RENEWABLE ENERGY AND SARDINIAN COASTAL AREAS: MARKET AND ENVIRONMENTAL ISSUES

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Abstract: The role of renewable energy sources is changing as they are set to replace fossil sources to accomplish the energy requirements in the next future. The direction is set, and energy planners specified quite close dates when to achieve important shares in energy production portfolio by renewables. After considering the meaning of energy communities in the development of renewable sources in a bottom-up perspective, the prediction of vertical axis wind turbines performance is presented to focus the attention on this configuration which is not full commercial TLR as well. The wave energy converters are another example of devices to exploit renewable sources which are gaining a special interest. An application concerning Sardinian coastal areas is presented and some results concerning its energy performance is discussed.

Keywords: wave energy converter, wind turbine, nearshore areas, energy community

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Introduction

Electricity generation from wind energy is clean, to the extent that it neither alters chemical composition of the environment by entering greenhouse gases nor issues noxious emissions that pollute the air as fossil fuels routinely do. This applies equally to other renewable sources, from the basic sun to the wave potential still under observation, which do not deplete the environment of essential elements to secure natural habitat and ecosystems.

The global power production from renewables is expected to reach 13 % in 2035 by global energy planners. However renewable energy sources still have a potential to be developed as in various areas they are not easily accepted for their environmental issues. To this respect coastal areas of an island like Sardinia are characterized by a very high environmental value with economic and commercial implications. Nevertheless, they are endowed with significant renewable resources concerning the sun, the wind, and the waves.

The exploitation of these energy sources must confront technical and landscape constraints. Namely quantifying the wave power resource and designing a device for its exploitation is still a challenge while that is not the case of the wind with its turbines or the sun with its PV panels, both using technologies at commercial TRL. In addition, the challenge when using wind and sea for electricity supply is their unsteady electricity production rate, which is not easy to adapt to the varying electricity demand. Previous studies (e.g. [1]) confirm that a mix of flexibility resources is needed to manage variability across all timescales and seasons. Turbines and panels require seasonal flexibility services, which can be provided from Wave Energy Converter (WEC).

The fulfilment of a growing share of electricity needs with renewable sources is following a complex path where, however, fairly clear trends can be identified. On the one hand generating assets based on large wind turbines and on arrays of PV panels that cover very large areas follow the logic of comparatively concentrated energy production to be fed into the grid, with actors and stakeholders external with respect to the territory. In a free market scenario, albeit in compliance with national and European regulations, the profit motive is associated with the use of increasingly larger machines, compatible with the objective of promoting renewable sources. On the other hand, the distributed generation, linked to the territory needs, keeps being one of the characteristics of renewable sources and this solution has recently been encouraged with specific directives.

The EU Renewable Energy Directive 2018/2001 (RED II) has unlocked the participation of local citizens and authorities in collective renewable energy projects through the concept of Renewable Energy Communities (REC). This Directive establishes a common framework for the promotion of energy from renewable sources. It sets a target for the overall share of energy from renewable sources in the gross final consumption of energy of the Energy Community in 2030, in line with Regulation (EU) 2018/1999. Energy communities are open and voluntary and combine non-commercial purposes with community environmental and social objectives [2].

Three directives describe the key elements of two types of Energy Communities, namely Renewable Energy Community and Citizen Energy

Community. Both the gas market directive and the electricity market directive fall under the category of city energy communities. A clarification and some detail can be helpful for both.

Renewable energy community is a legal person: (a) which, in accordance with applicable national law, is based on open and voluntary participation, is autonomous and is effectively controlled by shareholders or members who are located in proximity to renewable energy projects owned and developed by that legal entity ; (b) whose shareholders or members are natural persons, SMEs (small and medium-sized enterprises) or local authorities, including municipalities; (c) the primary purpose of which is to provide environmental, economic or social benefits to the community for its shareholders or members or to the local areas in which it operates, rather than financial profits.

Citizen Energy Community is a legal person who: (a) is based on voluntary and open participation and is effectively controlled by members or shareholders who are natural persons, local authorities, including municipalities, or small businesses; (b) has as its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas in which it operates rather than to generate financial profits; (c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or electric vehicle charging services or provide other energy services to its members or shareholders.

In a broad sense, energy communities are contiguous processes of both energy transition and social innovation. As decentralized and renewable energy projects, they can promote sustainable energy production and consumption practices. As consumer-empowerment and community-driven initiatives, energy communities can play a key role for social innovation as they reflect a fundamental shift in consumer behavior.

Italy is considered a laggard country since it presents significant shortcomings and delays in policy management and ECs setup and diffusion in its territory. The following list presents the principal regulations in the Italian regulatory framework regarding energy communities. ”Milleproroghe” Decree 30 December 2019 n.162 (converted into law on 28 February 2020 n.8) legally defines the energy communities through the art. 42bis, which specifies the two possible schemes of energy community feasible in Italy: collective self-consumption and Renewable Energy Communities (REC). Legislative Decree 8 November 2021 n.199 establishes that the REC participants regulate their relationship through a private law contract, which defines the rights and obligations of the individuals.

«Milleproroghe» considers RED II principles and defines the specific characteristics of the two schemes. It defines the scale at which the REC can operate since communities must be connected to the same medium voltage/low voltage (MV/LV) substation with the maximum incentivized power for each renewable energy system fixed at 200 kWp. Besides, the users can share energy instantaneously and use a storage system. Legislative Decree 2021 n.199 transposes the RED II Directive and allows incentives on the “shared energy”, evaluated as the net difference between the electricity fed into the grid and the energy taken from the grid. These incentives equal 100 €/MWh for self-consumption and 110 €/MWh for REC.

Among the environmental advantages of energy communities the spread of renewables, at present especially photovoltaic, but this does not preclude the use of other sources technologies, such as wind, or waves together with batteries instead of fossil fuels. This implies a decrease in harmful emissions of the gases responsible for the greenhouse effect, especially carbon dioxide. Furthermore, energy dissipation in network losses is avoided thanks to less distance to cover and direct self-consumption by members.

As for social benefits, the creation of a community attentive to environmental sustainability promotes the diffusion of models of inclusion and collaboration capable of generating benefits for the territory and for the people who live there.

Materials and Methods

This paper presents preliminary results of numerical application to a WAB located in the nearshore area along the Western Sardinian coast. This energy source can be profitably matched with wind, as they share the origin to a good extent. Modeling of a small size wind turbine for the same location is considered, focusing on configurations of wind turbines which have been intensively studied but are not widespread at present as Vertical Axis Wind Turbines. The wave and wind systems can be effectively proposed by a combined device in the coastal context due to their limited visual impact especially for small scale facilities. The energy community which contributes to increasing public acceptance of renewable energy projects and make it easier to attract private investments in the clean energy transition, is in the background.

Wind energy

Wind turbines are a convenient device to capture and convert kinetic energy of the atmosphere into mechanical and, most commonly, electrical energy. Wind turbines are classified in two major categories based on rotational axis: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) or cross-flow turbines.

Wind turbines currently in operation are mostly HAWTs, because they have evolved to a mature and competitive system because of extensive research and commercialization. Indeed, VAWTs are comparable to HAWTs from various angles altogether. Further, in certain areas of operation a VAWT appears preferable to a HAWT, such as in a gusty urban environment or in locations with strict space constraints. The arguments used to derive the Betz limit for a HAWT do not apply directly to a VAWT, as recent analyses using an evolutionary algorithm have shown. The optimal pitch curve can yield power output from a VAWT that is approximately 6 % higher than the Betz limit, due to its aerodynamic behavior [3].

The aerodynamic performance of a straight bladed vertical axis turbine is predicted by different models, ranging from those based on a 1D approach and the actuator disk theory to those which resort to CFD resources [4]. Hereafter the characteristic curves of a set of vertical axis wind turbines with straight blades, obtained by the free wake vortex model, are shown (Figure 1). The turbines are all equipped with three blades rotating at a distance R from the hub, but the chord length c constant along the blade span, is changing (Figure 2). The NACA 0012 airfoil has been adopted to design the blade sections, and its experimental data were integral part of the semi empirical modeling. TSR is the peripheral speed (ωR) referred to wind speed v, while C_P is the turbine power referred to the upstream wind power 0.5 $\rho A v^3$where A=2RH is the swept area being H the blade height.

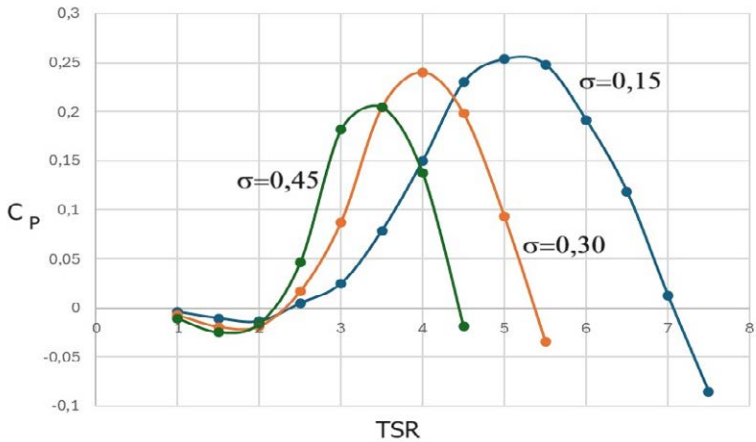

Figure 1 – Power coefficient (*CP*) vs. tip speed ratio (TSR) for 3 bladed VAWTs for different solidity values (σ=Nc/R).

These calculations are addressed to vertical axis wind turbine design, while more accurate models are used in wind turbine analysis. Helical Darrieus turbine can be calculated following the same approach, they account for a smoother operation at the cost of a more complicated setup.

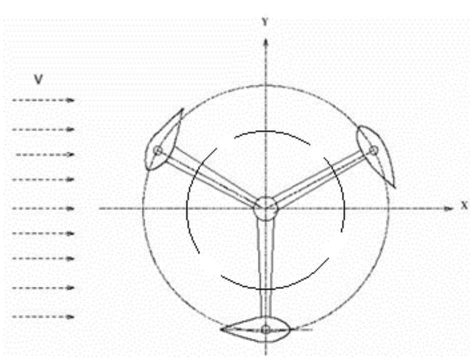

Figure 2 – Three bladed VAWT schematic.

The annual production of energy depends on the wind potential which is quite plentiful in Sardinian coastal areas as evidenced by measured data.

Wave energy

Wave energy is a renewable and pollution-free energy source that could have the potentiality to for a substantial contribution in the EU electricity energy market. The EU industry is the global leader for developing ocean energy technologies, mainly wave and tidal. Ocean energy technologies are relatively stable and predictable and can complement fixed and floating offshore wind. The EU Communication (see [5]) proposed an ocean energy strategy where different technologies should suit different sea basins. The variety and complementarity of European sea basins create a unique worldwide position, but different technologies development and commercial levels have become too large across European basins. While the North Sea is currently the world's leading region for deployed capacity and expertise in waves, the good potential for wave energy in the Mediterranean Sea is far to be properly used and wave technologies are still pilot and in demonstration phase. Recently, extensive and accurate estimates of wave energy along the Mediterranean coasts have been provided by many authors. Estimates of the available mean power (P_m) in kW/m and the related potential energy production suggests that an energy hotspot is located in the Western coasts of Sardinia (Italy) (see [6]) with P_m = 11.4 kW/m (Figure 3).

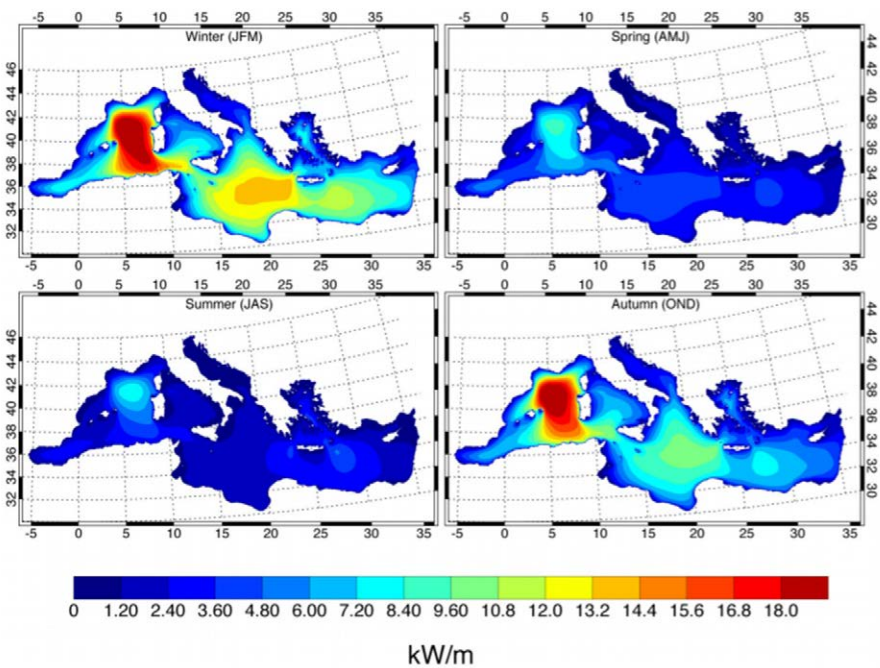

Figure 3 – Seasonal wave power in the Mediterranean Sea (adapted from [6]).

The main aim of the proposed research is to demonstrate that a proper selection and customization of a Wave Energy Converters (WEC) operating in an EU oceanic basin with greater energy potential could produce profitable power output in the Western coasts of Sardinia. Specifically, the assessment of the energy potential in the hotspot located offshore of the city of Alghero and the comparisons between the simulated WEC energy productivities in Alghero and in the North Sea will be presented. The content of the presentation will be of evident interest for Sardinian communities that want to invest in this field and thus need to optimize the WEC for specific wave climate to reach the level of commercial maturity. The seasonal trends of wind, solar and wave resource are shown in figure 4, where the demand variation is presented as well [7].

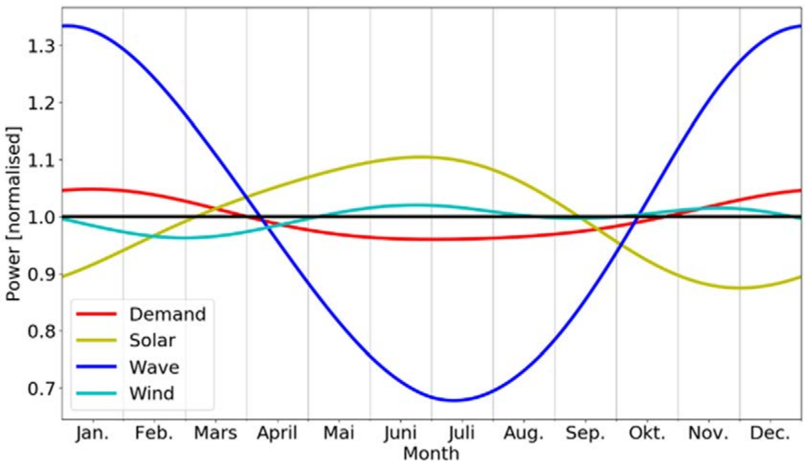

Figure 4 – Seasonal power fluctuations.

Results and discussion

The essential features in which a WEC should excel in order to show long-term economic potential include the survivability (reliable mooring system and preferably a passive safety system that can effectively reduce extreme loads), reliability and maintainability (easy access and inspection of the most essential parts of the WEC), overall power performance (efficient wave energy absorbing technology and PTO), scalability (capable of further enlarging its dimensions to improve its Levelised Cost of Energy - LCoE) and high environmental benefit (expected to have a great environmental benefit and a minimal environmental footprint). Floating Wave Activating Bodies (WAB) in offshore and nearshore areas have had successful results in technology development level (e.g., AquaBuoy, IPS Buoy, FO3, PowerBuoy, WavePiston, Pelamis).

The purpose of the study is to demonstrate a full-scale Wavepiston system with electricity conversion to verify the potential strengths and limitations for commercial projects.

The main properties of wave climate are an annual mean significant wave heigh of 1.2 m (and a peak period of 6.7 s) with a 18 year return time wave height of 9.2 m. The predominant wave direction is from North-West. According to the analysis at Mediterranean scale of Figure 3, here P_m is estimated as equal to 10.5 kW/m.

Long term changes in sea states are relevant to climate research and coastal applications along the coasts of Sardinia Island, located in West Mediterranean Sea (WMS). Recent sea state high-quality data records (satellite altimetry dataset from ESA, and reanalysis and hindcast products from ECMWF) show temporal trends in annual mean significant wave height (Hs) over 1992 – 2018 from a 2° x 2° grid in WMS (see [8]).

In enclosed basins as a gulf, the waves have characteristics rather different than in large environment. This is mainly due to their local generation, and they depend more on the quality of winds (coastal orography) and transformation (bathymetry) [9]. Sulis et al. [10] presented a 20-year wave dataset (altimeters on board of the ERS-1/2 and TOPEX/Poseidon satellites, and the operational wind and wave results from ECMWF) from which statistics have been derived in the grid point of coordinates 9.5°E; 39.0°N located at the mouth of the Gulf of Cagliari about 8 km south of the Sardinia coast (Figure 5).

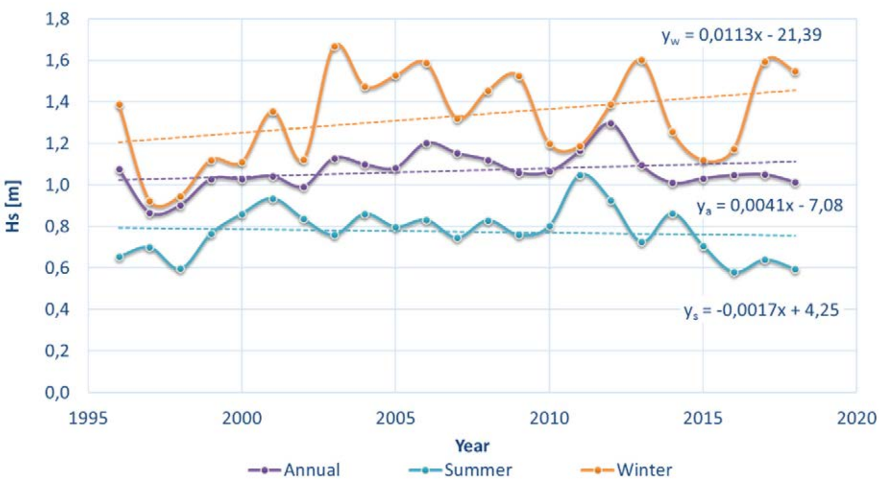

Figure 5 – Seasonal and annual trends of maximum wave heights in Western Sardinia coasts, offshore Alghero

Here temporal trends are estimated using simple linear regression over 5-year moving averages of annual maximum Hs [10]. Analysis shows a strong positive trend over the last decade along the ordinary least square equation (R^2 = 0.92), being the rate equal to + 4 mm/yr. Increases in maximum annual heights have been in accordance with mean condition.

The full-scale demonstration system consisted of a single Wavepiston WEC (the string) with up to 32 energy collectors (length 400 m, width 9 m) and a turbine generator on the PLOCAN platform for conversion to electricity. Multiple energy collectors are coupled on a string with each string corresponding to a wave energy converter. Each energy collector has a sail, which is moved back and forth by the passing waves (Figure 6).

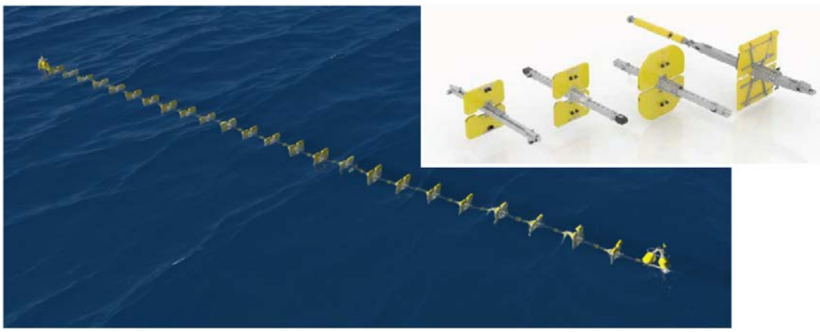

Figure 6 – Wavepiston WEC: string and details of different energy collectors [8].

The system is expected to have a peak effect of 200 kW, being able to produce 400 MWh per year with a fairly (equal to the electricity consumption of approximately 150 standard households), as shown in Figure 7 histogram.

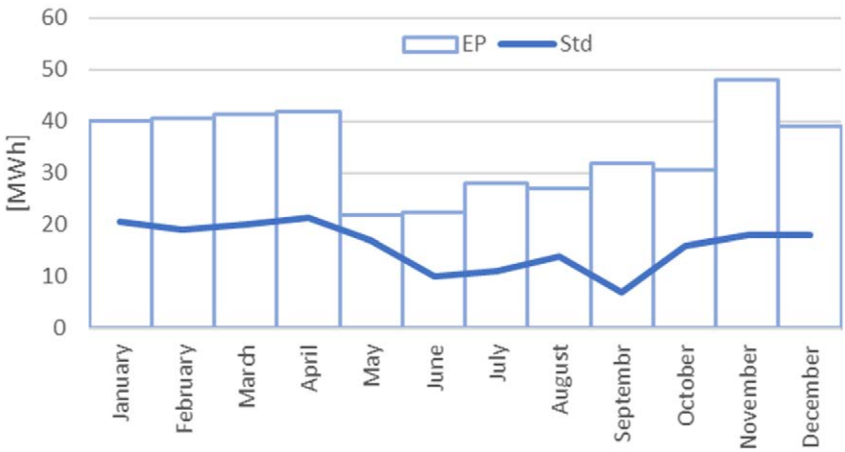

Figure 7 – Monthly average farm electricity production EP (MWh) and its standard variation Std of the simulation time [adapted from [8]).

According to other study on the implications of wave trends for wave energy exploitation (see [11]), the Alghero offshore area will experience a significant increase in energy production in future scenarios as defined by trends for annual mean values of wave height. In this research, we found a convergence in the trends for annual mean and maximum of wave height, and in a preliminary way we assessed a future relative variation in the annual energy production approximately equal to 8 % to 2050.

Conclusion

The wind and wave energy can be treated as an asset for Sardinian coastal areas. They can be profitably proposed in a combined device into the specific context due to their limited visual impact especially for small scale systems. The energy community which contributes to increasing public acceptance of renewable energy projects and make it easier to attract private investments in the clean energy transition, is in the background.

Some results about energy conversion systems have been obtained taking into accounts recent developments.

From the model application to Alghero climate conditions, it appears that the main strengths of the RES from wave motion can be summarized as follows:

- Final Development and Qualification Level (TRL) for fairly energetic wave climates (> 40 kW/m).
- Excellent synergies with other energy sources (e.g., offshore wind);
- Very low impact and high environmental sustainability.
- Good efficiency, lifetime and performance.
- Presence in Italy of excellence in research in the sector and in industrial development.

Then, the main obstacles to the exploitation of wave motion RES are:

- Need to customize devices for low-energy wave climates (5 – 15 kW/m);
- High initial investment of the systems now appearing on the market.
- Presence at national and regional level of complex regulations for the permitting and installation process of devices.

References

[1] International Energy Agency (2023) - *Managing Seasonal and Interannual Variability of Renewables*. G7 Report.

[2] Caramizaru, A. and Uihlein A. (2020) - *Energy communities: an overview of energy and social innovation*. Vol. 30083. Luxembourg: Publications Office of the European Union.

[3] Paraschivoiu, I., Sami A., and Saeed F. (2018) - *VAWT versus HAWT: a comparative performance study of 2–6 MW rated capacity turbines*. Transactions of the Canadian Society for Mechanical Engineering 42.4 (2018): 393-403.

[4] Gazzano, R., Marini, M., Satta, A. (2010) - *Performance Calculation for a Vertical Axis Wind Turbine with Variable Blade Pitch*", Int. J. of Heat & Technol., 28(2), 147-153.

[5] European Commission, (2020) - *Progress of clean energy competitiveness*, 953 pp.

[6] Gunn, K. and Stock-Williams, C., (2012) - *Quantifying the global power Resource*, Renewable Energy 42.8: 296-304.

[7] Vrana, T.K. and Svendsen, H.G. (2021) - *Quantifying the Market Value of Wave Power compared to Wind&Solar – a case study.* Proceedings of the 9th Renewable Power Generation Conference – RPG, Dublin.

[8] Timmermans, W., Gommenginger, C. P., Dodet, G., Bidlot, J.-R, (2000) - *Global Wave Height Trends and Variability from New Multimission Satellite Altimeter Products, Reanalyses, and Wave Buoys*. Geophysical Research Letters, 47 (9), DOI: 10.1029/2019GL086880

[9] Vicinanza, D., Cappietti, L., Ferrante, V. and Contestabile P., (2011) - *Estimation of the wave energy in the Italian offshore. Journal of Coastal Research*, Special Issue 64: Proceedings of the 11th International Coastal Symposium, pp. 613-617.

[10] Sulis, A., Henriksen, M., Svendsen, P.N. Serreli, S. (2021) - *Wave energy production in the Sardinia Western coast: current status and future prospects.* Proceedings of MODSIM 2021, 24th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, Dec. 2021,

[11] Simonetti, I., Cappietti, L., (2024) - *Projected Trends in Wave Energy Potentials along the European Coasts and Implications for Wave Energy Exploitation* (1976–2100). J. Mar. Sci. Eng. 2024, 12, 239. DOI: 10.3390/jmse12020239