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Feasibility of wave energy harvesting in the Ligurian Sea

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Abstract—**A series of short and mid-term guidelines have been established due to the pursuit to offer clean energy and reduce the environmental impact in the Mediterranean and European environment. Currently, the scientific community and the industrial sector promote to find new technologies and means to achieve these regulations. Efforts to provide sustainable ways to supply electricity in Italy have led to the exploration of marine renewable energies (MRE) in the Mediterranean Sea. In particular, in the Ligurian Sea, where the wave climate can provide one of the higher energy sources, represents an optimal opportunity for supplying this energy resource to coastal cities. However, the wave conditions are not as significant as those in other marine regions around the world. There are several devices currently developed which can be applicable to the region. Hence, an evaluation from a technical and economic perspective is advised. Additionally we also investigate the scaling and survival considerations for Wave Energy Converters (WECs) when facing extreme storm events. The proposed study offers the evaluation of a sustainable alternative for powering the electricity mix in the Liguria region, through the exploitation of the wave energy resource. Attractive findings emerge after the assessment of eight floating-body wave energy converters.**

Index Terms—**Wave energy harvesting, Cost of energy, Marine renewable energy, Mediterranean Sea**

I. Introduction

AMONG the worldwide challenges to be faced during the current decade are the reduction of greenhouse gas (GHG) emissions, and the use of clean energy [1]. Several studies have been conducted near coastal regions, where a large part of the population is situated [2], and many technologies have been developed to extract renewable energy from the sea. One form of ocean energy source that is attractive because of its high potential is wave energy.

Wave energy is a continuous force in time, predictable and dense [3]. Moreover, the technologies of wave energy exploitation have had a relevant upsurge in the last decades [4], [5]. Indeed, in 2021, the Recovery and Resilience Plan to mitigate the economic impact of the pandemic and invest in the ecological and digital transitions plan of Italy stated that a budget of 33 million US $ will be invested in the innovative development of renewable energy technologies, where wave energy is explicitly mentioned [6], [7]. Wave energy depends mainly on the metoceanic conditions and the mechanism used to convert mechanical energy into electrical energy in a given location.

In the last decade studies have provided a clear overview of the wind offshore and wave energy potential in the Mediterranean basin and on the Italian coasts, some of them are the research made by Vicinanza, et. al. [8], Liberti, et. al. [9], Riefolo, et.al. [10], and Pisacane, et. al. [11]. Subsequent evaluation surveys of wave energy converters (WECs) have been performed such as those carried out by Vicinanza, et. al. [12], Vicinanza, et. al. [13], Iuppa, et. al. [14], Zanuttigh, et. al [15], Vannucchi and Cappietti [16], Mattiazzo [17], Lavidas, et. al. [18], as well as the feasibility study of offshore wind energy converters by Maienza, et. al. [19]. Likewise, the WECs assessment published by Bozzi, et. al. [20], Bozzi, et. al. [21], and Bozzi, et. al. [22] introduced the evaluation of scaled WECs and its efficiency. More recent studies are focused on the attention in the WEC enhancements and a possible functionality in the future scenarios, as the presented by Simonetti and Cappietti [23] as well as Pourali et. al. [24]. Among the concluding comments of prior studies it is noteworthy to mention that the highest annual average wave power is spatially found between the Balearic Islands, Corsica Island and Sardinia Island [16], [25]. However, the Ligurian Sea offers potential wave energy that can be extracted through the technology adapted to the wave climate existing in this region. In the italian context, energy extraction from renewable energies was distributed among 4.8% geothermal, 15.7% biomass, 17.8% wind, 21.7% solar and 40% hydroelectric, in 2021 [26]. Therefore, this study proposes the evaluation from the technical point of view and the economic feasibility of eight floating body type WECs along the Ligurian Sea.

A. Ligurian Sea: studied locations

For determining the wave energy assessment locations a mapping of various cartographic information is required. Such mapped information is mainly related to fishing areas, private concessions, beaches, marine outfalls, restricted maritime and military transport areas, research stations, marine protected areas, marinas, docks and piers. Then, the resulting free region is delimited from depths of 40m to 160m. Then, 36 locations of the available wave information were established,

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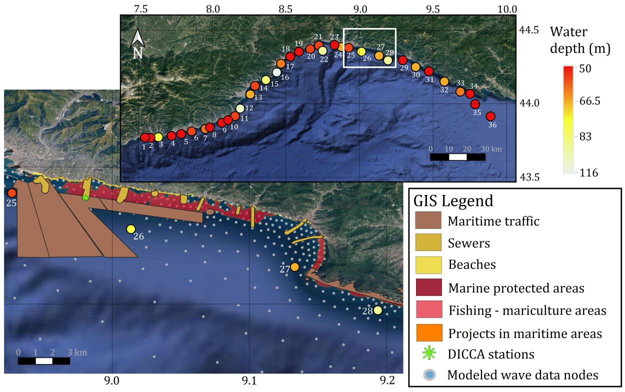

Fig. 1. Site assessed: 36 locations were identified following the survey of availability of regions for wave energy.

seeking a separation of approximately 5 km between the wave data nodes. The resulting locations are shown in the Fig. 1 and also listed in the Appendix A.

The employed wave data in this study is obtained from the wave hindcast generated by the WavewatchIII modeling along the Mediterranean Sea under an unstructured mesh generated, published by Lira-Loarca et. al. [27]. Hourly wave parameters from January 1^{st} 1979 up to December 31^{th} 2022 have been employed.

Sea waves are transformed as they propagate towards the coasts producing a net reduction on its energy content. In the Ligurian Sea, wave energy comes from predominantly from the Southwest direction, and its intensities vary according to characteristics of storms coming from the Atlantic Ocean [25], [28], [29]. Wave power (P_{wave}) is determined along the Ligurian Sea, it is usually expressed in kW/m and calculated as shown in (1):

$$P_{wave} = \frac{\rho_w \cdot g \cdot H_{m0}^2}{8} \cdot n \cdot \left(1 + \frac{2 \cdot k \cdot h}{\sinh\left(2 \cdot k \cdot h\right)}\right) \frac{w}{k}, \quad (1)$$

where ρ_w corresponds to sea water density of 1025 ($kg \cdot m^{-3}$), g corresponds to the gravitational acceleration of 9.81 ($m \cdot s^{-2}$), H_{m0} is the zeroth-order moment wave height, h is the water depth, k corresponds to the wave number, and w is the angular wave frequency. The n value equals to 1 is employed for intermediate and shallow waters whereas n equals to 0.5 for deep waters [30]. Results shown in Fig. 2 reveal that months from October to February content the highest wave power values in the region.

II. Wave Energy Assessment

Wave power offers a potential mechanical energy, nevertheless, the fact that this is scarcely constant and since the energy extraction technologies do not offer 100% efficiency leads to the evaluation of the type of converter that allows extracting the greatest amount of energy from the waves, considering also that extreme events can compromise the functionality of the WECs. This study considers the evaluation of eight WECs which are listed in Table II.

Likewise, the WEC performance indicators contrasting the its capabilities with the energetic resource supply give a quick idea of the suitability of a converter

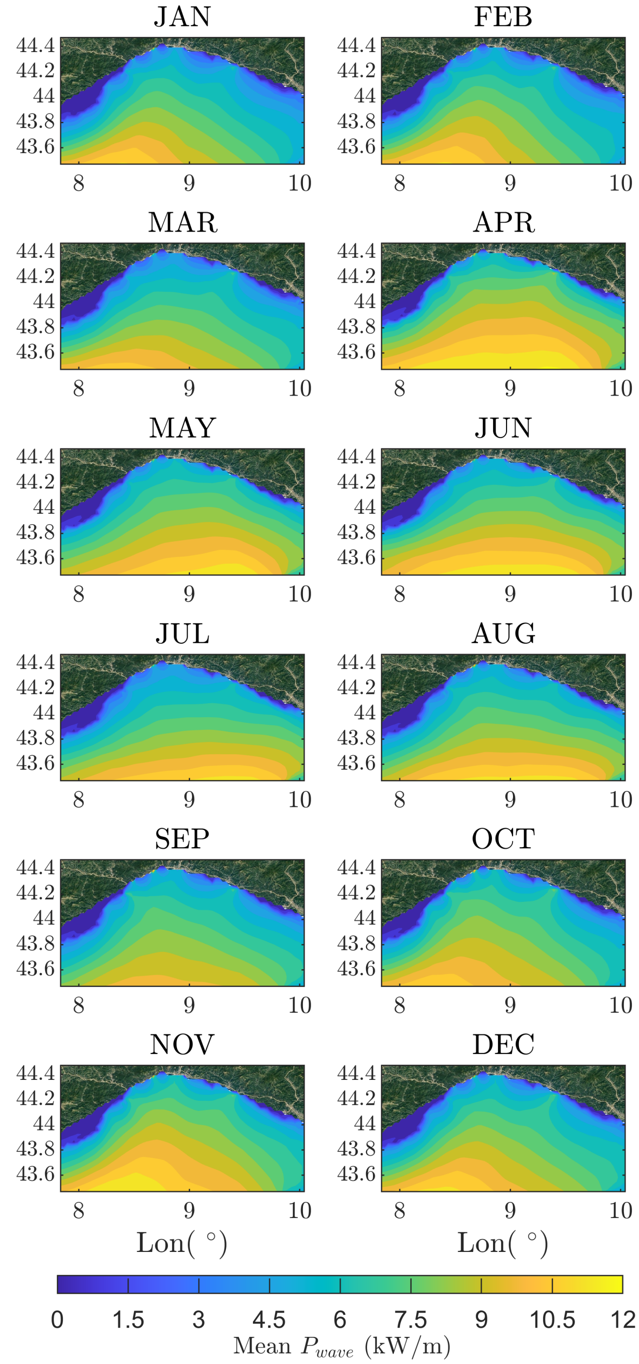

Fig. 2. Monthly mean wave power (kW/m) along the Ligurian Sea.

TABLE I
Wave energy converters features

Wave converter	Classification	Rated power	Reference
F-2HB	Point absorber	1000 kW	[31]
Pelamis	Attenuator	750 kW	[32]
SeaPower	Attenuator	3587 kW	[33]
Pontoon	Point absorber	3619 kW	[31], [34]
AWS	Point absorber	2470 kW	[35]
OEbuoy	Oscillating water column	2880 kW	[31]
AquaBUOY	Point absorber	250 kW	[36]
Langlee	Terminator	1500 kW	[31]

is for the wave conditions during an evaluated period. However, these indicators are unable to conclude their adequate functionality during extreme events. Therefore, this study also considered the evaluation trough the Selection Index for Wave Energy Deployments (SI-

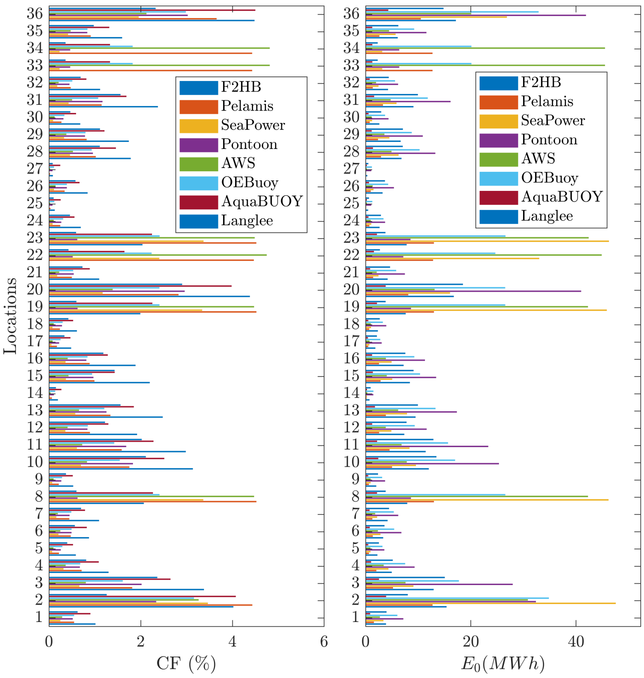

Fig. 3. Total energy produced (E_0) and Capacity factors (CF) for all WECs at each location.

WED) [37], and the Wave Energy Development Index (WEDI) [38], described below.

A. Wave exploitation through wave converters

The total energy produced (E_0) corresponds to the total amount of wave occurrence, expressed as the adjoint probability of occurrence between H_{m0} and T_p, indicating the power extracted by a specific WEC, as follows:

$$E_0 = \frac{1}{100} \cdot \sum_{i=1}^{nT_p} \cdot \sum_{j=1}^{nH_{m0}} p_{i,j} \cdot PM_{i,j} \,, \tag{2}$$

where the wave occurrence ($p_{i,j}$) corresponds to the adjoint probability of occurrence of T_p and H_{m0} obtained from the wave modelled data, and the power matrices for the evaluated WECs are represented by ($PM_{i,j}$). The captured energy by WECs can be rated by the Capacity Factor (CF) which represents the maximum theoretical value a converter can capture during a specific period usually a whole year of operation, and is calculated through (3):

$$CF = \frac{E_0}{P_0 \cdot \Delta T} \,, \tag{3}$$

where P_0 is the maximum potential wave energy that can be extracted using any WEC. According to this indicator for the wave analyzed conditions, the closer the CF is to 1, the more efficient the converter is. Fig. 3 presents the CF and E_0 for all locations.

CF values for the evaluated locations are presented at top panel in Fig. 3 . There is clear evidence that CF vary according to the assessed WEC even at the same location. It is also noticed that locations 2, 8, 19, 20, 22, 23 and 36 present the higher CF than the other locations. Thus, E_0 values exhibit similar behavior at those locations, as shown at the bottom panel of Fig. 3. In particular, locations 33 and 34 present high E_0 values for SeaPower and AWS converters. The CF of all converters indicate a low energy extraction capacity in the region for the devices of their standard sizes, for instance, if they are compared to those of the North Sea or Atlantic Ocean, where the estimated CF values are between 30% and 40% [20], [39]. Performance indices have also been estimated for each WEC. SIWED is one of the indices that allows to define the suitable locations from the technical point of view for the wave energy exploitation. This index considers the CF and the negative exponential decay of the covariance of H_{m0} over the wave height threshold defined from the Extreme Value Analysis methodology (H_{EVA}), and the maximum wave height (H_{Max}), defined as follows:

$$SIWED = \frac{e^{-CoV_{H_{m0}}} \cdot CF}{\frac{H_{EVA}}{H_{Max}}} \tag{4}$$

On other hand, WEDI corresponds to the ratio of the annual average wave power ($\overline{P_{wave}}$) over the maximum wave power (J_{wave}):

$$WEDI = \frac{\overline{P_{wave}}}{J_{wave}} \tag{5}$$

SIWED takes into account the resource, variability, extremes and technical potential of a WEC through its capacity factor. A site may have a high CF, i.e. a high energy output, but a high variability, which is therefore penalised, and which will subsequently intrinsically reduce the consistency of the output. In addition, this is also linked to the ratio between peak values and return values, which have a clear effect on suitability and costs. SIWED indices presented in Fig. 4 presented high variability among the evaluated converters at all locations, which means that the wave conditions in the region are not the most desirable, hence they are not the most suitable for constant and suitable energy. Locations with higher SIWED values are 2, 3, 8, 19, 20, 22, 23, 33, 34 and 36, although only for some WECs but these showcase larger potential. The WEDI index instead does not make distinction among WECs, as it is predominately a wave resource index. The WEDI values at all locations are close to its average value, except for the higher values at locations 3 and 32. The insight that remains from previous results leads to an evaluation of the WEC scaling in order to increase the efficiency of energy exploitation in order to increase the efficiency of energy exploitation, thus providing a financial justification for its development.

B. Wave energy converters scaling

An optimization of WECs allows to maximise the potential power extraction. This process consists to adapt the wave conversion device to the typical wave characteristics in a specific location, mainly due the WEC sizing. Thus, the PM of the sized, or scaled, WEC affects positively the CF, by setting the higher power rate P_0 to the most frequent wave conditions. The scaling of the devices has been done based on the $Froude$ similarity, i.e., by equating the Froude number

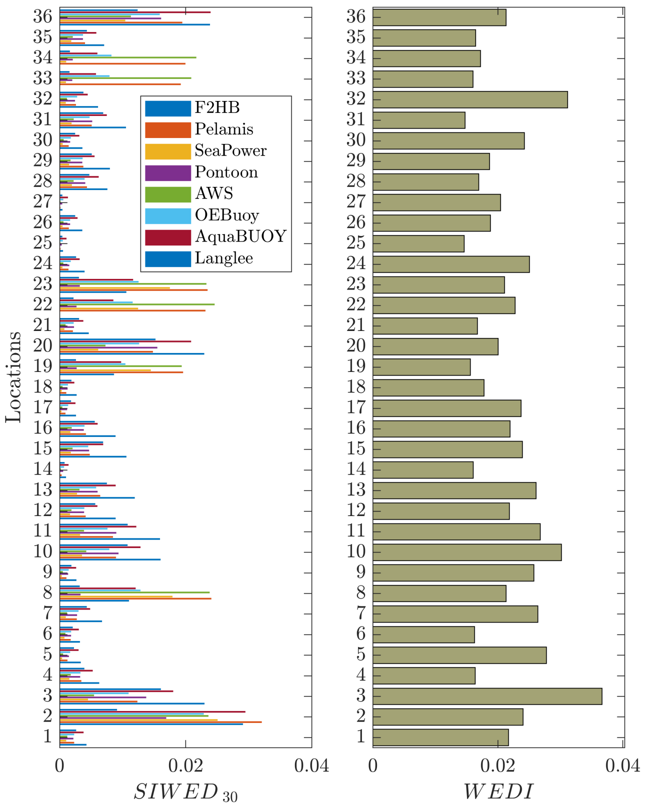

Fig. 4. SIWED and WEDI metrics at the studied locations.The subscript after the SIWED nomenclature indicates the number of years of the return period evaluated in the extreme event analysis, in this case 30 years.

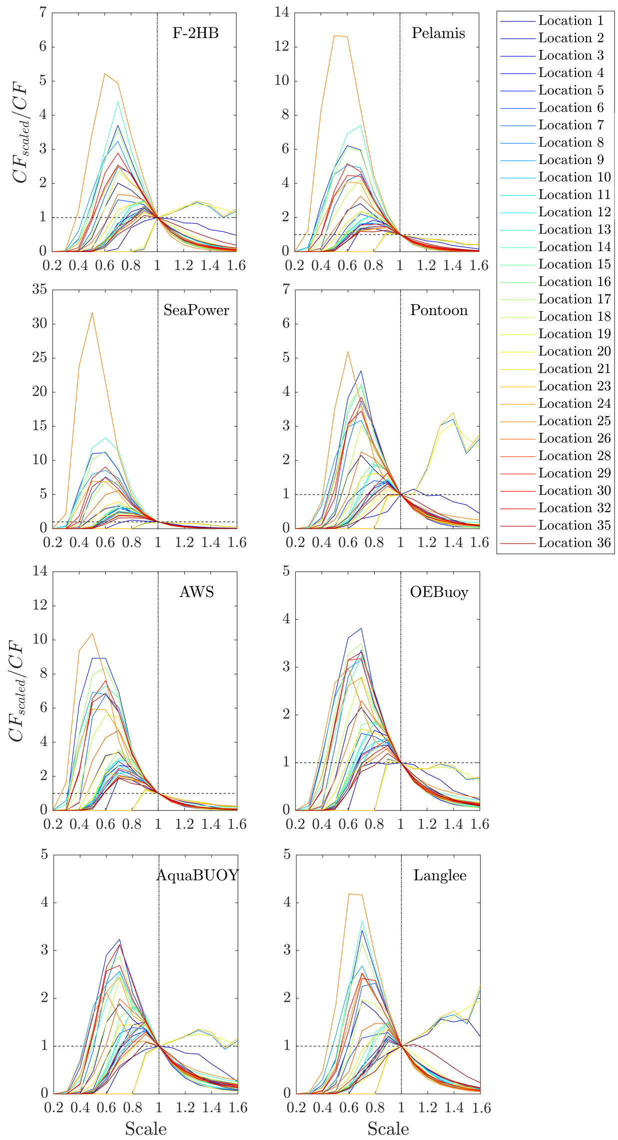

Fig. 5. CF scaled device over the CF of prototype device.

(Fr) of the prototype to the Fr of the scaled device. Hence, the geometric dimensions of the converter are scaled by multiplying by λ, the time is scaled by a factor of $\sqrt{\lambda}$, and the power varies by a factor of $\lambda^{3.5}$ [20]. The $\sqrt{\lambda}$ factor tested has been varied from 0.2 to 1.6 at a step of 0.1.

WEC scaling based on Froude similarity has proven to be appropriate in the converter power ratio between the prototype and the scaled model. However, it should be mentioned that there are discrepancies especially in the non-linearities, e.g. devices whose energy extraction mechanism is of the flap type and which do not really increase their efficiency when scaled down. According to Chozas J.F., et. al [40], for a field test stage and downscaled models, the uncertainties associated with the COE costs are around between -20% and 20%, a study from which several assumptions were taken up in the present investigation. Therefore, it is advisable to consider the technological and economic uncertainties in the case of a more detailed optimisation of a wave converter.

Fig. 5 presents how the devices downsizing produced the highest CF for most locations. However, locations 10, 18 and 20 offered higher CF for the up sizing of the Pontoon device. Thus, it is noted that the CF of WECs increased on scales around 0.7 for most locations for the F-2HB converter, with the exception of locations 8, 19 and 23, wherein the highest CF ratio occured at λ between 1.2 and 1.4. The SeaPower converter achieved up to approximately 30 times the CF of the prototype converter.

The improved energy extraction after the WECs scaling is followed by the recalculation of their performance indicators, particularly the SIWED shown in Fig. 6. It is clear that the performance has increased significantly compared to the performance indicators of the devices in their standard dimensions shown in Fig. 4.

The increased scaled SIWED ($SIWED_{30\,,\,scaled}$) corresponds to the ratio shown in Fig. 5. This increase is primarily owing to the CF increase. Thus, Pelamis, SeaPower and AWS converters are candidates for a converter to be implemented; however, such scenarios do not occur in all locations alike. Subsequently a further economic analysis must be done if an optimal device at each location is wanted.

C. *Economic analysis*

A commonly parameter employed in the economic assessment of converters is Cost of Energy (COE)

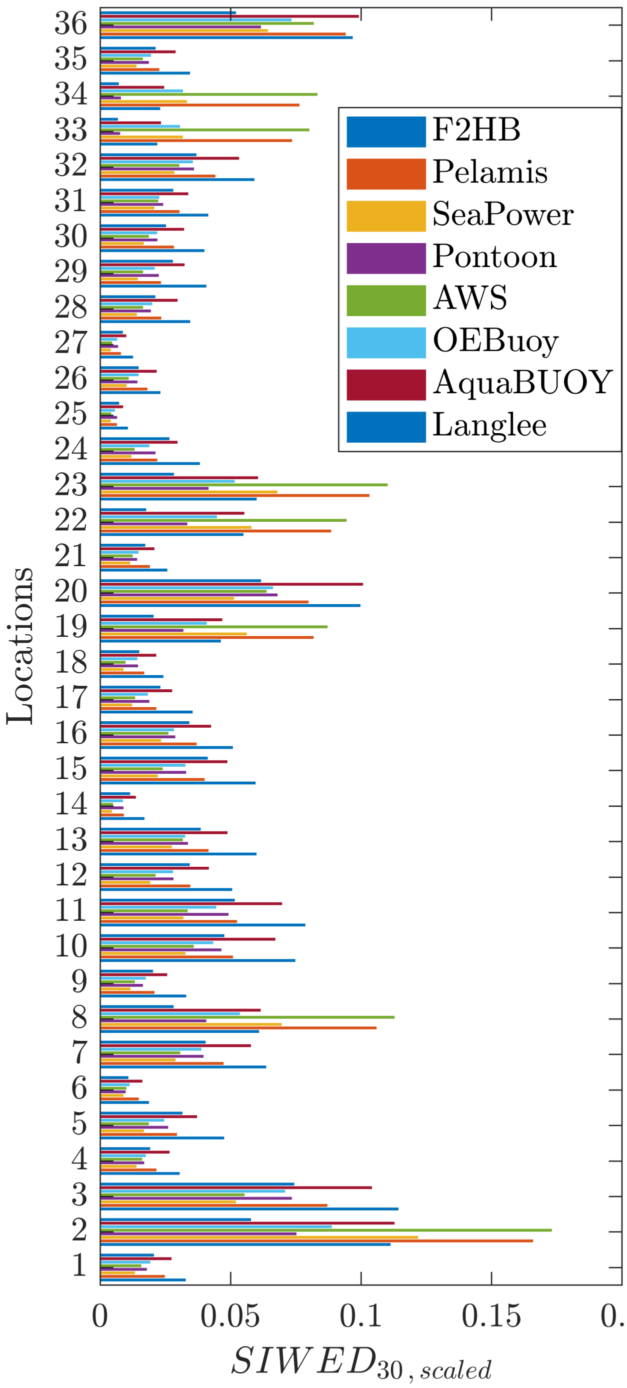

Fig. 6. CF scaled device over the CF of prototype device.

which is calculated through (6):

$$COE = \frac{CapEx + \sum_{i=1}^{n} OpEx_i}{\sum_{i=1}^{n} AEP_i} \tag{6}$$

where the capital expenditures (CapEx) corresponds to the initial investment for a WEC implementation considering related costs such as planning, engineering design, structures, preassembly, transportation, cables, mooring, and electrical controlling system. Likewise, the operational expenditures (OpEx) represents the maintenance and operation costs which are amortised over the n years of the lifetime of the converter. In this study it is also assumed that the OpEx is approximately 20% of the CapEx cost, based on approximations indicated by [39], then it is assumed as well in this study. The adopted lifetime for WECs corresponds to 30 years. The most commonly evaluated cost of energy conversion is the levelized cost of energy (LCOE). This indicator provides the cost of energy considering the annual operation and maintenance costs (OM) every year (i) of the lifetime, and brought to the present value by means of the discount rate (r) [41]:

$$LCOE = \frac{CapEx + \sum_{i=1}^{n} \frac{OpEx_i}{(1+r)^i}}{\sum_{i=1}^{n} \frac{AEP_i}{(1+r)^i}} \tag{7}$$

In addition, the costs associated in the COE and LCOE can be scaled for as a function of λ, as indicated by Chozas J.F., et. al [40]. The payback period (PBP) is defined as the number of years needed to recover the initial investment and annual maintenance costs. A 20-year maximum PBP threshold is commonly accepted, which is used in this study as a criterion for determining the feasibility of a converter. The formula used to estimate the PBP is shown in (8):

$$PBP = \frac{CapEx + RePower}{R_n - OM}\,, \tag{8}$$

where the R_n represents the guaranteed selling price of electricity, established as 300 € per MWh by the Italian National Electricity Authority [11], whereas the average OM value corresponds to 222 US $ per MWh [42], or 328.4 in € per MWh in 2023. The $RePower$ cost must be included in case that parts of the converter are affected a few years after the start of its operation, i.e. the cost of repair or replacement, as in the case of the Oscillating Water Column type (OWC) devices.

Once the highest $SIWED_{30\,,\,scaled}$ were found, COE, LCOE, and PBP were estimated for all locations, as shown in Fig. 7. Costs vary depends on location as well as the type of WEC. In the Ligurian region the AquaBUOY is the device with higher cost in mostly of all locations, whereas the more economic corresponds to Pontoon. There exist differences in costs at each location that can vary from tens to hundreds of euros for both COE and LCOE, being the latter slightly higher than COE costs. On other hand, most of the locations achieve PBP under the 20-years threshold however, some converters exceed the upper limit at locations 2, 8, 19, 22, and 23. In specific, at location 22, 33 and 34 all locations are not feasible according to the PBP.

Most of the LCOE costs of wave energy vary between 0.30 € per kWh and 1.20 € per kWh, as indicated by Guo C., et. al. [43]. In this study, LCOE values lower than 100 € per kWh have been found, mainly due to the high AEP achieved in some of the locations studied, which in terms of device survival may not be a viable option to consider. For this reason, it was proposed to combine this economic indicator with a converter efficiency index.

Then, in technical and economic terms, at each location a further step has been considered: the maximum value of $SIWED_{30\,,\,scaled}$ divided by the LCOE of each WEC at all locations indicates which converter corresponds to the optimal at each location. The obtained results are shown in Fig. 8.

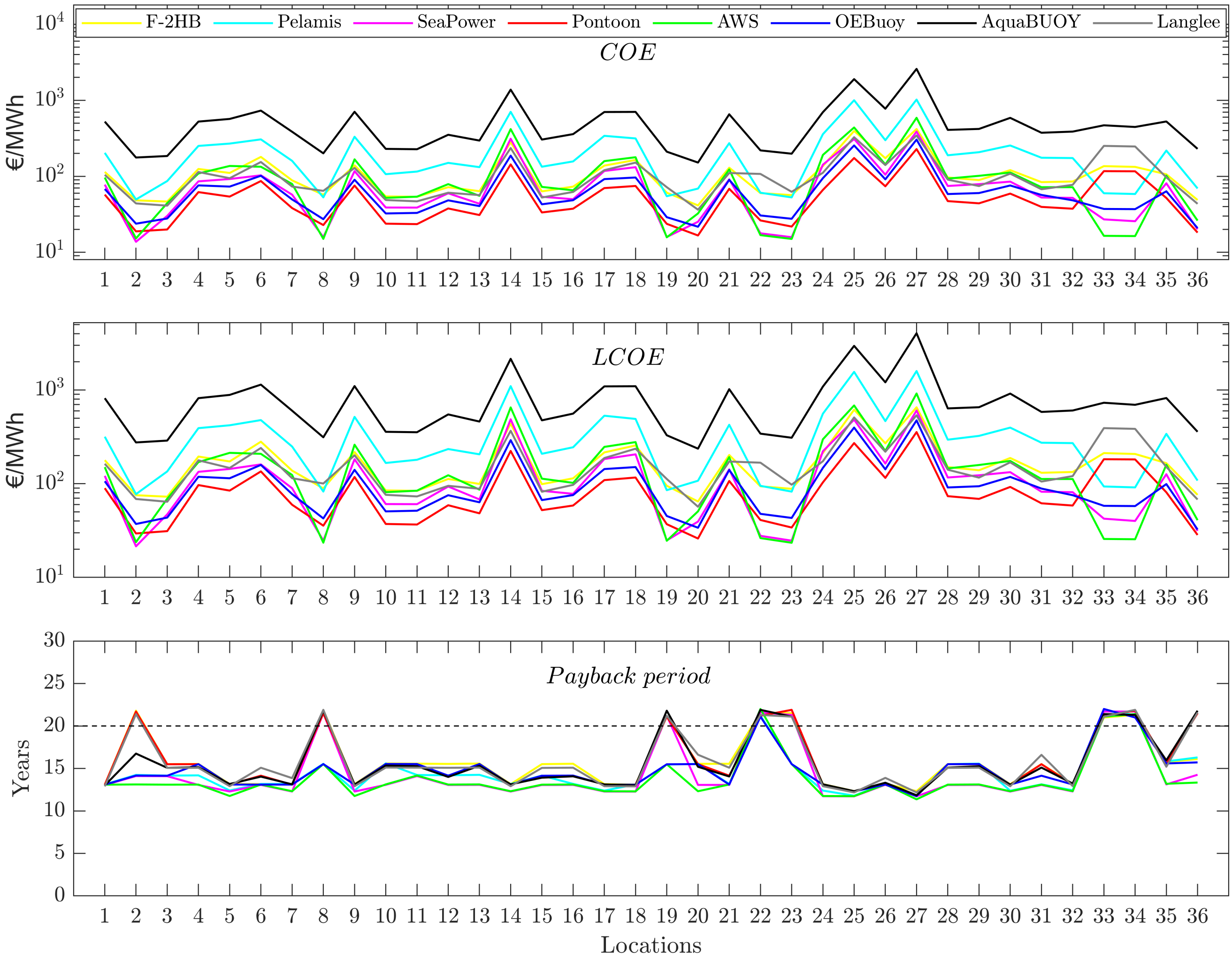

Fig. 7. Cost of Energy, Levelised Cost of Energy and payback period for the studied locations.

The aforementioned ratio does not consider the PBP, however the best WEC performance obtained are under the PBP threshold. The optimal converters by location are listed in Appendix B. A challenge faced in this study has been the lack of standards or definitive valuations of the costs contemplated in the COE and LCOE indicators, as these are variable depending on the geographical location, metoceanic conditions of the site, as well as the early stage in which we currently are in terms of establishing fees or investment rates for this type of energy exploitation.

A further environmental impact analysis has been performed through the estimation of the amount of carbon dioxide (CO_2) can be avoided if clean energy sources, as wind offshore and wave energies, are exploited. The wind energy can be calculated as indicated in (9):

$$P_{wind} = \frac{1}{2}\rho_a \cdot A \cdot v^3 \,, \tag{9}$$

where ρ_a corresponds to the air density (1.225 kg/m^3), A corresponds to swept area by the blades of a wind turbine, in this has been considered blades of 49m length, and v is the wind velocity (m/s) at each location. Then, the avoided CO_2 emissions can be estimated as follows:

$$E_{CO_2} = EF \cdot P_{eff.} \cdot 8760 \,, \tag{10}$$

where EF corresponds to the emission factor, defined as 532 equivalent grams of CO_2 per kWh (gCO_2 eq./kWh) in case of natural gas combined cycle power plant, and 762 gCO_2 eq./kWh for an oil fired plant [44], [45]. The term $P_{eff.}$ indicates the power of each renewable energy, wherein the P_{wind} is multiplied by an device efficiency of 50% [46], whereas a 49% represents an average of the efficiency between different WECs [47]. The avoided CO_2 emissions produced by the use of renewable energies at all locations are presented in the Fig. 9.

The avoided CO_2 per MW were estimated based on the converters production, subsequently, the wind and wave power consider the devices efficiency, as established through (10). Moreover, only one energy converter, i.e., one unit, has been considered for estimating the avoided CO_2 per MW. Fig. 9 presents the locations with the highest and lowest CO_2 avoided trends, as well as the average trend of the 36 locations. The aforementioned serves to provide a better interpretation of the graphs, being aware that the trends of the

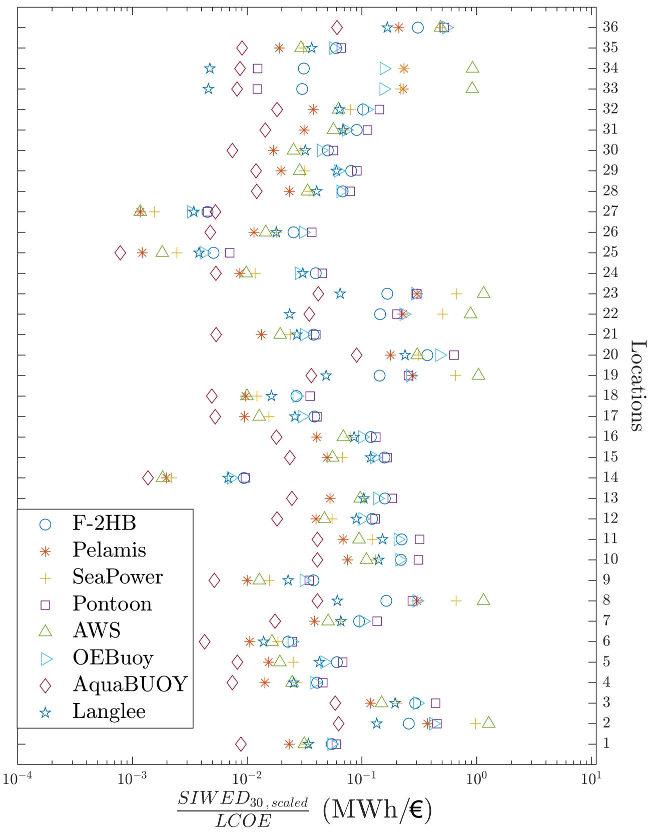

Fig. 8. $SIWED_{30\,,\,scaled}$ over the LCOE cost ratio. The highest value of this ratio indicates which WEC is suitable at each location.

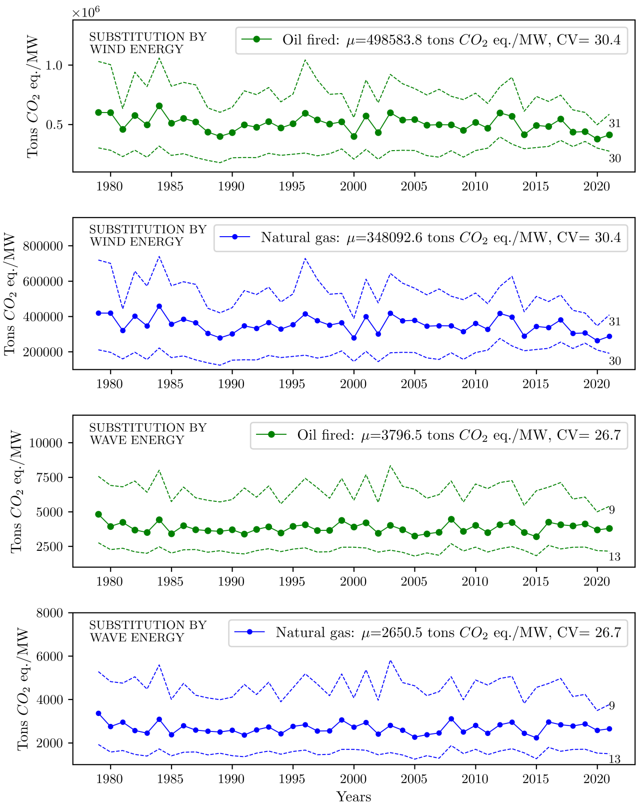

Fig. 9. Avoided CO_2 emissions by equivalent wind offshore and wave energy. Dashed lines correspond to the locations (written at the end of the trend) representing the maximum and minimum yearly values, whereas the solid line corresponds to the yearly mean value of the 36 locations.

remaining locations are at the maximum and minimum values indicated.

Regarding the estimation of the avoided CO_2 emissions by employing the wave energy conversion a mean efficiency value based on several converters is usually employed, which can bias the result accuracy for a specific converter. Based on the equivalent $C0_2$ avoided, wind energy has the potential to avoid, in average, up to approximately 8.5 times more $C0_2$ tons than wave energy at the 36 studied locations. Nonetheless, either the 3796.5 $C0_2$ tons per MW in substitution of oil-fired plant, or 2650.5 tons per MW in the case of natural gas plant, are significant amounts of this component of GHG.

III. Closing Remarks

Wave energy harnessing in the Ligurian Sea can be a good alternative to feed the electricity mix along the region in a sustainable way, as long as the WEC scaling is considered. The deployment of wave energy can become a feasible option although the Mediterranean basin offers a lower wave power contents compared to the open ocean along the temperate and frigid regions. The WECs scaling increased significantly the WEC performance at all evaluated locations as demonstrated in this assessment.

Thus, this study has shown that at any marine site it is possible to evaluate the possibility of obtaining wave energy, as long as the converter is adapted to the local wave characteristics. Since most of the λ factors which produced the higher performances were lower than 1, i.e., the converters were downsized, higher performances were found for most of the assessed WECs, and related costs of its implementation were reduced as well.

It is relevant to remember that determining the scale of the WECs that offer the highest CF does not guarantee that the optimal point has been reached since there exist nonlinear scale effects that must be studied in detail to understand how these affect the energy harvesting system. However, when combined with an economic indicator it provides a clearer idea of how to continue the detailed study of the WEC evaluation, as demonstrated in this study (Fig. 8). Our goal of focusing on scale effects and identifying which dimensions improve converter performance was achieved.

On the other hand, assumptions behind the COE and LCOE costs have been obtained from studies based on the North Sea and the Mediterranean Sea which makes them valid on the Ligurian Sea. Given the limited exploration of the marine energy resource in many regions around the world, it is not possible to establish the items associated with COE and LCOE costs, as indicated by Wang et. al. [48]. Certainly, it remains a drawback for generalizing or comparing potential cost findings in other latitudes of the world where such technologies have not yet been implemented.

Likewise, the mapping of potential regions where marine renewable energies (MRE) can be extracted is a proper first step to be implemented. Detailed mapping and regulations related to marine energy exploitation in Italy are required. However, regulations on the management and use of MRE are currently insufficient because wave energy extraction involves innovative technologies and has undergone development over the last two decades. Wave energy contributes in a sustainable way to the electricity mix, reducing thousands of tons of CO_2. Conversion of WECs such as AWS, AquaBUOY, OEBuoy, and mostly Pontoon, are defined as the most suitable for the locations evaluated in the Ligurian Sea. The optimal WEC selection based on the SIWED parameter represents an proper way owing to that index considers WEC operativity, and subsequently, the survival of converters during extreme events.

The average LCOE for all locations ranges approximately from 70 to 1150 € per MW, thus identifying the worst and suitable locations for wave energy exploitation. However, most locations present LCOE values between 100 and 400 € per MW for some WEC which represents an attractive alternative for the diversification of the electricity mix. Finally, there is the added advantage of reducing environmental pollution as demonstrated by the CO_2 avoided if renewable energy sources are considered.

ID	Longitude (°)	Latitude (°)	Depth (m)	Distance to the shoreline (km)
1	7.54441	43.77087	53	1.26
2	7.58157	43.76901	51	2.61
3	7.63560	43.77343	89	1.12
4	7.72464	43.78236	56	1.70
5	7.79011	43.79527	50	2.35
6	7.86119	43.81292	61	2.06
7	7.95337	43.82901	68	2.03
8	7.98501	43.83958	55	2.08
9	8.06536	43.87079	55	1.97
10	8.10805	43.88967	52	2.99
11	8.15561	43.91685	58	2.48
12	8.19063	43.96788	103	1.71
13	8.25927	44.06441	75	2.74
14	8.29116	44.12218	60	2.06
15	8.36539	44.16223	90	1.17
16	8.43884	44.21363	116	2.14
17	8.46772	44.27304	64	1.99
18	8.53074	44.32048	52	1.29
19	8.58924	44.35409	51	0.71
20	8.66587	44.37254	61	2.00
21	8.72468	44.39703	58	2.18
22	8.75038	44.36038	102	7.03
23	8.83122	44.39960	54	1.88
24	8.87802	44.38630	70	2.05
25	8.92684	44.38100	63	1.21
26	9.01363	44.35465	85	3.21
27	9.13305	44.32701	70	1.17
28	9.19365	44.29541	99	1.26
29	9.29381	44.29624	53	2.48
30	9.38171	44.25016	74	1.81
31	9.47145	44.22088	51	1.40
32	9.57666	44.15170	72	2.64
33	9.68491	44.08329	65	4.49
34	9.75133	44.06773	52	2.07
35	9.78530	43.99765	53	6.96
36	9.89009	43.91506	53	14.94

Appendix A
Locations of wave energy converters

Location	Best WEC	LCOE (€ /MWh)	PBP (years)
1	Pontoon (0.7)	58.60	1
2	AWS (0.7)	15.56	1
3	Pontoon (0.9)	20.41	3
4	Pontoon (0.9)	63.29	3
5	Pontoon (0.7)	55.25	1
6	Pontoon (0.8)	88.55	2
7	Pontoon (0.7)	39.01	1
8	AWS (0.9)	15.36	3
9	F-2HB (0.7)	148.38	2
10	Pontoon (0.9)	24.34	3
11	Pontoon (0.9)	24.00	3
12	Pontoon (0.8)	38.57	2
13	Pontoon (0.9)	31.61	3
14	Pontoon (0.7)	146.45	1
15	Pontoon (0.8)	34.18	2
16	Pontoon (0.8)	38.30	2
17	Pontoon (0.7)	71.47	1
18	Pontoon (0.7)	76.22	1
19	AWS (0.9)	16.09	3
20	Pontoon (0.9)	17.02	3
21	Pontoon (0.8)	69.98	2
22	None	- - -	- - -
23	AWS (0.9)	15.33	3
24	Pontoon (0.7)	67.61	1
25	Pontoon (0.6)	177.56	1
26	Pontoon (0.7)	75.51	1
27	AquaBUOY (0.5)	301.08	1
28	Pontoon (0.9)	48.19	3
29	Pontoon (0.9)	45.07	3
30	Pontoon (0.7)	60.48	1
31	Pontoon (0.9)	40.44	3
32	Pontoon (0.7)	38.27	1
33	None	- - -	- - -
34	None	- - -	- - -
35	Pontoon (0.9)	53.02	3
36	OEBuoy (0.9)	21.26	3

Numbers inside the parenthesis indicate the λ for the optimal WEC. "None" indicates that no device is chosen because all of them exceeded the maximum PBP threshold.

APPENDIX B
SELECTION OF THE BEST WECS BY LOCATION

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