# NEW ARTIFICIAL REEF IN COASTAL PROTECTION RECONVERSION AND ELECTRIC POWER PRODUCTION

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**Abstract** – Sea energy is characterized by the conversion of offshore pulsing vertical wave energy into inshore horizontal current energy in the seabed transition of shallow coastal waters. These currents cause excessive erosion compared to natural summer-winter erosion, which, as is widely known, is greatly increased by anthropogenic activities. The issue therefore, is to contain the kinetic energy in excess of the sea currents. An "innovative aspect" is illustrated analyzing a standard vertical section of "sea approaching the coast" as (fig. 1). Coming from the offshore deep sea we found that the wind energy produces vertical pulsating waves only until the seabed reaches 10 or 12 m depth. At this point a great number of water particles start moving horizontally to the coast, triggering a very strong horizontal current, just below the sea surface, which causes flooding and erosion, accentuated on the seabed by return currents. This stream is so regular that it produces a very calm zone until the seabed reaches about 5 or 6 meters, where the "heavy zone" starts. In the calm zone we propose to install series of "impeller wheels" in order to: 1) generate *electric power,* 2) diminish water velocity leaving sand in suspension with the result of *no more erosion but nourishment.* The proposal is to dampen the currents by means of artificial reefs positioned in the "calm belt zone". This is certainly brought about by the abovementioned energy conversion, which mimics the location of coral reefs. This makes it possible to overcome the delicate problem of maintenance of the new reef, which is situated far from the storm area. In contrast, the annual costs of upkeep of artificial nourishment and of breakwater barriers are very high and add to public spending. Coastal and seabed monitoring, particularly by satellite, has highlighted for many years the fact that breakwaters, rather than reducing erosion, have exacerbated it, to the extent that in America breakwaters have recently been banned. The proposal is therefore to reconvert existing coastal protection works by substituting breakwaters with an artificial reef, specially *integrated with new sea energy* productions. The impeller is between the floats and the blades are semi-submerged, close to an indifferent buoyancy, in order to favor the number of revolutions even at minimum currents. Moreover, they allow seagrass (posidonia nurseries) to grow in the protected area of the seabed, thus favoring the repopulation of fish stocks. The banking of the beaches also counteracts flooding, caused by the rising of the sea level, with further benefits deriving from every square meter of beach reclaimed for use by beach resorts. It should be emphasized that in eolic and fotovoltaic electricity production there are fewer hours of energy production, without the *beach recovery benefits*. The cost of a barrier is competitive with those of eolic offshore energy, especially floaters, and with the breakwaters and artificial nourishment. As regards the *regulatory context*, it is worth noting that the NTC2018 standard allows for the employment of the observational method where *initial experimental worksite criteria* must be respected.

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## 1 State of the art and innovative aspects

With regard to the production of energy from the sea (Bianchi 2012, ENEA 2022) a dozen types of solutions have been created with over 5700 patents in various countries, especially the WEC Wave Energy Converter: from Emec's vertical offshore pistons, to Flotec horizontal floats in Scotland, up to waves against cliffs by Oyster in Scotland or Oscillating floaters by Eco Wave Power in Gibraltar and Mallorca.

Currently in Italy are tested: sea kite type turbine with propeller of aeronautical type or under a raft (Coiro - Venice or Kobold - Strait of Messina), articulated pulsator (40South Energy, ENEL Green Power - Castiglioncello), columns of air resonating in the docks through the waves (Boccotti – Civitavecchia WEC SAX; Lipari), gyroscopic raft (ISWEC-Politecnico Torino, ENI, MORE - Ravenna, 2020), PEWEC pendulum (ENEA), oscillating floaters (Coastenergy Italy-Croatia).

Similar productions are obtained from multi-propellers in river currents (Watercity - Rovereto) or in the Gironde in Bordeaux, mini-hydroelectric (Lazzarini&Lucchini - Gottolengo MN) or in 13 weirs on the Arno (Iniziative Bresciane).

Our idea starts with the observation that when the bathymetry is deep, wind energy produces only *vertical pulsing offshore waves*. These can be enormous even in a stationary regime as they cannot move horizontally in the water, having to respect the balance of radial symmetry around any vertical axis (Boussinesq 1987). As they approach the coast, where the seabed is, for example, around 5 ÷ 10 m, the waves (fig. 1) are converted to *horizontal inshore currents.* These are directed towards the coastline, which they model to respect the balance of the wedge of water which flows along the sloping seabed, tending to laminate in the surface direction of the stranding and in the opposite direction on the eroding seabed.

This transformation of marine energy forms a calm band that enables the formation of coral reefs. Within this offshore / inshore calm belt, at about 300 ÷ 500 meters on average from the shore, there is the formation of horizontal currents. In this particular zone a new artificial barrier can be positioned as a soft defence (fig. 1 and 3), imitating a coral reef, positioned far from storm surges to avoid damage to the turbines, which is a first important innovative aspect. (patent N. 0001411057).

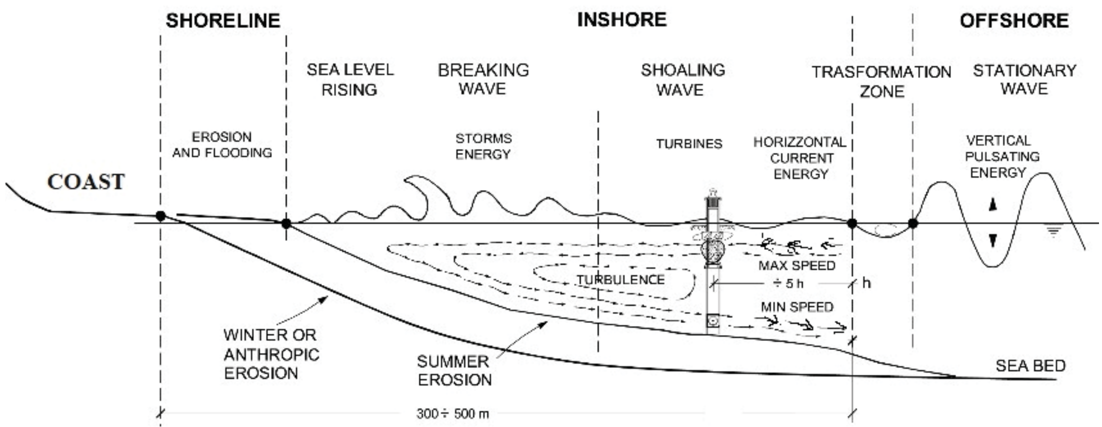


Figure 1 – Location of turbine barriers, resembling the soft protection of coral reefs, where the vertical pulsating energy of the waves (offshore) converts into horizontal sea currents (inshore) in the 2 opposing directions: superficial, and on the seabed.

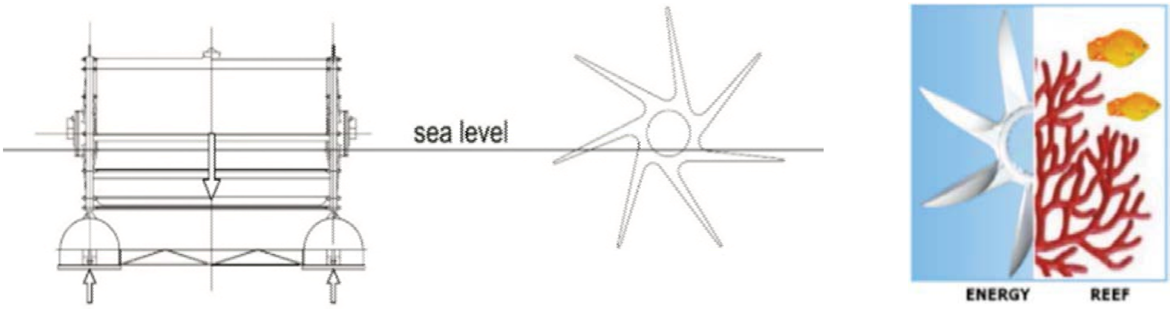


Figure 2 – Impeller close to indifferent equilibrium or in meso-float, similar to jellyfish, so that it can turn even at the slightest sea currents, and the project logo.

When the currents then proceed to lower depths of 4 ÷ 5 meters, they convert into storm surges, causing damage precisely where the energy should naturally begin to fade. However, this is where the traditional breakwaters are positioned, which instead have the effect of magnifying the energy, with upheavals of the seabed, which are clearly documented by satellite surveys (ISMAR, ESA).

The second innovative aspect is to couple the impellers to floats, in conditions close to the indifferent Archimedean buoyancy (fig. 2) or meso-float and allow the blades to turn even with the minimum speed of the currents. Thus, the surface currents, which are the strongest, are exploited; in fact, the speed of the stranding currents is rapidly reduced with depth.

The vast range of the spectrum of variation of the sea energy, with variation in wind speed, generates waves of the order L = 2 m in length with H = 1m in height with greater frequency. Consequently, more efficient and lasting production of electricity is brought about by the above-described transformation of these waves into currents.

It should be noted that the marine energy that must be dampened by the turbines is intensified by excessive erosion resulting from the modification of coastal areas, by the reduction of solid transport of rivers caused by dams and by the indiscriminate removal of sand from riverbeds, alongside urbanization, which has destroyed the dunes and the sloping Mediterranean scrub that protected the beaches from the wind, raising it above the shoreline.

Therefore, the limiting of irreparable changes in the area is a priority when choosing to use the turbine barriers, as well as for proposing naturalistic defences (green gratings, etc.).

On the other hand, the summer-winter erosion, characterized by shoals and mobile sand banks on the seabed, is a powerful natural damper of marine energy which defends the coasts.

This natural defence is in fact aided by the turbine barrier, which has a comb-filtering effect and serves above all to avoid excess anthropogenic erosion, in order to leave natural erosion. In this regard, coastal monitoring and research on the impact of storms along the coasts are very important (Ciavola P. et al. 2011, Maiolo M. 2022, Unical), in particular by inshore / offshore current meters such as: compound floats with GPS, or chalks oriented at wind rose, with differentiated consumption, or triaxial acoustic current meters or gravels running on the seabed equipped with GPS. The bathymetric survey of the mobile sandbank further identifies the strip of sea where the turbine barrier is to be located, in order to integrate the above-mentioned monitoring of the currents (fig. 1) which are to be exploited to the best.

## 2 New reef description

The first artificial barrier proposed to protect the coasts were based on floating finned cylinders anchored to ballast on the seabed, which did not produce electricity. Models in 1: 4 scale were tested at the CNR-INM (former INSEAN) naval tank in Rome with encouraging results regarding the damping of the wave height as the test frequencies increased (Ventura 1992).

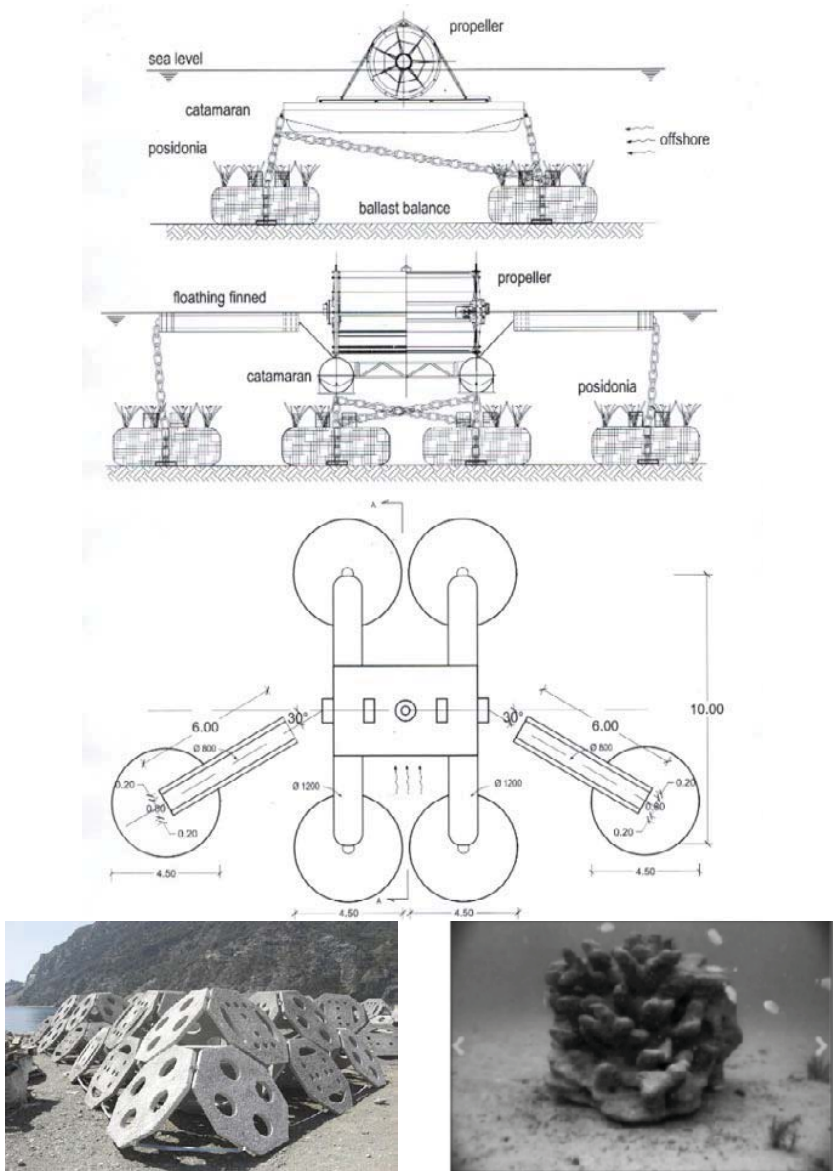


Figure 3 – Turbine with horizontal axis meso-float impeller with 7 semi-submerged blades in surface currents and counter-current air, covered with a shockproof hood, and with 2 generators of 30 kW. These are flanked by finned damper floats and anchored with chains, which can be doubled for damage resistance, to ballasts, such as submerged breakwaters of boulders, which are ecological (photo Tecnoreef or petrified sand for artificial coral, D-Sharp, Dini), and reusable in order to dampen the eroding currents on the other seabeds.

| Analisi dinamica Turbina HTP001 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternatore Alxion 400 STK 6M** | Unità | | | | | | | | | | | | |
| Potenza elettrica massima dichiarata sec. grafico Alxion: Potenza/Rpm [1)] | W | 2.320 | 5.175 | 8.555 | 11.970 | 15.175 | 17.800 | 20.100 | 22.400 | 24.470 | 26.501 | 28.549 | 30.588 |
| Velocità corrispondente dell'alternatore | Rpm | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
| Numero delle paia di coppie polari | N° | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Rendimento della turbina | % | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| Distanza dell'asse turbina sul livello del mare | m | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 | 0,30 |
| Raggio giratorio del baricentro della paletta | m | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 | 0,822 |
| Semilarghezza media della paletta della turbina | m | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 | 2,400 |
| Rapporto di trasmissione del moltiplicatore dei giri | N° | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Densità del fluido | $kg/m^3$ | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 | 1.020 |
| Coefficiente d'efflusso all'imbocco della turbina | - | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 |
| Frequenza elettrica generata | Hz | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| Rendimento dell'alternatore [2)] | % | 82,87 | 83,79 | 84,71 | 85,63 | 86,55 | 87,47 | 88,39 | 89,32 | 90,24 | 91,16 | 92,08 | 93,00 |
| Semisuperficie della paletta | $m^2$ | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 | 2,5056 |
| Velocità della corrente idraulica a valle e della stessa turbina [3)] | m/s | 0,538 | 1,076 | 1,614 | 2,152 | 2,690 | 3,228 | 3,766 | 4,304 | 4,842 | 5,380 | 5,918 | 6,456 |
| Portata massica della vena idraulica | kg/s | 1.100 | 2.200 | 3.300 | 4.400 | 5.500 | 6.600 | 7.700 | 8.800 | 9.900 | 11.000 | 12.100 | 13.200 |
| Potenza della corrente idraulica a valle della turbina | W | 159 | 1.274 | 4.298 | 10.188 | 19.899 | 34.385 | 54.602 | 81.505 | 116.049 | 159.189 | 211.881 | 275.079 |
| Potenza trasmessa all'alternatore | W | 2.800 | 6.176 | 10.099 | 13.978 | 17.533 | 20.349 | 22.739 | 25.080 | 27.118 | 29.072 | 31.005 | 30.698 |
| Potenza trasmessa alla turbina | W | 3.111 | 6.862 | 11.221 | 15.532 | 19.481 | 22.610 | 25.265 | 27.866 | 30.131 | 32.302 | 34.450 | 34.109 |
| Potenza della corrente idraulica a monte della turbina | W | 3.270 | 8.136 | 15.519 | 25.720 | 39.379 | 56.995 | 79.867 | 109.371 | 146.179 | 191.491 | 246.331 | 309.187 |
| Velocità della corrente idraulica a monte della turbina | m/s | 2,438 | 2,720 | 3,067 | 3,419 | 3,784 | 4,156 | 4,555 | 4,986 | 5,434 | 5,901 | 6,381 | 6,845 |
| Altezza dell'onda | m | 0,303 | 0,377 | 0,480 | 0,596 | 0,730 | 0,881 | 1,058 | 1,267 | 1,506 | 1,775 | 2,076 | 2,389 |
| Sfruttamento dell'energia disponibile della corrente idraulica a monte | % | 70,95 | 63,61 | 55,12 | 46,54 | 38,54 | 31,23 | 25,17 | 20,48 | 16,74 | 13,84 | 11,59 | 9,23 |
| Velocità dell'alternatore a vuoto | Rpm | | | | | | | | | | | | |
| Tensione elettrica dell'alternatore a vuoto | V | | | | | | | | | | | | |

Note

[1)] Con fattore di potenza = 1.

[2)] Linearizzato fra 220 e 600 Rpm come da dati del cosruttore.

[3)] Al raggio giratorio del baricentro della paletta.

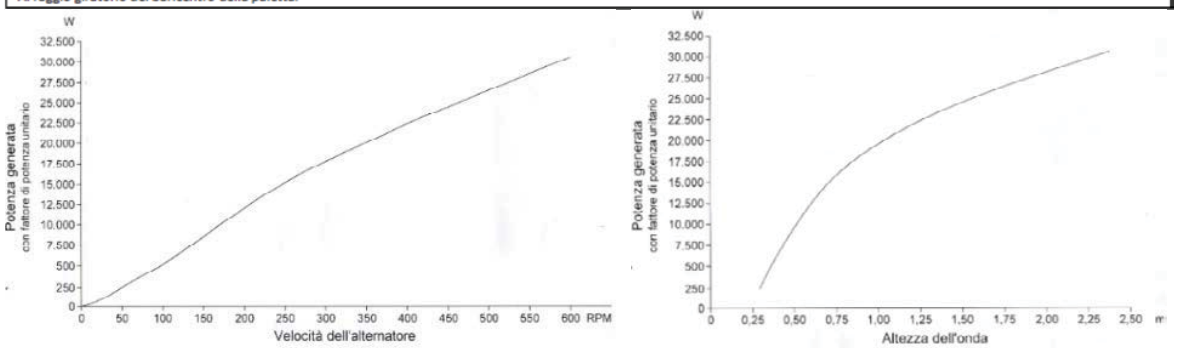


Figure 3 bis – Dynamic analysis to calibrate the turbine power on the marine kinetic energy. The production marine energy with 200 impellers/km becomes 12 MW and 30 GWh/yr/km. This analysis must be supported by specific experimental research in true magnitude. *The article is proposed to develop the Italian research on renewable marine energy.*

This proposal, which differs from many other patents, subsequently integrated these anti-erosion floats with indifferent floatation turbines by means of a catamaran supporting horizontal axis turbines (fig. 3) to increase the production of electricity, through a barrier of staggered turbines (CNRSOLAR 9861TR2914).

The above-mentioned innovative criteria, which are necessarily based on the scientific roots of the past, have converged in the most efficient choice of horizontal axis impellers with large extensions.

The prototype, patented with the Energy Reef logo, (fig. 2) was elaborated in the project report, drawings tables, reconversion of the traditional breakwaters and the bill of quantities.

The 2 generators and the impeller are supported in conditions close to the indifferent balance of the masses by means of a catamaran (fig. 3), consisting of 2 ϕ 1200 floats anchored by chains to the 4 ballasts.

The chains are under slight tension in conditions of hydrostatic calm, and in tension in hydrodynamic operating conditions. This allows the impeller to rotate even with minimum speeds of surface sea currents and makes it possible to limit the size of the chains and ballasts. There are also 2 ϕ 800 floats, with 4 radial fins of 20 cm, (fig. 3), similar to models tested in the naval tank mentioned above, as an obstacle to sea currents, which are moored in a longitudinal barrier on the sides of the catamaran, while the ends of the floats are ballasted by chains similarly to the turbine-carrying catamaran. These floats are anchored with crossed chains in order to minimize the roll-pitch-yaw. The bracing chains also serve to ensure against any breakage of the vertical chains and are equipped with strain gauges to guarantee the prompt repairing of any problem areas. Scheduled maintenance should, however, guard against the need for such repairs. The finned floats are also inclined planimetrically at 30 °, creating a funnel-shaped effect, which directs the sea currents to the blades.  This process is also favoured by meso buoyancy, as mentioned above.

Each catamaran has 2 turbines and has a width in the order of 10 m of the floats transversal to the impeller; the longitudinal length of the module is in the order of 20 m, therefore with a maximum of 1 turbine / 10 m, or a barrier of 100 turbines / km.

The modules are independent so they can be arranged diagonally in staggered comb formation in the barrier and are therefore adaptable to the various prevailing wind angles of the site to be protected. Initially, a minimum distance between the modules is proposed, so that they can be positioned in a continuous formation (fig. 4) to obtain maximum protection against erosion of the beaches.

In the light of the experimentation and the weather-maritime characteristics, it will be possible to thin out the floats and offset them appropriately to counteract the sea currents.

The choice of materials is particularly important, namely the epoxy powders of large wind turbines which are usable for 3D printers. Given the much smaller size of offshore wind turbines, turbines can also be made with aluminium alloys for the impellers and steel for the shoulders, which must be adequately protected from corrosion. The use of lighter and new economical fiber-reinforced materials or recyclable natural resins and polymers is therefore proposed; thus, the floats are expected to be made of recycled tires, which will reduce illegal landfills. The use of glebanite, a new material derived from the recycling of reinforced fiberglass with lamellar tearing anti-abrasion and non-toxic *anti-fouling,* to minimize maintenance of the descaling ballast, is also envisaged.

Furthermore, by slightly pressurizing the coated rubber floats, the elements of the module are made more resilient to impact. Fatigue resistance is also concentrated in the anchoring shackles of the suspension chains, with periodic maintenance programmed. It should be noted that the turbine blades are only half immersed (fig. 2), with the other half in the air above sea level, rather than counter current. The impellers are therefore completely immersed during the active phase and emerge in the next phase, emulating the efficiency of traditional water mills, albeit with a different ratio between the dimensions of the blades and the diameter of the wheel. The 7-blade impeller (fig. 3) is covered by an emerging shockproof hood and wave guard, with vents to eliminate the air conveyed by the upper half-blades. The number of blades to be tested is 7, each with dimensions of 4 $m^2$ in the prototype. These will be adapted to the site that is to be protected, to exploit the sea currents to the maximum and in a compromise between performance and costs. The impeller, supported at the ends by widely sized roller bearings, drives 2 three-phase current generators, each of 30 kWp (cosφ = 1) of nominal or peak power subsidized by a planetary multiplier with a transmission ratio of 8/1. This transmission ratio together with the high number of poles, equal to 12 couples, of the generators makes it possible to enhance the efficiency of the generators and to achieve electrical frequencies, in conditions of maximum power, up to 12 x 10 Hz (50 Hz ≈ 12 x 8 x ½ Hz of the impeller with the longest lasting power at 15 kW) (fig. 3 bis).

The construction uses a signalling lantern powered autonomously by a photovoltaic cell and cutting-edge construction solutions in terms of materials, corrosion protection, lubrication, static and dynamic seals, generator temperature monitoring, and their electrical connection through umbilicals for the transport of energy to the ground and maintenance. It will be possible to separate the turbine from the float, which will remain anchored to the seabed. The floats are anchored to ballasts (fig. 3) consisting of mattresses with nets containing perforated discs such as Tecnoreef or Oceanus (Budoni) or sand traps (Teti) or boxed (geocontainers) Reef Ball or artificial coral to favor habitats for fish. An ecological new barrier is created that can be visited and which constitutes a deterrent to combat illegal fishing. These ballasts can have a circular or oblong plan for 2 crossed chains, upwind type, which will withstand the various angles of prevailing wind, especially from longitudinal coastal currents. The ballasts can be integrated with soil to act as a nursery for posidonia (fig. 3 and 4), in order to also imitate coral reefs and minimize the environmental impact of the new submerged protection without altering the landscape. It should be noted that the set of *ballasts* constitutes a sort of submerged reef that dampens the currents which erode the seabed, while at the same time letting sand pass for natural nourishment. Simultaneously, (fig. 1) the kinetic energy of the surface currents is damped both by the energy-producing *impellers* and by the dispersions caused by the obstacle of the *finned floats*.

It should be noted that satellite analysis of the seabed affected by breakwaters made of boulders and artificial nourishment have indicated significant increases in erosion, despite the mounting costs of these protections.

The use of traditional breakwaters and groynes has therefore recently been banned in the USA, so it is necessary to study new coastal protection systems. The proposal to start modifying coastal protections by eliminating at least 3 breakwaters (fig. 4) is therefore very important, in order to enhance the maximum erosion between them.

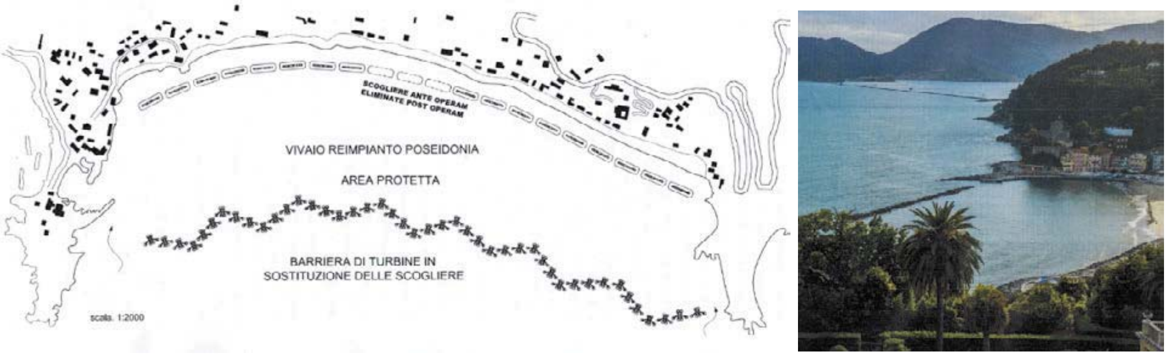


Figure 4 – Experimentation of the anti-erosion effectiveness of the artificial barrier, compared to traditional breakwater of boulders in the simplest case of a bay. The row of anti-erosion modules also allows a posidonia nursery to take root in a protected area.

The coast in front of the removed breakwater must therefore be protected, with a proposed barrier of suitable length, in order to test its effectiveness in worst-case erosion conditions. The proof of the barrier's anti-erosion effectiveness is simplified if it is carried out to protect a bay between two promontories, where the littoral currents do not influence the reduction of the beaches (fig. 4) and where, as previously highlighted, there are no significant variations in the surroundings.

On the other hand, in the case of open sea, i.e., where there is not a bay between promontories, lateral protections are provided at the ends of the barrier, such as in figure 3, to counteract the coastal currents even in shallow waters.

To speed up the experimentation times, the new barrier can be coupled with a contained artificial nourishment strip, without however modifying the sandy seabed in front of the beach for bathers. Monitoring of the beach where the breakwaters have been removed, as well as of the artificial nourishment that simulates the natural mobile sandbank, will increase the anti-erosion efficiency of the barrier.

The planimetric distribution of the turbines, which restores the sandbank or bar of moving sand, must be adapted to each coast (Ricci Lucchi 1992) based on the geomorphology of the seabed and maritime meteorological data (*marine energy spectrum, swell, fetch…*).

These data characterize the energy of the waves, ranging from over 10 kW / m in Sardinia to less than 5 kW / m on the Tyrrhenian coast (Sannino 2012).

The executive sizing of the barriers must naturally be carried out according to average wave energy at the chosen site, assisted by the current and pressure measurements mentioned above. The drawings are based on the hypothesis of a sandy seabed at a depth of 8 m, with wave energy of 5kW / m, and on drastic pseudostatic analysis, which are the first point of reference for the reliability of the calculations (§ 10.2 NTC2018).

Appropriate computer simulations (CFD) and full-scale fluid dynamics tests conducted on the offshore prototype will be able to define precisely the characteristics of the generator and its proportions; in particular, these will evaluate the speed increases of the blades due to the reduced buoyancy, which is close to indifferent.

Dynamic analysis of the kinetic energy usable by 2 generators was carried out on the prototype, driven by prototype blades of 4 $m^2$ which makes it possible, as the speed of sea currents systematically increase, to exploit a nominal design power of up to 30 kW.

## 3 Cost/Benefit analysis

The limitation of coastal erosion and the increase in the level of sand on the beaches, to stem the rise in sea level, represent a significant economic advantage. The other important benefit is produced by the numerous, small, low-impact marine electricity units.

It should be noted that the *maintenance costs* of the barriers are much lower than those of the breakwaters and artificial nourishment. The protection of the coasts is "soft" with minimal side effects, unlike traditional defences.

The location of the turbines is far from storm surges, like that of mussel farms, meaning the modules do not require continuous repairs. The energy of the sea acting on almost indifferent floating turbines makes them turn even with minimal currents, making them competitive with onshore wind. Electricity is also produced with higher nocturnal production hours than photovoltaics, especially in winter.

The *functioning* of the new defence makes it possible to eliminate the breakwaters, allowing contracts which are calibrated with the observational method.

*The patent moreover* allows *the contract to be exclusive.*

The redevelopment of the original landscape is carried out with the *removal* of the breakwater; the boulders from this can be crushed, transforming them into gravel and sand, allowing granulometrically suitable nourishment or the production of ballast.

The need for inland quarries for the extraction of boulders would be *eliminated* as would the removal of sediments, which are often unsuitable for nourishment, obtained with the extraction of sand at sea or on land, thus reducing other significant environmental damage.

The new *defence* also leads to the raising of the level of the beaches through natural nourishment, which will realistically defend against the rise in the level of the Mediterranean Sea (currently 3 mm / year) caused by climate change.

In Italy, erosion affects over 1200 km of coastline, which is the equivalent of 1/3 of sandy beaches, with over 25 m of average erosion, or more than 2.5 ha / km.

The barriers provide further advantages as they allow posidonia (Marsella 1986) to take root. This is a typical marine vegetation that prevents erosion and favours fish repopulation and marine depollution.

The twenty-year-plus life of the barriers favours the growth of sea grasslands, and even submerged dunes or matte posidonia, which constitute precious natural defences against erosion. The mobile barriers can then be transferred to new sites in need of defending.

The barriers allow for the creation of protected areas and indicate the coastal limits for fishing (no fishing zone); the safety of bathers is increased by delimiting recreational boating and favouring panoramic navigation along the coast parallel to the barriers. This protection can also lead to the development of underwater tourism to visit the turbines, even setting up sections of the barrier for water-sub sports and for fish-watching. Generating electricity, especially for coastal lighting, increases night-time safety.

Energy storage can be achieved with classic accumulation in direct current, which is then transformed into alternating current at 50 Hz. Alternatively, it can be stored with hydraulic accumulation, by means of reverse turbines that pump water to a higher altitude, if close to the coast, as is typical in the Apennines. It can also be stored with the use of accumulators.

Marine energy can also be used to pump desalinated water from osmotic membranes lying on the seabed, as has been done in Perth in Australia, and especially in areas undergoing desertification, where there is a lack of aqueducts, such as on many islands.

It is also possible to equip the barrier with a series of marine aspirators (*seabins*), whose function is to free the sea from plastic and other floating waste; at the same time, underwater robotic systems can be used for the collection of waste on the seabed, which is often much more consistent than that which is found floating. This collection will be particularly useful if the barriers are positioned at the mouths of rivers; in order to collect the waste thrown indiscriminately along the riverbeds. Sensors for permanent weather and chemical monitoring could also be incorporated, to document the quality of the water and increase the number of "*blue flags*" displayed on the beaches.

In addition, the protective hood on the turbines shields the motion of the blades and protects swimmers; the blades favour the oxygenation of the water, thereby improving the flora and fauna of any nearby mussel farm.

The turbines, protected with screen cleaners, can also be used in rivers, especially in the deltas and during the ascent of the sea in the mouths of rivers (mascaret).

It is possible to temporarily moor pleasure boats along the turbines, such as dolphin, also for battery recharging. This frees up ports, which become especially choked in summer. Berth owners could also purchase turbines (Prosumer) to power the boats via charging stations on the docks.

The supply of electric power to ships in ports is another particularly promising benefit, as it removes the pollution caused by diesel engines which are otherwise permanently turned on. This has been installed in Norway and has been proposed for the port of Livorno.

The barriers, marked by red buoys and illuminated by red LEDs at night, limit recreational navigation to a safe distance from the shore; naturally, there are gates for the passage of boats from the land.

The barriers, with their recycled rubber floats, could also make a significant contribution to the reduction of car tire dumps by recycling tires into composite materials.

They could also help to reduce the crisis in the automotive and nautical industries by converting them into *marine turbine factories*.

It is worth noting that the proposed conversion could defend many kilometres of beaches, gradually replacing the 1291 kms of breakwaters, with a significant contribution to the production of renewable electricity, thus favoring the development of the *Ecological Transition (Laudato si').*

New training courses and jobs would be activated: from design to maintenance, from planned evaluation (*auditing*) to environmental protection. The very topical theme of apprenticeships through training schemes and retraining would get a good contribution from the sector of coastal protection with the production of marine energy.

The risk of corrosion and incrustation can be prevented by standard marine protections and by the fact that the alternator-blade monoblocks can be removed for periodic cleaning and maintenance and for lubrication. Maintenance work can also be carried out annually by divers; the low depth of the interventions, immediately below the water level, mean immersion times would be short.

Turbines, especially those made of light materials, have an equivalent mass similar to water and bearings with negligible friction, or zero relative mass, so they also have a zero-oscillation period that is not affected by resonance, because the proper period is $T \div 0 < T_{Tirreno} \div 3s$, similar to the harmonious frequency of the surf. They are therefore anti-seismic and will function in an earthquake. They also self-submerge and mitigate tsunamis when the anomalous waves are not enhanced by shallow waters, as happened instead in Livorno (1742.) Furthermore, the submarine cables, which are not susceptible to damage caused by storms and snowfalls, like those on land, are much shorter than offshore ones.

For the 62 eolic offshore floaters proposed by Falk Blue Float in Sardinia the the length of the underwater cables is 40 ÷80 km. The harmful collateral effects on pitch-roll-yaw vibrations and the environment, evident in all other electricity production, including hydroelectricity, are also negligible with the proposed barrier. We can hope for a *comparison between Blue float, Iswec-Eni, Pewec-Enea, other renewables* and *Energy reef.*

The project also includes a detailed time schedule for the construction of the prototypes, from current measurements to the certification of the beach's anti-erosion efficiency. The cost of the prototype barrier can be amortized according to its length, and can be reduced as mass production increases and the kW / m of the chosen site increases.

It is also worth noting that as the depth of the seabed increases, the ballasting chains can be lengthened with little expense; this is very different from the costs of breakwaters which instead have rapidly increasing trapezoidal sections.

By conservatively assuming an average production of 50 % of the maximum power of the turbine barrier, we obtain 15 x 100 = 1.5 MW / km or, for about 4000 hours or 50 % per year, an order of at least 6 GWh / y, which can be increased to 12 GWh / y with 10 kW / m waves instead of the assumed 5 kW / m.

In addition to the income from electricity, for every m/km of beach, further income can be derived in the space of a few years from the recovery of the beach. This occurs as tourist activity in the bathing establishments increases, considering that the life of the barrier is in the order of 25 years.

The current costs of the breakwaters and nourishment, in the absence of quality aggregates and the closure of the quarries, are comparable with those of the new proposed barrier. The costs of seasonal maintenance, such as the replacing of boulders in breakwaters or new artificial nourishment after the undermining caused by storm surges each winter (Cipriani 2021) are certainly greater than those of the proposed barrier. Moreover, the new "winter sand traps" (Teti), tested along the coast of Torre Guaceto (Bari), are less expensive, but without the electricity production and seabed protection of this project.

In contrast, the costs of 1 kilometer of barrier are very competitive when compared with those of floating offshore mega-wind turbines, proposed to Budoni or to Civitavecchia, or with the mini-hydroelectric turbines positioned in rivers (Arno).

The kinetic energy of transformation of the waves into marine currents is furthermore greater than that of the wind currents in eolic production.

The comparison with the costs of photovoltaics is competitive, as 3 MWp photovoltaic production requires 2 hectares of panels, with daytime supply only and low production < 1 MWp in winter. Moreover, night-time supply requires accumulators to be changed after 10 000 cycles / 10 years and it is also not very productive in winter. By contrast, the barriers are also productive at night when energy is most needed and in winter when the sea currents are greater. It is essential that renewables should be increased to more than 20 % of Italian electricity consumption (280 000 GWh/y). The lifespan of the turbine barriers also makes the cost of nurseries for the gradual regrowth of sea grasslands and the restoration of the ecosystem economically viable. This is currently not feasible with traditional defences, as evidenced by the lack of successful root-taking, especially facing the breakwaters.

It is interesting that *Energy-Tourist Communities*, with cooperation of the prosumer; and outcome funds, are developing for use the various benefits mentioned above.

It is worth repeating that ecological conversion with the proposed production of marine energy, which is clean, very useful locally and competitive thanks to the recovery of the beaches, has significant economic advantages compared to other renewable sources.

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