to the incoming wave.

Concerning the combination of offshore wind and solar power, a case study from the north of Spain is presented [5]. The power resources and production are assessed based on high-resolution data and the technical specifications of commercial wind turbines and solar photovoltaic (PV) panels. It is reported that, relative to a typical offshore wind farm, a combined offshore wind–solar farm can increase the capacity and energy production per unit surface area by factors of ten and seven, respectively. Hence, the utilization of the marine space is optimized, and the power output is significantly smoother.

Regarding the combination of offshore wind energy devices and WECs, one of the papers assesses the performance of a combined farm located on the northern coast of Portugal, in terms of energy production, power smoothing, and LCoE [6]. The authors conclude that the co-located farm increased the annual energy production by approximately 19% in comparison with the stand-alone wind farm for the studied region. Furthermore, they report that the LCoE of the hybrid farm reduces drastically in comparison with the stand-alone wave farm, presenting a value of USD 0.116 per kWh. Finally, one of the articles discusses the challenges in the scaling and physical modelling of power take-off systems for WECs [7]. Set-up enhancements, calibration practices, and error estimation methods are covered. Recommendations on the organization and conduction of the experiments are also provided, together with a brief overview of three different case studies.

In summary, this Special Issue covers attractive current topics in MRE and its applications in the context of hybrid systems, providing valuable contributions and motivation for further developments.

Author Contributions: The authors jointly carried out the activities leading to the Special Issue and co-wrote this editorial. All authors have read and agreed to the published version of the manuscript.

Funding: This work was partially supported by the project PORTOS—Ports Towards Energy Self-Sufficiency, with the reference EAPA_784/2018 and co-financed by the Interreg Atlantic Area Program through the European Regional Development Fund, and by the OCEANERA-NET COFUND project WEC4Ports—A hybrid Wave Energy Converter for Ports, with the reference OCEANERA/0004/2019, under the frame of FCT. This work was funded by the project ATLANTIDA (NORTE-01-0145-FEDER-000040), supported by the North Portugal Regional Operational Programme (NORTE2020), under the PORTUGAL 2020 Partnership Agreement and through the European Regional Development Fund (ERDF).

Acknowledgments: The authors wish to thank all contributors to this Special Issue as well as the professional and efficient JMSE editorial staff without whose excellent assistance this issue would not have been possible. Additionally, the authors thank Cheryl Huo and Angela Xia for their assistance.

Conflicts of Interest: The authors declare no conflict of interest.

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