Wave Energy Assessment and Performance evaluation in Mediterranean Sea

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***Abstract*—The paper proposes a revolutionary device for the utilization of a new entry of renewable energy sources: sea wave. This technology is based on linear generators, able to converts directly a linear motion into electrical output, limiting to minimum the chain of energy conversion. A preliminary feasibility assessment considers a case study applied in Lampedusa, a small island in the Mediterranean Sea. Economic and environmental evaluations are here reported.**

Keywords— Sea wave, linear generators, small islands

I. Introduction

Last recent reports underline that renewable energy systems represent a key point for global development.

The generation of electricity from renewable energy (RE) sources includes technologies such as hydropower, wind power, solar power, tidal and wave power, geothermal power, and power from renewable biomass.

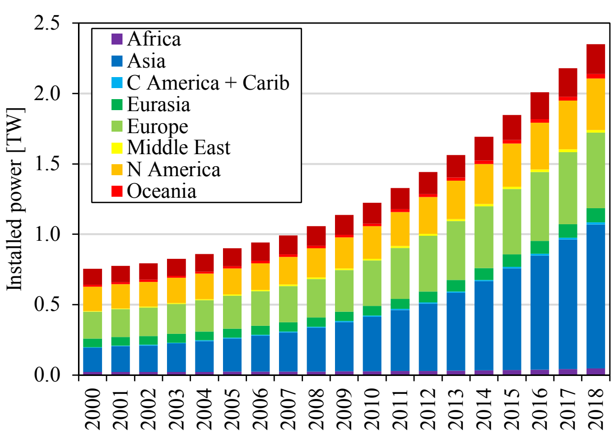

Fig. 1. Total installed power from renewables in the world

According to an IRENA report, in less than 20 years, the installed power is almost tripled, ranging from 753.95 GW in 2000 to 2350.76 GW in 2018. The distribution worldwide is reported in Fig. 1, from which it is possible to observe that the main contribution is played by Asian countries [1].

In order to face the even increasing energy demand and achieve the goal of the progressive energy transition from fossil fuel to RE supplied plants, huge investments are required. According to an IEA report, a progressive increase of the annual expenditure for the improvement of the electrical energy sector, from 460 billion USD in 2005 to 775 billion USD in 2018, was observed. Focusing on RES, the worldwide investment was equal to 120 billion USD in 2005 and 305 billion USD in 2018 [2].

In this context, sea wave is an emerging energy source, still today not yet exploited [3]. Several studies reveal that sea wave energy represents a strategic source for the next future, thanks its peculiarities [4]. Among these, sea wave is characterized by:

- a huge energy potential around the world, as shown in Fig. 2 [5]
- a greater regularity in comparison with other renewable source (for example wind power) [6]
- a high energy concentration [7].

All these properties encourage the exploitation of this source [8], [9].

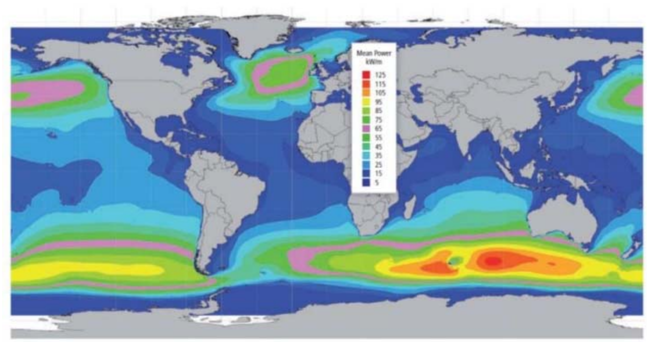

Fig. 2. Global annual wave energy potential

Important drivers for wave energy are its vast potential across multiple countries and regions around the globe, the relative environmental impacts [10] even when compared to other renewable energy technologies, and its small visual impacts on the shoreline. This has led to support of both governments and private sector and has resulted in a large number of prototype devices at a demonstration phase (as shown in Fig. 3).

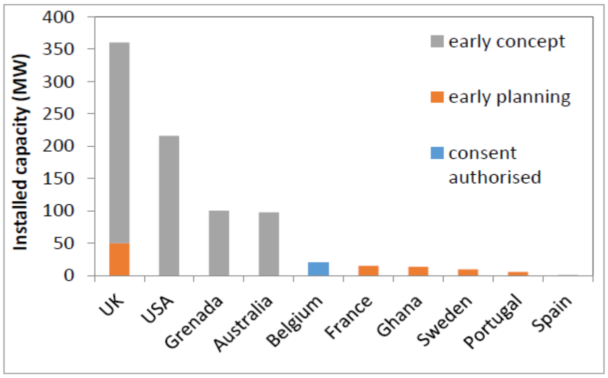

Fig. 3. Geographical installation of wave energy devices in development.[5]

In particular, an innovative research is WEC's (*wave energy converter*) installation in small islands [11], [12]. This option represents the best solution thanks to the favorable fraction of the length of coastline and the surface of the island or the sea wave energy source can be successful used to cover a significant part of the electrical energy demand [13], [14], without occupying the territory. In fact, the sea wave converters typically must be installed away from the coast, in order to maximize the electrical energy production.

II. THE WAVE ENERGY CONVERTER

In order to exploit sea wave source, the paper presents an innovative system, designed and developed at the Palermo University. The device is able to produce electrical energy using two different renewable energy sources: sea wave and photovoltaic. This system is schematized in the following Fig. 4.

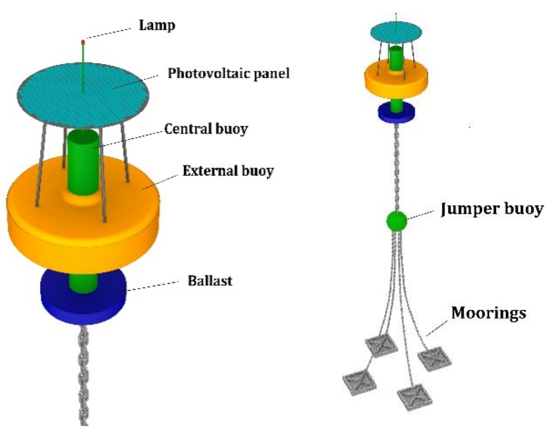

Fig. 4. Rendering view of integrated photovoltaic and sea wave energy converter

The device is composed by two floating buoys, fixed to the seabed thanks the four moorings [15]. The external buoy is used to collect the mechanical energy of sea wave and transfers it to the electrical generators, installed inside the central buoy. The photovoltaic source is also used by a panel installed in the upper part of the external buoy.

Inside, the mechanical energy introduced as vertical motion is transformed into unidirectional rotary motion, usable to produce electrical energy through alternators.

The core of the electrical device is a mechanical motion converter, composed by a bifacial rack, four freewheel (2 installed in contact with rack, 2 in the axis of alternators), two toothed wheels, two belts. As for the electrical part, we assumed to install commercial alternators (two polar pairs, with a nominal power of 30 kW).

The main component is the bifacial rack, having a length of 6000 mm, with a mass equal to 50 kg. Other components are common in the automotive sector.

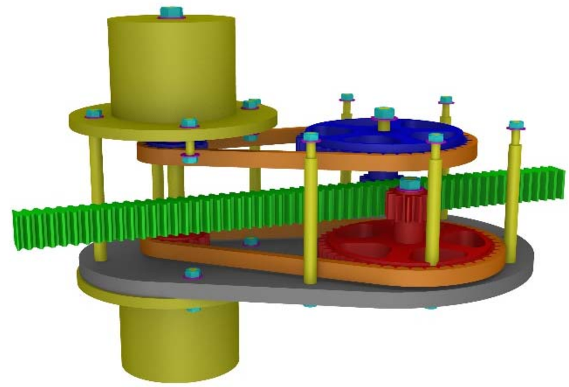

Fig. 5. 3D Model of commercial alternator used.

III. THE CASE STUDY: LAMPEDUSA

The second fundamental step of sea wave energy research is the identification of installation site.

As previously mentioned, global wave energy potential represents a huge source unexplored. If we put more attention about Italy or, more generally, Mediterranean coastline, Sardinia and Sicily are the areas which could produce more energy from the sea. Indeed, Liberti [4] and Besio [16] carried out specific energy assessment of the wave energy resources in the Mediterranean Sea using a third generation wave model. In both cases, these studies indicate the area between Sardinia and Balearic Islands as the most promising of entire Mediterranean Sea.

Sardinia is the region which may convert the most energy from the sea in the whole Mediterranean, with a potential 13 kW/m of coast, a value close to those of EU States - like Denmark- at the forefront in the development of this renewable source, especially the north west area near Alghero and the south-west area.

Sicilian studies of the wave energy flux showed that the most energetic areas are located on the western side of Sicily and in the Strait of Sicily. The offshore values of the observed energy flux are close to 8 kW/m on the western side, with a reduction in the Strait of Sicily to 4–6 kW/m. The wave energy flux is further reduced to 2–3 kW/m on the north and east sides of Sicily [17]. This is confirmed by Fig. 6, reporting the annual average wave energy flux around Sicily.

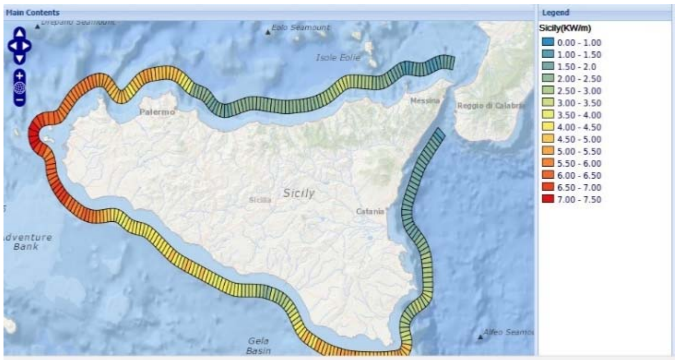

Fig. 6. Energy Flux Map (Sicily)[18]

Fig. 7 shows the scatter table of sea wave potential in one of the most favorable point in the western area of Sicily. From this graph it is possible to extract useful information like the most frequent sea states, to which a wave energy converter should be subjected.

Energy Line Sicily (kW/m)

Average	Jan-Mar	Apr-Jun	Jul-Sept	Oct-Dec
6.47	10.30	4.74	2.18	8.71

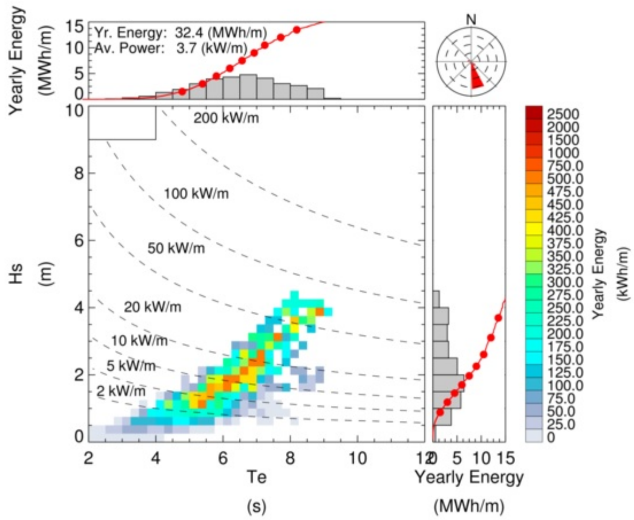

Fig. 7. Scatter table of wave energy potential in a western area of Sicily [18]

As case of study, the authors consider Lampedusa, a small Italian island in the Mediterranean Sea. It is located at south of Sicily (one of the major Italian islands), about 167 km from Tunisia and 205 km from Sicily. The island, with triangular shape, has a surface about 20.2 km^2 and a coastline about 26 km. As other Mediterranean small islands, Lampedusa presents a small electrical grid, not connected to the mainland [19].

Fig. 8. Lampedusa web GIS image

Generally, small islands constitute a representative community considering its specific energy systems and other common aspects [20], [21]:

- High seasonal variation in inhabitants
- Significant annual increase in energy demand
- Lack of innovation and increase in smart grid
- Low use of renewable energy sources (FER)
- High fuel cost (due to the need to import it from the mainland)
- Limited freshwater resources
- Tourist-environmental priorities.

Furthermore, the electrical energy production is based on diesel plants. Fossil fuels are regularly transported by boat from mainland, so bad weather conditions put at risk the energy supply of the island. The electricity demand for this island will meet a medium-term reduction due to the energy efficiency programs and an increase (+2%) in the long term, due also to the electric transformation of the transport system.

In the fossil free scenario proposed, almost two thirds of the production will be covered by wind, 28% by solar and 7% by wave power.

In this context, the objective of the paper is evaluating the electrical energy demand (equal to 37.66 GWh/y in 2016) and proposing an off-shore solar wave energy farm, able to cover about the 20% of the electrical energy demand [22].

The following graph reports the most significant climate data for this application: sea wave power flux and monthly solar radiation.

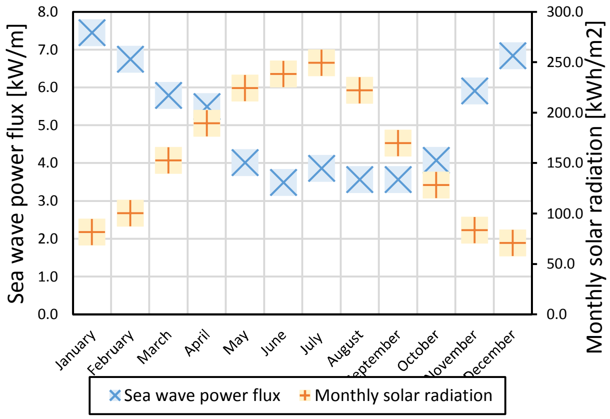

Fig. 9. Comparison among Sea Wave Power Flux and Solar Radiation

Using the data above reported, the authors simulated the electrical energy production during the year, assuming the installation of a solar wave energy farm around the island of Lampedusa. The avoided emissions and diesel consumption are considered.

IV. RESULTS

Considering the sea wave climate and the solar radiation at the latitude of Lampedusa, we consider the installation of a solar wave energy farm composed by three lines, each one composed by six DEIM point absorbers, with an installed power of 1.64 MW (1.44 MW from sea wave and 0.2 from solar). These values are oversized in order to consider the fluctuation of inhabitants during the summer and high electrical consumption of desalination plants of the islands.

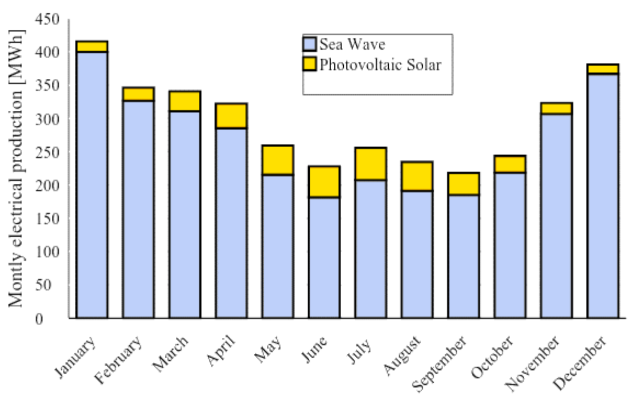

Fig. 10. Renewable (wave and photovoltaic) energy electrical production (year 2016)

As regard the avoided emissions, the authors considered an emission factors γ_{CO_2} for the electrical production fixed to 0.682 t CO2/MWh. In conclusion, considering the evaluation of annual electrical production, 373 MWh/y by the sun and 319 MWh/y by sea wave, the annual avoided emissions Γ_{CO_2} are equal to 2433 tons of CO_2 per year.

V. CONCLUSION

Considering small islands, the use of renewable energy sources is an important opportunity to decrease the greenhouse gas emissions, environmental pollutions and limit the energy dependence from fossil fuels. By using RES, the costs (3-4 times) of conventional sources are lowered and at the same time the environmental tourism characteristics of the territory are preserved.

Specifically, our research is addressed to Lampedusa, a little Italian island near Sicily and Africa.

The great results can create a new energy scenario with the installation of a solar wave energy farm (composed by 18 DEIM point absorbers) that is able to satisfy the electrical energy demand.

Actually, the only restriction for the installation is the cost that is less competitive with other renewable energy systems.

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