NEW COASTAL PROTECTION
AND SEA ENERGY PRODUCTION

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Abstract - A new location for coastal protection is in the seabed transition zone, where offshore pulsing vertical wave energy is converted into inshore horizontal current energy. Artificial reefs, which consist of staggered barriers made up of turbines, create a soft defense of the coasts that mimic coral reefs, close to the calm belt, far from the storms. These barriers reduce the sea current speed below sea level with the consequent deposition of suspended sand for natural nourishment. The second advantage is that the vertical turbines are made up of a helix fixed to a floating spinning top so that it is in an indifferent equilibrium in the water, turned, therefore, by minimum currents. The supports on which the propellers are pivoted, are implanted in recycled material powder trusses for 3D printers. They are laid on the sea bed and are movable, in the same way as a naval wreck. Electric energy is produced even with a low number of revs, but this production is long lasting, and therefore with a higher number of hours of production per year than eolic and photovoltaic MW. The production, 5 ÷ 10 GWh/km per year, is dependent on the exploitable marine energy (minimum 3 kW/m to max 10 kW/m) and the extension of the propellers and artificial reef distribution. The costs of these barriers are very advantageous compared to current coastal defenses, based on the costs of beach artificial nourishment and on the maintenance of breakwaters. This is because the production of electricity covers the cost of amortization, and in particular the high annual cost of maintenance. Moreover, as well as the favorable MW/€ comparison with eolic offshore energy production, there is also the question of beach recovery, which does not occur in the case of eolic production. Furthermore, the cost of the floating foundations and the submarine cable inshore is significantly lower than the offshore costs. The total submersion of the artificial inshore reef minimizes the environmental and landscape impact compared with the current systems. A further advantage of this new defense is that it prevents sea-level rise due to climate change by embanking the coast by means of natural nourishment and re-growth of the marine grasslands, thereby recovering hectares of beach, with subsequent economic benefits especially for tourism. In Italy, erosion affects over 1200 km of coastline, equal to 1/3 of the sandy beaches, which have been reduced by up to 25 m, or more than 2 ha/km, with great economic loss. The rise in the beach level and limitation of coastal erosion represents the principal economic benefit. The proposal is to substitute traditional nourishment and breakwaters with energized reef turbines so as to favor the marine ecosystem and the landscape, and to promote sea depollution, with systematic control of plastics. It highlights the importance of monitored experimental research, in real scale, to develop the economic and environmental benefits.

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1 Introduction

The first proposed breakwater to protect the coasts (Ventura 1992) was based on finned cylinders anchored to ballast on the seabed, like Bristol cylinders, without the production of electric current.

The 1:4 scale models were tested at the INSEAN naval tank in Rome with encouraging results regarding the damping of the height of the waves as the test frequencies increased.

The new type of artificial barrier for the protection of the coasts was designed by Palmarocchi-Ventura (2018) and made known through STES: Scientists and Technologists for Development Ethics (www.stesecoetica.it).

The main activity of this *cultural volunteering organization* is to document projects for the protection of the environment integrated on an ethical basis.

With regard to this objective, the new barriers make a valid contribution towards marine energy production and coastline-seabed protection.

In fact, the traditional protection based on rockfill breakwaters and nourishment is anti-ecological and anti-economic.

The new barrier was approved by the Munich Patent Office and is registered in the CNR SOLAR (Scientific Open-access Literature Archive and Repository) database as a technological innovation. The barriers are usable by Start Ups within the framework of the Green Economy and the 20/30 European Green Deal.

2 Description of the new defense

The idea starts from the observation that the energy of the wind produces enormous pulsing vertical waves on the sea, stationary regime (Boussinesq 1897), when the bathymetry is deep.

Approaching the coast, where the seabed is around 6÷7 m, the same waves (Fig.1a) are converted into direct horizontal currents towards the shore (G. Ferro, 1970).

This occurs, according to the marine geomorphology (Mas-Pla, Zuppi, 2009), about 300 ÷ 500 meters on average from the shore, when the currents then proceed at lower depths, 3 ÷ 4 meters, they are converted into storm surges, which cause erosion.

After the offshore/inshore calm area there is the *inshore mature, "festina lente", formation of horizontal currents*. In this particular zone a new artificial reef can be placed as a soft defense (fig. 1a), which *mimics the coral reef* (Fig. 5a), *whit location far from the sea storms* (fig. 1b).

In this regard it is very important the coastal monitoring and research to the storm impact along coastlines (Ciavola P. et al. 2011) in particular by inshore/offshore *currentmeters*, from compound float or "differentiated consumption wind-rose" chalks to triaxial acoustic (Fig. 2), and *telewattmeters*.

The traditional defenses of the coasts are based on rockfill breakwaters near the beaches (Fig. 3), which also induce upheavals on the seabed and erosion of the unprotected coast. The artificial nourishment of beaches with traditional rocky barriers is supplied via powerful pumps which extract fine sediment from the seabed offshore. However, this sediment, which is granulometrically unsuitable, is systematically removed by storms.

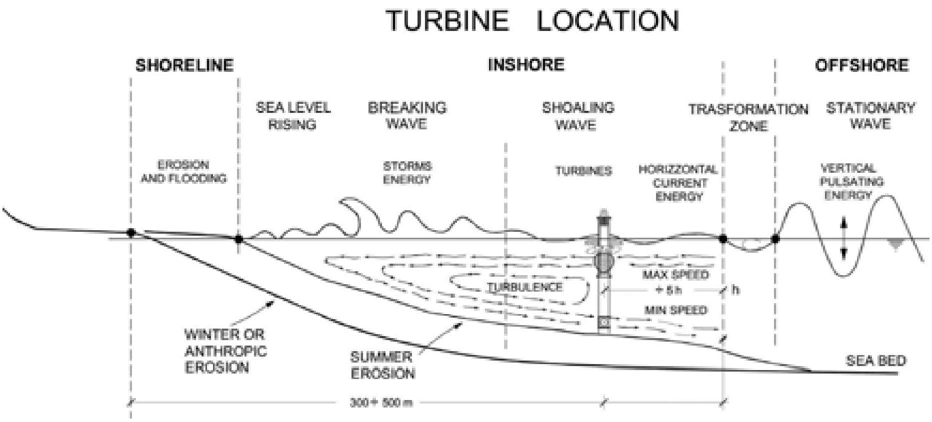
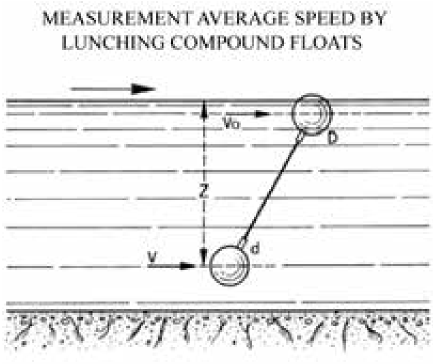
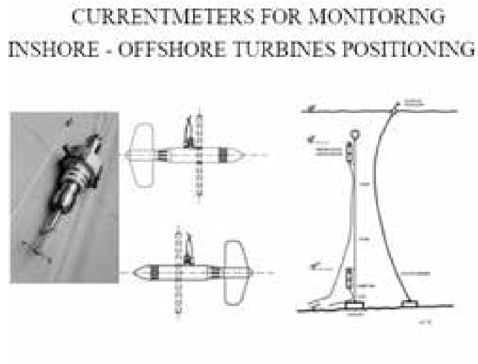


Figure 1a - Turbine barrier location, similar to that of coral reefs (fig. 7), is where the energy of the vertical pulsating waves (offshore) is converted into horizontal sea currents (inshore). This constitutes a *soft defense,* with electricity production. Excessive erosion resulting from anthropic causes is reduced by the particular positioning of the turbines, which simultaneously dampen the currents on the seabed. Conversely *rigid defenses* (rockfill, piers, etc.) during the sea storms increase breaking of the waves, especially at low depths.

Figure 1b - Offshore/inshore calm area during a strong storm surges in Tuscany.



a)



b)

Figure 2 - Old (a) and modern (b) currentmeters for monitoring inshore/offshore marine currents, for turbine positioning and research of antierosion efficiency.

Both these types of defenses are inefficient and expensive. To help modify these traditional types of defenses, a new energized reef is proposed, which substitutes the natural damping of the *winter mobile sand shoal.*

The patented vertical axis turbines (Fig. 6a, b) consist of propellers fixed immediately below the sea level between two floats: the superior disc is for lamination of the currents and the inferior disc is a whirligig for spin stabilization.

Kinetic sea energy is more *competitive than eolic*. The turbine, with specific gravity equivalent to water, is in indifferent equilibrium in the water and turns at minimum levels of marine currents. The electric energy is produced even with a low number of laps and it is long lasting, with *higher hours of production* than eolic and photovoltaic.

The tubes on which the propellers are pivoted, are implanted in the sand like "sea razor clam" shells, and are produced by 3D printers using metal powder recycled scrap.

They are thus similar to (Fig. 5b) coral reefs with sand (Dini 2020), or fiber-reinforced ones which are already on the market for offshore structures.

The floating propeller block is also made of the same material by 3D printers, and it drives a low-frequency multipolar dynamo.

The turbine, nearly 20 kW, converts marine energy starting from 2 ÷ 3 kW/m of the wave energy. Furthermore, the hours of electricity production are much higher than for wind, as the water pushes on the propellers much more than the air, and they are more efficient than photovoltaics, since the marine turbines can also work at night.

The tubes are vibro-infixed at a suitable depth in the seabed, similar to mooring dolphins (Ventura 2019), so as to constitute a *strong foundation* with a prefabricated tripod module, which is bonded at the base by means of a triangular mesh.

To keep the propeller disposition stable, these fixed pipes can also be replaced by foundations consisting of a continuous truss anchored on the seabed and with stresses adaptable to marine displacement.

This submerged foundation will have the same impact as that of a naval wreck, and increase diving tourism.

The truss on the seabed can also be transported for the defense of other coastal areas, after stabilization of the ecosystem. The life of the barriers also allows for regrowth of the posidonia, preventing the uprooting of the nurseries (Marsella 1986).

The arrangement of the turbines, which are staggered in the barriers, results in significant damping of the marine currents thereby reducing the speed and creating a *"soft" defense* of the coasts without negative side effects.

It should be noted that the marine energy to be damped by the turbines is caused by excessive, urbanization-induced erosion, which has destroyed the dunes and the Mediterranean maquis that protected the beaches from wind.

On the other hand, summer-winter erosion, especially that which replaces the movable sandbank on the seabed, is a powerful natural damper of marine energy which defends the coasts.

This natural defense by sand nourishment is enabled by the turbine reef, comb filtering effect, which serves above all to avoid excessive anthropic erosion (Fig. 1, 3 e 4).

The planimetric distribution of the turbines, which replaces the mobile sandbank, must be adapted to each shoreline (Ricci Lucchi 1992) based on the geomorphology of the seabed and maritime weather data of the fetch.

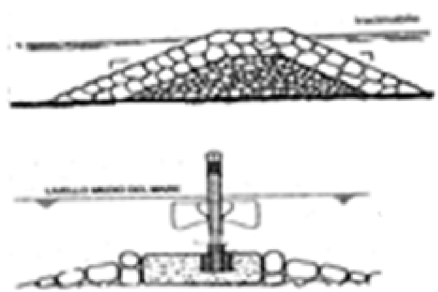
Both characterize the energy of the waves, which go from over 10 kW/m in Sardinia to less than 5 kW/m on the coasts of the Tirreno.

The new reef defense makes it possible to raise the level of the beach through natural nourishment, in order to guard against the rising sea level (3 mm/year) caused by climate change and significant melting of glaciers.

Areas of beach flooding, nearly 1 m/10 years (slope 3 cm/m), are embanked thanks to the proposed defense, especially where the sediment transport of rivers is low.

In Italy, erosion affects over 1200 km of coastline, equal to 1/3 of the sandy beaches, with reductions of up to 25 m, or more than 2 ha/km.

a)



b)

Figure 3 - a) Increasing erosion and seabed desertification near rockfill breakwaters during storm surges; b) Increasing extension and cost of the rockfill breakwater with the increase in the depth of the sea. With the new turbine defence this cost is negligible as the only added requirement is a longer shaft. The turbines can also be used on existing submerged breakwaters, thus providing synergetic protection.

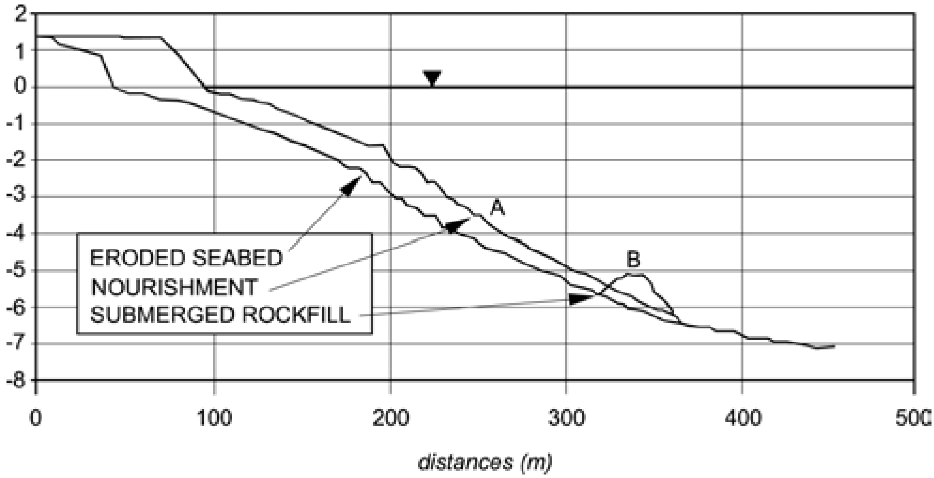


Figure 4 - Traditional beach artificial nourishment (A) and submerged rockfill barriers (B) only slow, but do not stop, excess erosion caused by the removal of the dunes and the Mediterranean maquis. The submerged top (B) must not reach sea level; otherwise the speed of the currents will increase. Similarly, during sea storms the emerging rockfill breakwaters, which are specifically situated in the breaking waves zone (Fig. 1a, b), exacerbate erosion of the seabed in unprotected beaches, both frontally and laterally (Fig. 3a).

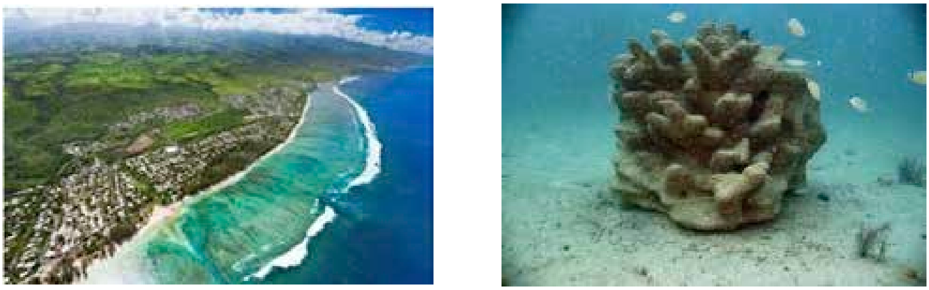

a) b)

Figure 5 - a) Coral reef in the offshore/inshore transition zone (Fig.1), imitated by using an energized barrier for the reconversion of traditional coastal protection (Fig. 3 e 4); b) Similarity to artificial coral reef produced by 3D printer (Dini).

The barriers provide further advantages regarding the rooting of sea grasslands, in particular of posidonia, which prevents erosion and promotes fish repopulation and sea de-pollution. It also prevents eutrophication, which is amplified by rockfills close to beaches.

In particular, the boulders of the rockfills could be transformed into gravel of a suitable artificial nourishment granulometry for integrating the turbine barrier defenses, with the restoration of the original littoral landscape.

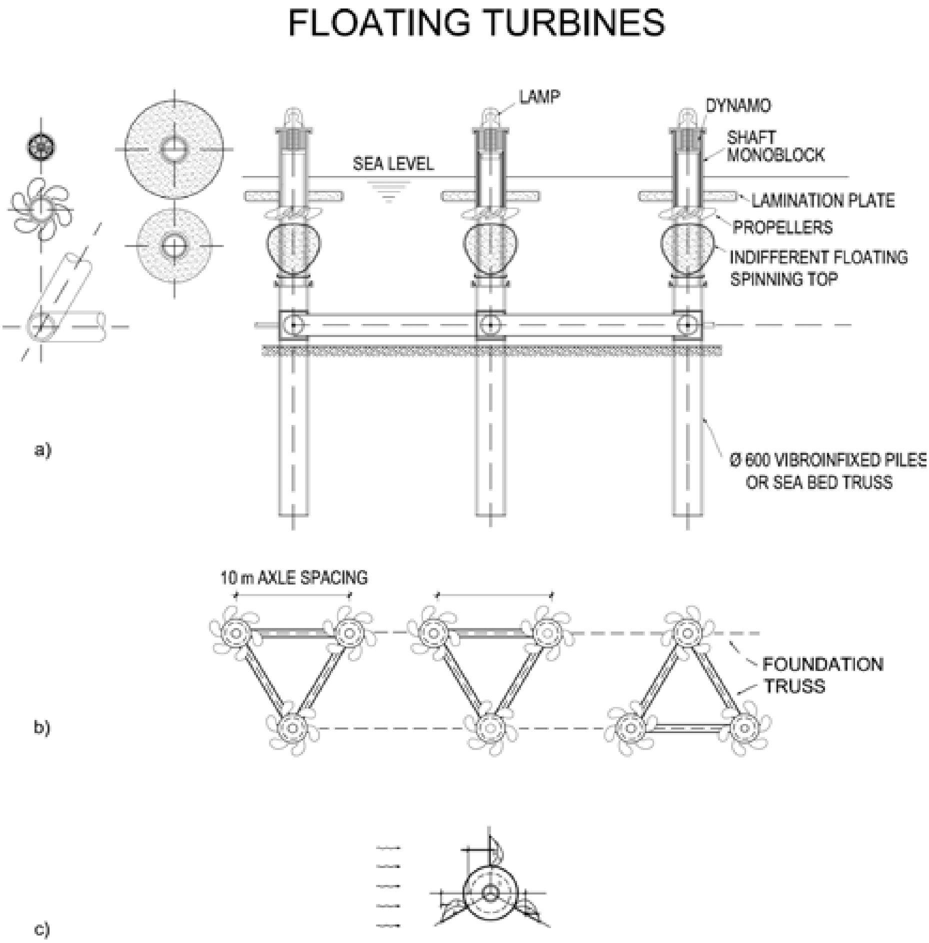


Figure 6 - a) Turbines with indifferent floating monoblocks (patent n° 0001411057; database CNR SOLAR code 9861TR2019) are pivoted on tubes. The pile-tubes are vibroinfixed in the sea bed, or founded on a reticular truss placed on the seabed, similar to a naval wreck; the whirligig is filled with sponge to prevent infiltrations from impacts; the propeller, whirligig and piles are printed in 3D using metal powder made from recycling machine scrap, or internal piles in fiber-reinforced.
b) Prefabricated tripod piles, similar to dolphins, adapted to marine geomorphology and meteo-maritime prevalent fetch; incremental current damping is achieved by reducing the axis of the comb and alternating the spin of the propellers;
c) Research of propeller efficiency: number, extension, external convex curvature, *cup type anemometer or pinwheel,* eccentrical to internal concave curvature of the blades, to differentiate the thrust arms, also convex water-repellent curvature (similar to sharks).

The extraction of sand at sea or land is eliminated, thereby decreasing significant environmental damage.

The descaling of the turbines is facilitated by the simple extraction of the propeller block from the foundation tube. The cost of maintenance is covered by kWh production.

The turbine reef, with gaps for the passage of boats, places a limit on fishing and recreational navigation, and is positioned at the regulatory safety distances. It is possible to moor boats along the turbine reefs, thus freeing up the ports.

This new energy production could recharge accumulators, and boat owners in particular could buy turbines.

It is possible to insert a series of marine vacuum cleaners *(seabins)*, whose function is to free the sea of finely shredded *plastic and other garbage*. Sensors for *chemical control* could also be incorporated, with safe water quality documented by "blue flags" displayed on beaches.

The turbines, which have the same equivalent mass as water, have a period of null oscillation that are not affected by resonance ($T \div 0 < T_{Tirr} \div 3$ s) and are therefore seismic resistant, so they would continue to work in the event of an earthquake. Moreover, submarine cables are significantly less susceptible to damage by bad weather than terrestrial ones.

The proximity of the coasts to the Apennines also allows for hydraulic *storage* of renewable energy by pumping water to a high altitude with "reverse" pump-turbines.

This would balance the uncertainty of renewable current production and help to mitigate the release of CO_2, and fuel particulates (HC, NOX, CO, PM).

3 Economic competitiveness of coastal protection by turbine barriers

Wind power production in Italy is set to reach 10 GW, with a further contribution made by the above-described marine energy production. This will help both the global-local green economy of the renewable energy and above all environment protection.

The investment for 1 km of coastline varies for a barrier of 100 compared to a barrier of 200 turbines (Fig. 7), with a significant increment of energy, depending on the exploitable marine energy, *extension and number of the propellers*.

The production of electricity, from 5 ÷ 10 GWh/km per year, supports the maintenance, amortization, public lighting and domestic utilities of coastal municipalities, also through renewable dispatching.

As their lifespan is at least 20 years, there would be a very favorable economic recovery of the beach with probable maximum sizes of 1ha/km for beach activities.

This lifespan of the turbine barriers allows for the re-growth of vegetation (matte) and the restoration of the marine ecosystem, which is currently unfeasible through traditional defenses. The turbines do not produce waste (circular economy) as the floats can be recycled for the production of new turbines or, while still in service, can be transferred with a tug to defend other shorelines.

In any case the defense function of the barrier remains, even if it is not energized. The barrier, moreover, can be more economical when sandwiched with static breakwater silhouettes, of the Ferran type (1980) on the beach of S. Maria di Potenza (MC).

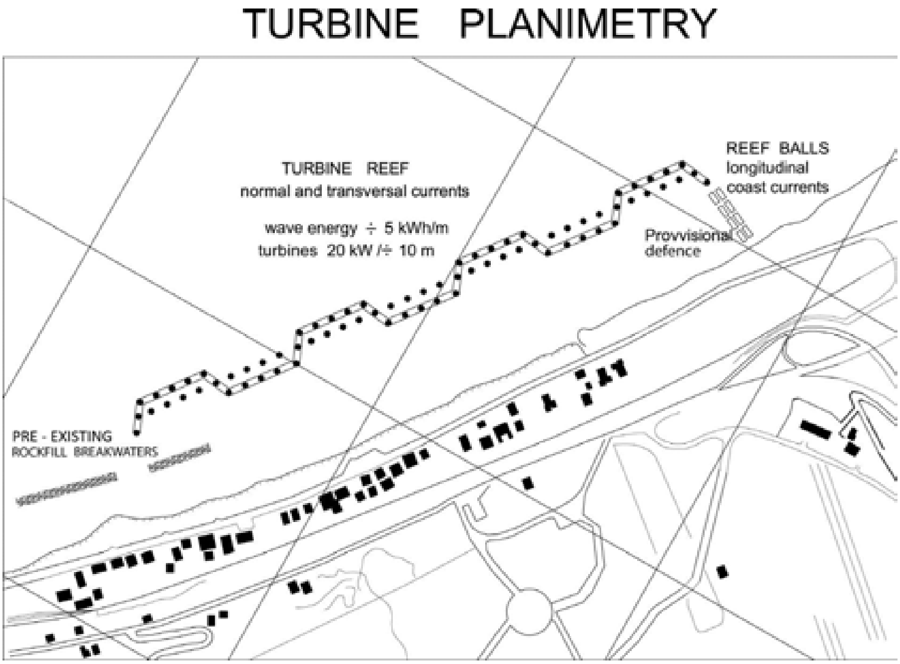


Figure 7 - Turbine planimetry and distribution, to be adapted to marine geomorphology and fetch in replacement of artificial nourishment and breakwaters. Both the comb shape and the reduction of the distances between turbines increases “Blue energy”; the distribution of the turbines also allow for depolluting filters. Littoral currents are damped by provisional reef balls or by static shapes similar to Ferran barriers, which are movable from terminal defence of each yard lot.

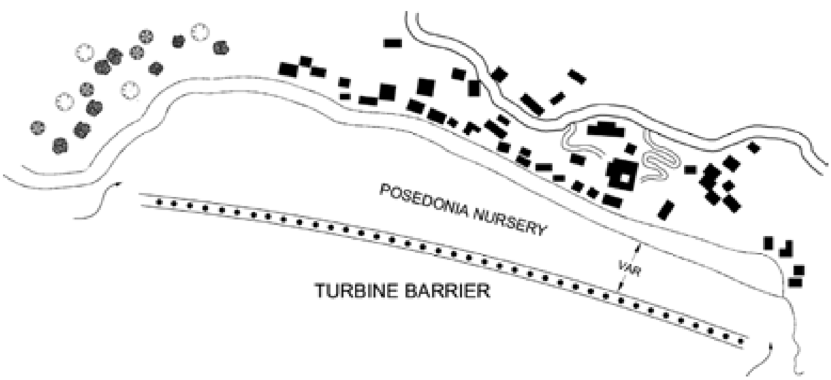


Figure 8 - A simplified protection, to shield from littoral currents, could consist of a barrier made only with a row of turbines in a bay between two promontories. It makes it possible to simplify experimental research of anti-erosion efficiency and electricity production efficiency.

The cost and correct executive control of construction of rockfill and nourishment is higher, especially considering that seasonal maintenance is considerably more than one million €/km/year, without any of the added advantages. This is especially the case if the beach is restored with forcibly extracted fine seabed sediments, which are quickly removed by winter storms, with exponential costs.

The turbine reef therefore becomes particularly competitive from an economic viewpoint in the *reconversion of current traditional defense* (Fig. 3 e 4).

This is especially true as regards annual maintenance, with a *public spending review* and the significant gains of beach establishments, which is proportionate to the hectares of beaches recovered and redeveloped.

Progressive fossil/renewable transition is favored by these energy barriers, especially if they are proposed in place of nourishment and rockfill breakwaters.

Currently in Italy (STES 2012) other turbines are utilized, such as propeller below raft (Kobold, Stretto di Messina), or articulated pulsator (40South Energy-Enel Green Power, Castiglioncello), or wave-air resonant columns in piers (Boccotti, Civitavecchia), or gyroscopic raft (Isvec-Eni, Ravenna), or multi-propeller in fluvial currents (Watercity Rovereto). There are also many other prototypes of marine energy international production (from Emec, Scotland to Eco Wave Power, Gibraltar).

The advantages highlighted support the financing of a gradual experimental research project. This would comprise the marine geomorphology, effective fetch, collection of data on marine currents, fluid dynamics simulation (CFD) and experimentation on a group of turbine prototypes in real size.

The research should be focused (Fig. 6 b, c) on the extension and shape and number of the propeller blades to be calibrated in function of the damping necessary to reduce the erosion in excess, according to the marine currents and selected seabed on a case-by-case basis. It is very important to study the historical dynamic evolution of the coast by means of comparative cartography and present-day satellite surveys (ISMAR-CNR webcam).

Furthermore, initial monitoring of the currents and geotechnical tests need to calibrate the foundations of the turbines instrumented with telewattmeters.

The experimental study of *erosion control and energy efficiency* is based on observational methods (NTC2018), similar to landslide stabilization.

Above all the center distance of the comb planimetry and shape of the barrier must be calibrated (Fig. 7). This is simplified for bays, where littoral currents do not affect erosion (Fig. 8). It should be noted that financing in Europe and in China regarding the production of marine energy (WEC Wave Energy Converter) is in full development.

It is important to promote Italian Research (CNR Fig. 6), whether for Start Ups, or Benefit Corporations which are active above all in Europe-Africa.

4 Conclusion: Benefits of the Research

The rise in beach levels and the limitation of coastal erosion represent the principal economic benefits. Also worth mentioning are the long lifespan and very low maintenance costs of barriers and the reduction in sea current speed, with the consequent natural deposition of suspended sand. Not only is there parallel power production, but the turbines dampen only speed current in excess, induced by anthropizations, thereby allowing for natural summer/winter mobile erosion.

Sand extraction is eliminated and there are no detrimental effects with regard to the new soft defense against erosion, as opposed to nourishment and rockfill breakwaters.

Turbine location after the calm zone, due to offshore/inshore energy conversion and away from sea storms, make it possible to reduce maintenance costs.

Other benefits are the fact that the kinetic energy of the sea on the new floating turbines, which turn with minimum currents, is competitive with eolic turbines.

The type and superior number of the propellers makes it possible to increase the power in each turbine. The monoblock of the turbines are produced by 3D printers, with metal powder recycled scrap.

As well as marine ecosystem recovery and consequent decontamination and landscape retraining, engraftment of a marine grassland nursery prevents sea bed erosion, and the coastal limits to fishing and recreational boating increase swimmers safety. The levels of beaches and river delta banks are increased to prevent flooding caused by rising sea levels.

Marine energy production for new barriers covers the cost of maintenance and amortization and there are significant economic benefits and landscape retraining through the recovery of hectares of beaches, which has a high economic value.

It is also important to underline that economical reconversion of the existing artificial nourishment and rockfill breakwater protection to new turbine reefs results in a significant reduction in public spending on coastal defense maintenance. The operative life of the energized reef, which is approximately 20 years, is regenerable in new defense.

Given their long lifespan, the barriers allow for the engraftment of marine grasslands, which prevents erosion. The reef can then be transferred to another seabed after regrowth of the posidonia and beach stabilization.

Electricity production in particular for lighting of the coastal municipalities, increases safety at night. Energy storage can be hydraulic, by reverse turbines pumping water to a higher altitude, if close to the coast, or hydrogen production by nanotube electrolysis.

The elimination of emerged rockfill breakwaters prevents eutrophication and promotes seabed decontamination. The new barrier should mitigate the effects of climate change in the coming decades.

The barrier is equipped with seabins to remove garbage, as well as sensors for chemical control, depolluting filters and oxygenation. Good water quality will mean that the beach can boast “blue flags”.

The barrier can be reinforced with two nets to form a ribbon-like aquarium nursery, so that the fish are not over-concentrated.

The crushing of the rockfill boulders into sand and fine gravel allows for appropriate particle size nourishment and landscape retraining.

The barriers limit recreational navigation to a safe distance from the shore.

The turbines could be purchased by boat owners, or charging column prosumers.

As they have an indifferent relative mass to water, which avoids resonance, they are also operational during and following earthquakes.

When protected with rakes, turbines can also be used in rivers, especially in deltas and during the mascaret.

The barriers would also make a contribution to the transition from fossil to renewable energy, and to new coastal defenses.

There would be new training and jobs in coastal defense, auditing, and marine propeller design: in fact, a 10 % re-conversion of scrapped cars to turbines could defend 100 km of Italian beaches.

The risk of sea storm damage to the turbine foundations is prevented by their particular inshore location and in any case by the strong tripod truss.

Corrosion and descaling risk are prevented by standard marine protections, and by the fact that the dynamo-propeller-floating monoblocks can be easily removed from the shafts for cleaning and maintenance.

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