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Assessing the integration of an oscillating water column at the planned Genoa breakwater

George Lavidas[1*], Francesco De Leo[2], Giovanni Besio[2]

[1]Department of Civil Engineering and Geosciences, Delft University of Technology
[2]Department of Civil, Chemical and Environmental Engineering, University of Genoa, Italy
[*]Corresponding author: g.lavidas@tudelft.nl

Abstract

The option to have an WEC integrated breakwater at the port of Genoa ensures that the port will protect the area from harsh incoming waves, but also contribute towards the port decarbonization. However, for the solution to be viable, a first layer analysis must estimate its profitability. This works uses a long-term high fidelity wave numerical model from 1979-2018, estimating the potential energy production for an integrated OWC at the Port of Genoa.

Keywords Wave Energy, Oscillating Water Column, Capacity factor

1 INTRODUCTION

Coastal regions in the Mediterranean are in immediate risk of Climate Change, sea level rise driving increases in extreme events, potential flooding and erosion (Makris *et al.*, 2016). This can create severe problems for coastal populated areas, cities, and the security of operations for crucial sectors such as harbors. Indeed, the Mediterranean shores are densely populated and about 20% of the world's seaborn commerce passes through the Mediterranean Sea.

The increasing pressure at Mediterranean coastlines requires adaptation measures and rethink coastal infrastructure design, embedding policies that pursue sectoral decarbonization and carbon neutral operations. These have been particularly developed over the past years, with leading port infrastructure California, Shenzhen and the Port of Rotterdam (Samadi *et al.*, 2016). Most of the proposed solutions include photovoltaic and onshore wind as sources of renewable electricity. However, wave energy production remains one of the most overlooked and under-utilized resources, with high synergies at coastal locations for power production, and coastal protection.

The Italian energy mix is heavily dominated by oil and natural gas with net energy consumption≈315 TWh per year (IEA, no date). Italy has translated the aims for Blue Growth and further development of ocean energies into tangible targets, reducing greenhouse gas emissions by 40% (compared with 1990) and 30% of gross energy consumption from renewables by 2030 (European Commission, 2020). Focusing on a future perspective, the Italian National Energy and Climate Plan (NECP) has set ambitious goals for the development and regional Mediterranean cooperation for wave energy development. Wave energy is part of the Blue Growth agenda, and part of the technologies are represented in the SET-Plan.

An “hybrid maritime structures” is an innovative integration technique to combined WEC into existing or planned coastal structures with the purpose of the structure as a whole to maintain protection from metocean harsh events. It is, however, a logical evolution for someone to think that the integration of WECs into coastal structures will also benefit other sectorial developments. WECs are distinguished by their deployment applicability and are separated into shoreline, nearshore and deep-water devices (Rusu and Onea, 2018). However, knowledge of metocean conditions is vital to ensure the optimisation of any type of power take off for WEC.

2 MATERIAL AND METHODS

For the detailed characterization of the local wave climate, we took advantage of the hindcast data provided by the Department of Civil, Chemical and Environmental Engineering of the University of Genoa (Mentaschi *et al.*, 2015). The data are defined on a hourly base over the period 1979–2018 in the node000230 at a depth of about 650 m (http://www3.dicca.unige.it/meteocean/hindcast.html), and were therefore subsequently downscaled in front of the dike with Simulating WAves Nearshore model (SWAN). The use of SWAN allows for higher fidelity simulation near shallow water, where oceanic models often use approximation for shallow water dynamics, thus allowing for properly accounting for the large depth variations the regional bathymetry is characterized by (see Figure 1).

Figure 1: Spatial representation of the domain used, indicating the point used for boundary information to propagate the high resolution SWAN model

Using a nearshore model driven by validated boundaries takes advantage of faster computation time and higher shallow water accuracy with similar model chains. Our boundary conditions are extracted by a validated and calibrated model, and considering the small fetch, validity of the underlying data benefits by the shallow water source terms of SWAN. The figure shows a close-up of the investigated area, highlighting the input and output wave data nodes, with the latter further used for the estimation of annual energy production.

3 RESULTS

The focus here is the integration and hybridization opportunities offered by an OWC converter to a harbour expansion. While OWC design has been installed and is operative (i.e., Mitruku) (Ibarra-Berastegi *et al.*, 2018), their power matrix is not available and, as mentioned in (Naty, Viviano and Foti, 2016), this can hinder development of studies. For the potential OWC, we have adopted the power matrix of an OWC and obtained the capacity factor (CF) based on a 40 years hindcast analysis, as indicated by other studies (Rusu and Onea, 2016; Lavidas and Venugopal, 2017).

The port of Genoa, comprised of the Genoa and Savona hubs, it is one of the busiest ports in Italy and Central Europe. The port encompasses several specialised terminals that can handle different types of cargo, from technological equipment to fresh produce. Operative versatility also means that energy requirements must be constantly met, especially in the case of sensitive produce.

The large traffic has increased requirements in cold ironing (i.e., berthing) for parked ships. It currently handles≈2.6 million TEUS, and this amount is expected to increase in the next future. As such, in 2018, the Port Authority launched a project for enlarging the port capacity, implying the building of a new dike farther seaward with respect to the actual existing one. In addition, the Port Authority has set an ambitious plan for energy efficiency and production by renewable sources (Lavidas, De Leo and Besio, 2020)

The historical wave climate can be assumed to be representative of the future climatology of the area. Indeed, as far as wave parameters are concerned, the investigated location is not characterized by relevant historical trends, nor it is expected to be significantly affected by future variations. Annual energy performance of the OWC is given in Figure 2, along with the estimated Coefficient of Variation (CoV). At the port of Genoa, the mean value of CF is 8.85%, the CoV indicates a small level of variation expected annually, therefore showing little drops in performance.

As it can be seen in Figure 4, there seems to be a cyclic maxima performance every three years, followed by a decrease every two years. The energy analysis indicates that, through the region, performance and capacity factors are similar, with maximum value ≈11.5%. Surrounding the Ports of Genoa, the CF is ≈6–11%, with mean value of ≈8%. Focusing at the Port of Genoa, the specific location data representing 44◦24′N 8◦53′E were extracted. The analysis uses 40 years of data allowing for robust energy estimates, considering the effects of Climate variation on the OWC performance.

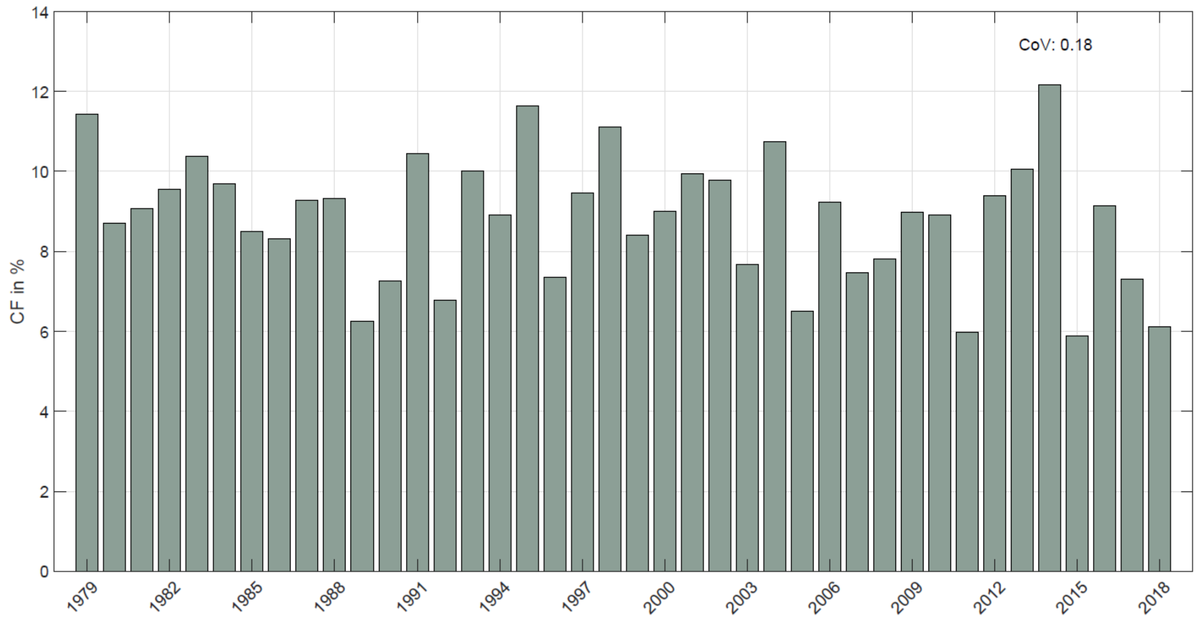

Figure 2: Annual estimated Capacity Factor for the location of the OWC in Genoa

A metric that can be used to compare different energy technologies is the Levelized Cost of Electricity (LCoE), regardless of their resource origin, the comparisons are expressed in currency per electricity produced. There are two main components for LCoE estimations, cost/expenditure, and energy production. LCoE does not indicate the economic viability, but it evaluates the probable aggregated energy cost. Avoided emission per fuel type and avoided energy imports are also estimated and used with the produced electricity to assess additional benefits by quantifying avoided emissions. The energy estimates and avoided emissions per fuel type, dominant in the Italian energy mix are given in Table 1.

Table 1: Performance in annual energy production and avoided emission from the potential installation(s) of the OWC proposed.

	0.5 MW	1 MW	1.5 MW	2 MW	2.5 MW	3 MW
AEP (MWh/year)	387.55	775.11	1162.6	1550.21	1937.77	2325.32
Oil avoided Tn CO_2/year	293.92	587.85	881.77	1175.70	1469.62	1763.54
Natural Gas avoided Tn CO_2/year	199.52	399.05	598.57	798.10	997.62	1197.14

Given the fact that one specific device is proposed here, LCoE will be mostly a function of CapEx. As the installed capacity increases, the LCoE sees a reduction. The lowest LCoE 185.80 €/MWh is for 3 MW installed capacity, with a total CapEx 1,500,000 €. The highest LCoE is 627.05 €/MWh when the cost per MW is 3,000,000 €, and for a 0.5 MW configuration total costs scale to 10,800,000, see Figure 5.

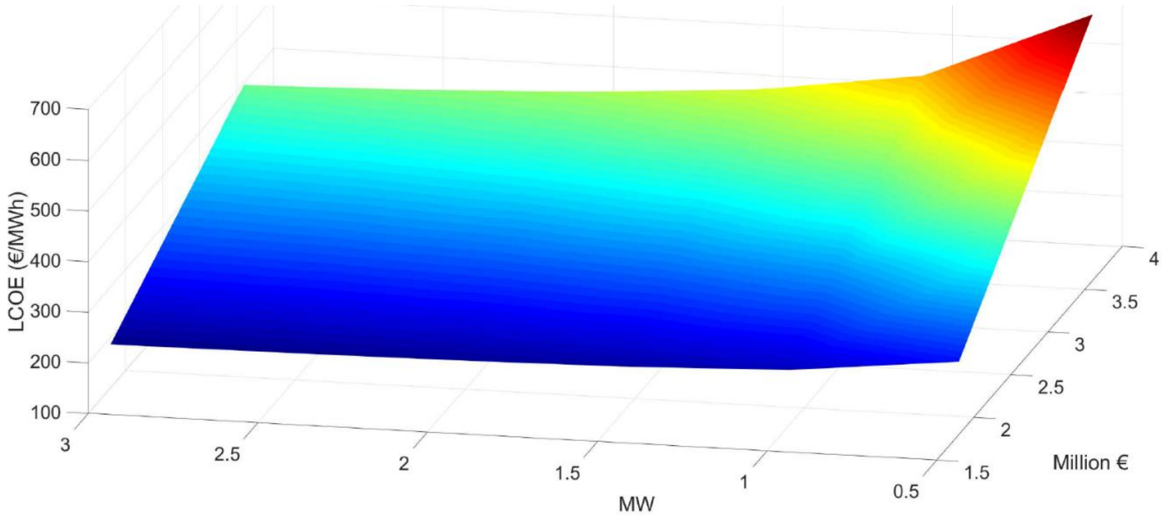

Figure 3: LCOE distribution of the OWC with regards to CAPEX (Million €) and installed capacity (MW)

4 CONCLUSIONS

Within this study determined the potential energy benefits and economic feasibility of an integrated OWC at the Port of Genoa. Through the coupling of multi-model nesting, energy analysis and utilizing a non-optimized WEC solution, ratios are proposed for which an investment would be feasible. Past studies indicated the possibility of tuning the converter behavior to local condition, hence scaling its performance is expected to increase the energy production by at least 50%. An integrated breakwater OWC operates at shallow water areas where surge and depth breaking will be more dominated, and thus simple Froude scaling is not possible.

Incorporating an OWC also offers significant benefits in offsetting carbon emissions by conventional sources, and hence increasing the sustainability of operation for the Port of Genoa. These values can be from ≈300–1763.54 Tn CO_2/year for oil-based electricity and ≈200–1200 Tn CO_2/year for Natural Gas (NG), effectively reducing the carbon budget and making the Port of Genoa highly competitive and sustainable regarding its emissions.

Another under-estimated characteristic is the beneficial mismatch of operation with other renewable energies. This in fact can enhance the utilisation of energy by renewables, whilst minimizing expensive solutions as batteries, which for industrial solution can be as high ≈1000 €/MWh (as stand-alone solutions), and from ≈280–360 €/MWh (as part of storing electricity by photovoltaics). Besides the aggregated annual energy performance, the hourly power production was analysed, and a filter was applied to focus only on hours that photovoltaics do not produce (from 6:00 p.m.–8:00 a.m.). The minimum hours operated in this timeframe of non-sunshine, the lower value was in 2005 with 5.85% in total hours, the maximum was 10.72% in 2000, with mean power production in such hours representing 8.25%.

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