PERSPECTIVES FOR MARINE ENERGY IN THE MEDITERRANEAN AREA

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PERSPECTIVES FOR MARINE ENERGY IN THE MEDITERRANEAN AREA

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EDITORIAL
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Editorial: Perspectives for Marine Energy in the Mediterranean Area

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Editorial on the Research Topic

Perspectives for Marine Energy in the Mediterranean Area

A recent report by the World Economic Forum (WEF, 2020) showed that the five most likely risks to the global economy are of environmental origin; the same holds for four out of five threats that have the potential of giving the worst effects. Among them, climate change and its consequences are at the top. If we want to take these indications seriously, the necessary energy transition has to be fast and unrelenting. To this purpose can we afford to exclude around 70% of our Planet from the possibilities to deploy renewable energy? This refers to the amount of the Earth covered by oceans and seas and we now need to be ready to include "Blue Energies" in energy planning: tides, currents, offshore wind, waves (onshore and offshore), saline and thermal gradients, and even marine algal biomass.

Europe is the front runner in this effort and the Green Deal may provide further momentum. Of late, the North Sea, Northern Atlantic, and the British Channel are the most favorable spots in Europe, but, as highlighted by Pisacane et al., the technological readiness of the different solutions allows for the expansion to the Mediterranean Sea. Although waves, winds, currents and tides are generally less intense than in northern Europe, the conditions are promising, especially for wind and wave energy, the latter for its continuity and high predictability.

Feasibility, legal frameworks and technological and environmental challenges have been studied in the 12 papers of this Research Topic. Goffetti et al., have focused on the main strengths, weaknesses, opportunities and threats for marine renewable energy technologies, considering several dimensions: technological, environmental, social, economic, and legal.

Nikolaidis et al., provide an analysis of the potentials in the whole Mediterranean area from which it emerges that wind energy is the most mature technology and the main technological efforts are directed in facing the problem of the depth of the Mediterranean Sea which requires the implementation of floating devices. In particular, Abanades shows the technological and economic feasibility of a gravity-based solution for the foundation of Wind Turbine Generators in the Cadiz area (Spain). Azzellino et al., suggest that floating wind turbines can allow also the co-installation of technological solutions for the capture of wave energy thus increasing greatly the energy generation potential of a certain area.

The potentials of wave energy are evaluated by Mattiazzo, with a paper that lists several solutions already at the pilot stage and being implemented in the Mediterranean area claiming that at least some of these technological solutions are already competitive. These can be further improved when the number of devices is increased. Waves can be exploited both offshore and onshore with devices that can be integrated into ports. Examples of onshore realizations are Overtopping Breakwater for Energy Conversion devices that can be improved in their design by means of the method illustrated by Kralli et al., that optimizes the size of the OBREC reservoir in order to consider the combined

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effects of shoaling, refraction, diffraction, reflection, and breaking of waves. The same system is analyzed by Patrizi et al., that, by means of a Life Cycle Assessment, show the effects of the whole life cycle of the components on greenhouse gases emissions. An important outcome of the analysis is that if we considered the whole plant built on purpose, it would have a very high impact; instead, if we consider just the amount of energy and materials that have to be added to a port, that has to be built anyhow, for energy production, the impacts would be negligible.

Coiro et al., point out that offshore wave solutions require site-specific calibration of the technology. Furthermore, large differences between average and peak response may arise requiring the optimization of the control strategy. Also, the exploitation of currents can be problematic in the Mediterranean area: the possible suitable locations are few and the implementation risky due to the depth of the areas.

A decisive step for the implementation of Blue Energies in the Mediterranean area is identified by Soukissian et al.'s cluster(s) development. Clusters are the key to the development of the Blue Energy sector by means of innovation, agreements on legislation, and financial stimuli. Clusters are also the place where stakeholders that can provide solutions and policymakers looking for the best technologies for their areas can meet and establish the basis for the production of renewable energy.

Another aspect that has to be taken into account, as pointed out by Andreadou et al., is the possible conflict of Blue Energies with tourism. The Mediterranean area is a tourist attraction having a unique character for its climate, culture, and landscapes. And tourism is also one of the main factors for the economy of the area. The beauty of technological solutions has to be pursued in order to make them a further reason for the attraction of tourism and to avoid conflict. Fotiadou and Papagiannopoulos-Miaoulis suggest that the realization of Blue Energy can help policymakers to see the Mediterranean Sea as a "space": Maritime Spatial Planning can be the key to harmonize all the activities that are carried out on the Sea, limiting in this way the competition for space and creating synergies between Blue Energy and other uses.

The number of views of the papers in this Research Topic (more than 30,000 up to date) shows that there is a need for these kinds of studies. Blue Energies have to become part of our future. No big plants with high impacts but many plants diffused all over the Mediterranean area. Technologically speaking we can say that we are ready for this. But some aspects have to be fixed, especially at the legislative level: for example just one plant for wind energy has been authorized in the Mediterranean area. It is in Italy, in front of the industrial site of Taranto and it took more than 10 years to get this authorization.

The possible conflicts with other uses and negative reactions from citizens can be avoided if a different approach is taken, as suggested by the Interreg MED projects MAESTRALE, PELAGOS, INNOBLUEGROWTH, and BLUE DEAL: evaluation of sustainability, involvement of citizens in the presentation and discussion of possible technological solutions, careful planning, making these solutions more appealing and integrated into the landscape. Beauty and Science allied for a sustainable future (Tiezzi, 2004).

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. SB drafted the paper that was improved by the three co-authors before submission.

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Marine Energy Exploitation in the Mediterranean Region: Steps Forward and Challenges

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This works aims to describe current perspectives for marine energy exploitation in the Mediterranean basin, highlighting challenges and opportunities as well as the factors that still limit its market deployment. Technologies for the conversion of Marine Energy (ME) into electricity are now ready for full-scale deployment in farms of devices, making the final step from demonstration to operability and commercial exploitation. Although marine energy is more abundant along the Atlantic and Nordic European coasts, significant resources are also available in the Mediterranean Sea, opening up new perspectives for sustainable energy production in sensitive coastal areas and for the economic development of Southern Europe. The implementation of ME converters in the Mediterranean is in fact liable to induce significant technological advancements leading to product innovation, due to the local low energy levels which impose more restrictive constraints on device efficiency and environmental compatibility. In addition, the milder climate allows the testing of concepts and prototypes in the natural environment at more affordable costs, lowering capital risks for new and innovative small and medium enterprises. Research institutions and industrial players in Mediterranean countries have already taken up the challenge, despite the numerous limiting factors that still need to be removed. In particular, the ME sector adds up to the many different traditional maritime activities and to the new ocean-related industries that are developing, potentially exacerbating the competition for the use of marine space in the Mediterranean region and threatening its environmental status. The ME sector needs therefore to design suitable instruments to involve all the relevant stakeholders in a participative public debate as to how to best manage the maritime space. As the prospective sea use patterns are rapidly changing, an adequate international legal and policy framework needs to be designed for the coherent management of sea space, and Marine Spatial Planning needs to be finally implemented by EU Member States also in the Mediterranean area. To this end, the creation of transnational clusters of stakeholders is expected be an effective catalyzer, especially as they can foster the exchange of knowledge and best practices both across European countries and between the North and the South shore of the Mediterranean basin.

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INTRODUCTION

During recent years, the EU has progressively intensified its coordinated efforts to finally achieve the Energy Union, by accelerating the implementation of actions supporting its core objectives i.e., security of supply, sustainability and competitiveness), while the necessity was still recognized to continue rapidly delivering a number of enabling measures, to ensure that the transition to a low carbon economy fully contributes to the modernisation of Europe's economy (Communication From The Commission To The European Parliament, 2017). A number of dedicated programmes and projects have therefore been funded in order to make progress toward the realization of five closely related and mutually reinforcing dimensions: energy security and diversification, a fully integrated internal energy market, energy efficiency, the decarbonization of the economy and the development of research, innovation and competitiveness.

Among the available renewable sources, marine energy is experiencing increasing interest and development (Jeffrey et al., 2013). Marine Energy comprises offshore wind energy plus energy that can be harnessed from the ocean (namely surface waves, tides/currents, and thermal and salinity gradients), the latter referred to as Ocean Energy (OE). The phrase *Blue Energy* (BE), which is also used in the following when appropriate, indicates both marine energy and the energy obtainable from marine biomasses.

The Marine Energy (ME) sector clearly stands at the intersection of all the converging paths of EU energy policy, as it promises substantial breakthroughs in low-carbon and clean energy technologies, reinforces the EU competitiveness on the global market, calls for transnational regulation and management (also in view of the Maritime Spatial Planning Directive - 2014/89/EU), reduces dependence on energy imports by leveraging indigenous resources, lowers emissions and drives the economic growth of coastal communities (TP Ocean, 2016). As a matter of fact, the Blue Growth Strategy proposed by the Commission in 2014 (COM(2014) 254) emphasized that harnessing the economic potential of Marine Energy in a sustainable manner represents a key policy area for the EU, which would enable the sustainability of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources. The ME sector is, in fact, expected to drive the creation of high-quality jobs and pave the way for a new wave of science-trained professionals, enhancing eco-efficient value creation all along the value and supply chain. In particular, remote islands and coastal regions would especially benefit from ME development, as it would provide a viable alternative to expensive and heavily polluting fossil fuelled plants, and contribute to their energy self-sufficiency (Rusu and Guedes Soares, 2012; Fadaeenejad et al., 2014; Franzitta et al., 2016; Franzitta and Curto, 2017). Moreover, small and medium sized port (SMP) management and the marine energy industry have mutually reinforcing interests, as SMPs could offer sustainable yet relevant marine services and satisfy their own needs of electricity by incorporating devices in port structures, at the same providing excellent sites for testing and monitoring new devices.

ME exploitation clearly opens new frontiers in the maritime sector, by creating synergies with long established traditional activities, yet opening the door to knowledge-driven innovation. It offers the opportunity to pool costs and boost several connected economic sectors.

The European Strategic Energy Technology (SET) PLAN recently prioritized Key Actions for the ocean energy sector, aiming at confirming the EU global leadership in the field, and filling the residual gap between research or prototype demonstration projects and their commercial deployment. Substantial reduction of costs is essential, as well as further demonstration of technology reliability and survivability in aggressive sea conditions. The SET Plan recommends to concentrate efforts on a limited number of promising technologies for energy conversion from tidal streams and waves, targeting the necessary reduction in the levelised cost of energy (LCoE) to improve their competitiveness in the electricity market (European Commission, 2017a).

Offshore wind farms probably represent the most advanced solution if the technological maturity of converters alone is considered, as they can rely on the expertise gained in several years of exploitation of their land-based analogs and on the stronger and less disturbed winds that are available offshore compared to on-land. On the other hand, devices for the production of wave and tidal generated electricity are in fact currently exiting the research and development stage and stably entering the operational, commercial phase, and the deployment of full-scale prototypes in real-sea environment is now underway (Magagna and Uihlein, 2015a,b; Magagna et al., 2016).

In this framework, the Mediterranean area in particular presents a variety of cross-boundary issues. Under current emission scenarios, the Mediterranean is and will be more and more affected by climate change in the course of the twenty first century, with severe impacts on the environment and human welfare (IPCC, 2014). The traditional economic activities that have been guaranteeing the livelihood of coastal communities for centuries are all at risk, in particular agriculture, fisheries and tourism. The adoption of sustainable and efficient forms of energy production clearly lies at the heart of the climate change mitigation issue, while the on-site development of renewables would at the same time address the growing local energy demand and secure the sustainable energy independence of coastal areas. Investments in the sector of renewable energy can no longer be delayed if the costs of non-action are to be counterbalanced (Plan Bleu, 2008). However, that of energy demand, efficiency and sustainability in the Mediterranean is a tale of two shores. As a matter of fact, the North countries have already taken a transition path by substantially introducing renewable sources in their energy mix and by effectively implementing measures to lower their energy demand. On the contrary, the South Mediterranean has experienced sustained economic and population growth over the past years (+6% and +5% respectively), with an energy demand growth of +6% since 2010 (MEDENER/OME, 2016), still insufficient measures to improve energy efficiency and renewable energy exploitation (United Nations, 2012; MEDENER, 2014), and little of no attention for marine renewables (El-Katiri, 2014; Bekkar Djelloul Saiah and

Boudghene Stambouli, 2017). Such an interest has been revived only recently, and marine energy proposed as a resource for coastal areas (Mahdy and Bahaj, 2018; Olaofe, 2018). Indeed the latter, together with small islands, deserve special consideration as they are subject to enhanced seasonal energy demand due to the tourism industry, both in the North and in the South Mediterranean (UNEP/MAP., 2000; Pirlone and Spadaro, 2017).

Developing and implementing marine energy technologies has not been so far a priority in the Mediterranean, as it was considered less cost-effective when compared to other renewables (e.g., solar or land-based wind energy). Offshore wind farms are not yet operational in the Mediterranean Sea despite the large resource availability (deCastro et al., 2018), due to both environmental and technological constraints and non-market barriers (EWEA, 2013), while OE converters are still at a pre-commercial stage (Uihlein and Magagna, 2016). Nevertheless, the share of marine energy in the total energy budget for the Mediterranean region is expected to constantly increase in the forthcoming years, in particular as regards offshore wind energy generation (EWEA, 2013; Piante and Ody, 2015), while the potential contribution of ocean energy is still often underestimated (see, for instance, Piante and Ody, 2015). On the contrary, recent technological advancements have made the targeted LCOE of OE converters more realistic (European Commission, 2017b), while the overall consideration of both explicit and implicit costs in the Mediterranean fragile environment (e.g., including the effects of landscape disruption and changes in land use) strongly recommends the adoption of less invasive devices for energy conversion such as these. Stepping up the role of ocean energy in the Mediterranean now appears more a necessity than a choice, as testified by the increasing interest of local authorities and administrative bodies (e.g., the Italian ANCIM, Associazione Nazionale Comuni Isole Minori-National Association of Municipalities located in Small Islands).

In the context of such renewed interest, the Mediterranean Sea has been proved to offer substantial opportunities for both significant energy production (Zodiatis et al., 2014; Monteforte et al., 2015; Besio et al., 2016) and technological development. The latter is mainly favored by the milder climatic conditions with respect to the North Sea And the Atlantic Ocean, which allow the affordable testing of devices and stimulate the design of particularly efficient technologies for energy harvesting. On the other hand, the accentuated vulnerability of the Mediterranean environment and sensitive species (e.g., Poseidonia meadows) prompts the development of innovative technologies that, while guaranteeing the energy independence of coastal areas, also preserve local exposed habitats and ecosystems. Under this respect, the design of a methodological framework for the environmental impact assessment (EIA) of OE converters has been recommended (Margheritini et al., 2012; Witt et al., 2012).

Building on their long-standing experience in maritime activities, R&D institutions and private enterprises in Mediterranean countries have been striving to gain and consolidate their position also in the marine energy sector. However, the still too low level of coordination and networking among the potential actors and the absence of a long-term stable funding programme on the part of national governments have prevented the sector from obtaining visibility and securing the essential sustained support from large enterprises, administrative authorities and local governing bodies.

In particular, OE technologies that have been specifically developed for the Mediterranean environment now need to complete their technological readiness level (TRL) path and enhance their visibility on the international stage (Sannino and Pisacane, 2017). In addition to the usually acknowledged barriers to industrial roll-out and final commercialization (technology development, finance, consenting and environmental issues, and the availability of grid infrastructure), the timeline for their further development also critically depends on the level of public support offered in the short- and medium-term by the EU, by national governments and by regional authorities (Negro et al., 2012). The provision of significant stable and predictable funding would prevent the loss of the accumulated knowledge now that it is close to repaying the initial investments made by national and international research programmes and private enterprises, and reinforce the position gained by Mediterranean players. Unfortunately, national investments are often insufficient to guarantee their participation in co-funded EU programmes and their access to co-funded financial instruments (e.g., OCEANERA-NET Cofund, http://www.oceaneranet.eu). The implementation of effective government policies, often solicited in EU official documents, would definitely sustain the improvement of technologies, bring down costs, and facilitate project financing, in a clear regulatory framework (Communication From The Commission To The European Parliament, 2014; Corsatea, 2014; Magagna and Uihlein, 2015a,b; Ocean Energy Forum, 2016; European Commission, 2017c).

As many reviews and reports are already available that deal with the status of marine energy development in Europe in general that contain information about the most popular devices developed in Northern and Atlantic Europe (Magagna and Uihlein, 2015a,b; Magagna et al., 2016 and references therein), this paper will only focus on the endogenous resources and efforts of Mediterranean countries, in terms of innovative devices, support technologies, environmental assessments and current policy instruments. The paper is organized as follows: Section Technologies for Marine Energy harvesting briefly reviews the most promising converters and the technologies involved in the supply chain, section Dedicated policies presents relevant policies implemented at the EU and at the regional and national level and Section Sustainability deals with sustainability issues, while key messages are summarized in the Conclusions.

TECHNOLOGIES FOR MARINE ENERGY HARVESTING

As already mentioned, offshore wind appears to be the closest-to-market ME technology, while the most promising ocean energy technologies are:

- Converters extracting kinetic energy from tidal currents;

- Converters exploiting the difference in potential energy arising from the rise and fall of sea levels between high tide and low tide (tidal range);
- Wave energy converters, extracting kinetic energy from wind-driven waves;
- Ocean Thermal Energy Converters, exploiting temperature differences between deep and surface ocean waters;
- Salinity gradient converters, harnessing the chemical potential of differences in salt concentration in ocean waters.

Although Northern and Atlantic European countries have made more progress on the road to marine energy exploitation, also Mediterranean countries can boast a high number of qualified developers from Universities, Spin-offs, SMEs and large Enterprises. For a survey of the Italian initiatives in the OE sector (see Sannino and Pisacane, 2017), while information about recent developments in Italy, Spain and France can be found in (OES, 2017) (the two latter mainly concentrating efforts outside the Mediterranean basin).

Efforts have been mainly concentrated on wave and tidal energy converters, which represent the most apt and promising options for the Mediterranean conditions, and for which different technical solutions were developed, either by adapting existing technology or by designing innovative devices. Several prototypes and pre-commercial devices have been designed and tested, some of which are now entering the commercial phase. The main advantage offered by such technologies is that, by being specifically projected for the Mediterranean environment, they had to specifically address the issue of efficiency, due to the relatively low wave energy levels in the basin. On the other hand, in order to export these technologies to the global market, it is necessary to prove their survivability in more severe sea conditions and the actual feasibility of their upscaling.

Parallel technological research and innovation activities are being conducted to enhance the efficiency in energy conversion and/or in storage and distribution, and transversally affect all the marine energy technologies.

Devices for the Conversion of Marine Energy

Wave Converters (WECs)

Several technologies for wave energy conversion have been developed, reaching different stages of technological maturity, and some full-scale prototypes have been already tested in real ocean conditions (Cagninei et al., 2015; Arena et al., 2016; Iuppa et al., 2016). The mechanical process of wave energy absorption and conversion requires a moving interface, which can either be a partly or totally submerged moving body whose kinetic energy is exploited by a Power Take Off (PTO), or a moving air/water interface subject to time-varying pressure as a function of wave incidence. The latter solution is known as Oscillating Water Column (OWC), and exploits the alternate compression and decompression induced by waves on the air trapped in the device, forcing air to flow through a turbine coupled to a generator. The main advantage of the OWC vs. other WECs is its simplicity, as the only moving part of the energy conversion mechanism is the rotor of a turbine, located above water level, rotating at a relatively high velocity and directly driving a conventional electrical generator. However, they only appear to be cost effective when incorporated in onshore conventional breakwaters, offering the advantage of a limited increase in costs in conjunction with ease of maintenance and coastal protection, while their use in large floating platforms has not been proven feasible (Falcão and Henriques, 2016). As a matter of fact, when any wave converter is located away from the coast, where waves are higher and potentially offer larger energy resource, both risks and expenses are liable to increase due to more severe sea conditions impacting both on the device and on the necessary submerged structures and electrical connections to the distribution grid (Rahm, 2010). The feasibility of offshore plants crucially depends on the availability of advanced mooring material and technologies, as well as of robotics, and informatics for the remote monitoring and efficient operational support (Borthwick, 2016).

The first full-scale OWC prototype in the Mediterranean is under construction in the port of Civitavecchia (Rome, Italy), as the Port Authority recently decided to upgrade its infrastructure and adopted the REWEC3 technology for the realization of 17 new caisson breakwaters. Each REWEC3 caisson is 33.94 m long and includes 6-8 independent absorbing chambers. The total length of REWEC3 caissons is 578 m. A first Wells turbine of 20 kW, without any optimization, has been installed, while the total installed power will be of 2.5 MW (Arena et al., 2016; Sannino and Pisacane, 2017).

Wave converters developed by the Israel-based company Eco Wave Power have been cemented to the sea wall surrounding Jaffa Port, where a 10 KW research and development power station has been installed (http://www.ecowavepower.com/jaffa-port/). Most of the technical equipment operates on land, thus improving reliability, reducing stress on equipment and providing easy access for maintenance and repair. In 2016, Eco Wave Power also installed the first commercial wave energy array in Europe selling electricity to the electrical grid through a PPA (Power Purchase Agreement) with the Government of Gibraltar and the Gibraltar Electricity Authority. Upon completion of the whole 5 MW, this site will provide Gibraltar 15% of its overall consumption of electricity.

In August 2015, the first full-scale prototype of the Inertial Sea Wave Energy Converter (ISWEC, TRL 7), a point-absorber suitable for mild climate seas such as the Mediterranean, with a nominal power of 100 kW, was moored 800 m from the coast of Pantelleria, Italy (Cagninei et al., 2015), while the H24 wave energy converter developed by 40 South Energy was installed off Marina di Pisa, in Tuscany (Italy).

However, transparency and accountability issue arise as to the actual performance of devices in real sea conditions, and as to their operational behavior. The lack of public data often impairs the fair comparison of the proposed technologies, while an objective evaluation of technology progress through the adoption of common metrics is indeed necessary to illustrate the impact of funding and to ensure appropriate allocation of future funding to the most promising technologies (European Commission, 2017c; OES, 2017).

Tidal Current Converters

Tidal energy technologies extract kinetic energy from either sea level fluctuations (through tidal barrages, usually effective in resonant estuaries) or from tide-driven currents (tidal energy converters - TECs). A PTO then converts mechanical motion to electricity. The local low tidal excursion and the marked dependence of the energy of tidal currents on local conditions and topography, suggest that only TECs can be considered as promising technologies for specific location in the Mediterranean, namely the straits.

There is a wide variety of TECs available (Magagna and Uihlein, 2015a,b and Magagna et al., 2016; Sleiti, 2017), whose suitability clearly depends on the application under study. Again, technologies specifically designed for the Mediterranean environmental conditions are being developed (Sannino and Pisacane, 2017), while a prototype of the Kobold vertical axis turbine (6 m diameter) has been installed in the Strait of Messina (Coiro et al., 2013). However, due to the limitation and constraints for the optimal siting of TECs in the Mediterranean, no extensive studies as to their potential performance and exploitation have been conducted so far.

Offshore Wind Energy and Multipurpose Platforms

Offshore wind-turbine technology has essentially followed that of its onshore analog. Turbines usually consist of three blades rotating around a hub, with rotor diameter well above 100 m and hub height around 100 m, reaching a rotational speed of 10 rpm and nominal power production just below 10 MW, but rapidly increasing as development continues. Their technology is in fact rapidly evolving, and it appears feasible to further upscale individual wind turbines, although problems might still arise from noise and blade erosion (Borthwick, 2016). Their use in arrays (wind farms) is now widely implemented, and at the end of 2017, the total worldwide offshore wind power capacity was nearly 19,000 MW (GWEC, 2017).

However, the installation of offshore wind farms in the Mediterranean has been so far hindered by the characteristic depths of the basin, which do not allow fixed foundations for the turbines at a distance from shore that is at the same time compatible with landscape preservation and cost effectiveness. After substantial delay, mainly due to public opposition, which led to longsome appeals to the Administrative Court, the first near-shore plant is currently under construction in Taranto, Italy, with total capacity 30 MW (https://www.4coffshore.com/windfarms/parco-eolico-nella-rada-esterna-del-porto-di-taranto-italy-it31.html).

The exploitation of wind power in the Mediterranean is in fact still in want of appropriate and innovative solutions for offshore foundations and floating support structures specifically designed for deep waters, so as to allow distancing the installations from the shore and preserving valuable landscapes (Borthwick, 2016; Soukissian et al., 2017; deCastro et al., 2018). An analysis conducted in 2013 by the European Wind Energy Association concluded that deep offshore designs were necessary to unlock the promising offshore market potential in Mediterranean, developing technologies that could be globally exported, initially to Japan and the US. It also foresaw that the first deep offshore wind farms could be installed and grid connected by 2017, provided the challenges then existing were overcome (EWEA, 2013). As a matter of fact, the first pilot floating farm is now going to be installed 15 km off the coast of Gruissan, in the Gulf of Lion, France, for a total capacity of 24.8 MW (http://www.eolmed.fr/en/the-pilot-farm/).

The opportunity of integrating offshore wind technologies and WECs on multipurpose platforms, possibly also hosting different maritime activities such as aquaculture or maritime transport, is currently being explored, as it allows cost sharing and the more sustainable planning and management of the electric grid and of auxiliary infrastructures (Pérez-Collazo et al., 2015; Astariz and Iglesias, 2016; Craig, 2018; Di Tullio et al., 2018). In particular, the inclusion of co-located WECs into wind farms would further accelerate the development of wave energy technologies, and prompt the adoption of a common regulatory framework and the development of simplified yet rigorous licensing procedures, in compliance with the Maritime Spatial Planning (MSP) Directive and with Integrated Coastal Zone Management (ICZM) principles (Pérez-Collazo et al., 2015; Astariz and Iglesias, 2016). The integration of multiple different sea energy converters would also guarantee a smoother power output and minimum energy production at a constant rate independently of meteorological conditions, therefore ensuring the survival of security systems and power transmission systems, and increasing the platform service factor (Stoutenburg et al., 2010). The operational life of the offshore platforms would therefore be lengthened, positively responding to the financial and insurance concerns of investors and increasing the interest of potential stakeholders. Studies concerning trade-offs and synergies with other economic sectors responsive to marine resources exploitation, such as aquaculture, maritime transports, beach tourism, naturalistic tourism, or installations for biotechnologies, are also underway, which are attempting to assess the economic potential and risks of co-using sea areas, as well as the mutual effects on the sustainability of the concomitant uses (Buck and Krause, 2012; Leira, 2017).

Support Technologies

The positive international outlook for ocean energy deployment has also induced researchers involved in subsidiary fields and potentially connected industrial players to approach the marine renewable sector. Many industrial sectors of Mediterranean countries in fact actively contribute to designing the building blocks of innovative ocean energy converters, either by developing ad hoc technologies or by optimizing existing ones, while research institutions, environmental agencies and operators of the green economy constantly strive to enlarge the existing database of environmental and product design constraints.

Environmental Modeling: Resource Availability, Environmental Impact Assessment, Optimal Design of Installations and Operative Parameter Tuning

For the exploitation of marine energy it is essential to determine where sufficient resource exists, so as to guarantee adequate return on investment and increase the confidence of investors by minimizing risks (Uihlein and Magagna, 2016).

Forecast systems delivering reliable and updated maps of relevant parameters, such as significant wave height, wave energy period and mean wave direction, need then to be considered as a component of the engineering of devices, as they allow optimal plant siting and calibration, predictive maintenance, and a better understanding of site characteristics and vulnerabilities.

Despite marine energy being characterized by higher predictability with respect to other renewables (tidal current energy is periodic, while wind is less subject to disturbances offshore than onshore), as the size and complexity of the installations increases, the tools used to project or measure the resource, and to assess the environmental impacts of the plants, become more and more critical and need to integrate a variety of complex modeling and monitoring techniques, also in view of the accentuated variability in the basin, which cannot rely on the comparatively coarse resolution, non-specific, projections available through international websites (Uihlein and Magagna, 2016). Several international programmes and projects have been dedicated to the improvement of projections and assessments for the Mediterranean area, often already in view of future exploitation opportunities (e.g., the on-going H2020 Project MUSES - https://muses-project.eu/ - and the FP7 Project COCONET - https://www.coconet-fp7.eu/). In particular, the MED-Cordex Initiative (https://www.medcordex.eu/) provides projections from regional atmospheric, land surface, river and oceanic climate models as well as from coupled regional climate system models, aiming to increase the reliability of past and future regional climate information for the Mediterranean region (Ruti, 2016).

In addition to these time-limited or climate-oriented coordinated efforts and to the EU-wide support provided by the Copernicus services (http://copernicus.eu/main/marine-monitoring), research centers in many Mediterranean countries routinely provide environmental forecast for general or specific use based on national initiatives (e.g., http://openskiron.org/en/).

In Italy, for instance, specific support to ocean energy related activities is offered at ENEA, by performing ocean wave modeling activities aimed at both quantify ocean energy availability in the Mediterranean Sea (**Figure 1**) and at providing the necessary information for the optimization of the operational set-up of wave energy converters. A wave forecast system was developed and validated by ENEA in collaboration with Enel Green power, and has been operatively running since June 2013 (https://giotto.casaccia.enea.it/waves/). Forecasts cover the entire Mediterranean basin while nested higher resolution projections are provided for 10 sub-basins along the Italian coasts. A sample projection for the western coast of Sardinia is shown in **Figure 2**. When coupled to real-time measurements, the forecasting system can further support the operation of wave energy generation devices, predict actual electric power generation and give the alert in case of severe sea conditions.

ENEA is also running climatological experiments with a high-resolution tide resolving ocean model (MED-MITgcm) capable of assessing the available tidal power in selected locations in the Mediterranean basin (**Figure 3**).

Similar activities, for specific sites or periods, are also carried out at several academic and research centers in the context of specific national projects (Sannino and Pisacane, 2017).

The private sector as well has developed environmental services in the support of sea-based operations. Large consulting companies (for a review of those operating in the Mediterranean see Sannino and Pisacane, 2017) are capable of performing meteo-ocean modeling and to offer support for the optimization of design parameters of engineering projects in offshore

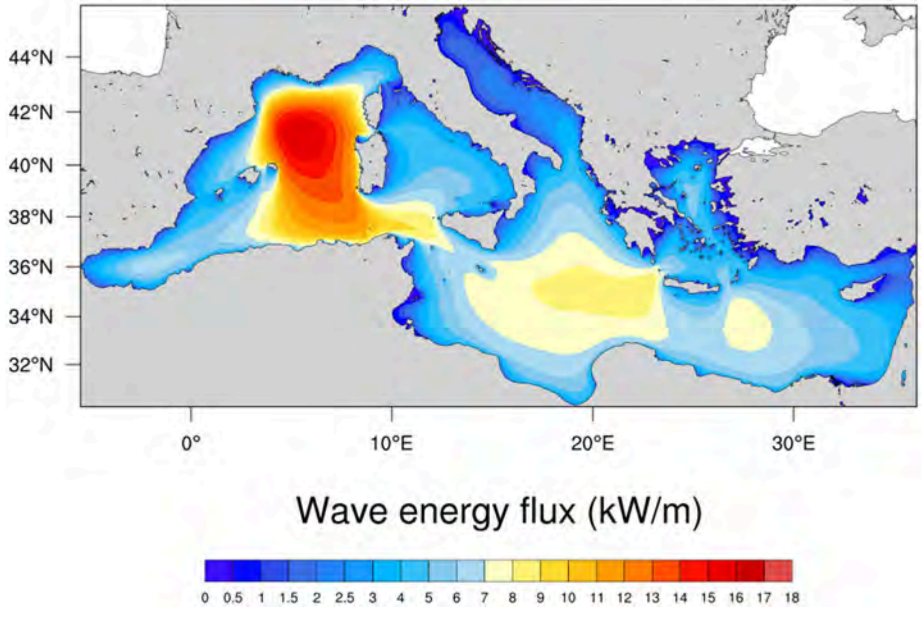

FIGURE 1 | Mean claimatological wave energy flux in the Mediterranean for years 2001–2010.

FIGURE 2 | Sample forecast of Significant Wave Height along the West coast of Sardinia.

areas (platforms), marine, waterfront (harbors) and coastal (beach protection) environments, and the minimization of their environmental impacts. Offshore geotechnics services are carried out for offshore platforms, subsea structures, pipelines, floating structures applications, including non-linear dynamic modeling capacity. Characterization of the typical environmental conditions and processes at the project site is therefore feasible, including longshore/cross-shore sediment transport and contaminant dispersion. Innovative monitoring systems for the design, installation and management are also available on the market.

In their turn, large national and international utility companies (e.g. ENEL, https://www.enelgreenpower.com/) also carry out strategic activities in the Mediterranean to support the development of promising devices and to predict and classify the potential environmental risks of marine energy plants from concept to decommissioning. Sites characterized by lowest sensitivity to project characteristics can then be selected and the associated socio-economic impacts evaluated.

Device Optimization

Besides optimal siting, further development of devices for marine energy conversion also requires the careful assessment of the expected performances in realistic operative conditions in the Mediterranean environment, where most of the existing wave power technologies are oversized. *Ad hoc* numerical models for the performance assessment of the most promising concepts are consistently implemented by technology developers, which virtually mimic the mechanical and hydro-dynamical and the electrical aspects of devices, also accounting for the control system, for the characteristics of their industrial components and for the constraints of grid connections (Bozzi et al., 2013; Folley, 2016). Simulations are carried out in a variety of sea conditions and multiple device arrangements, and finally provide optimal configuration and scaling, geometrical layout and layout orientation, together with the estimate of maintenance requirements and yearly average productivity (Sannino and Pisacane, 2017 and references therein, Lopez-Ruiz et al., 2018). Costly non-linear models are systematically upgraded to refine the system configuration around its best overall layout, and to assess the performance and productivity of wave farms as a function of location, mutual hydrodynamic interaction and electric connection, also estimating maintenance requirements and optimal operating conditions. These methodologies also analyse system response to severe sea states. Results are validated against available experimental data, providing however the added value of statistically significant uncertainty analysis based on large size data samples, and representing a key step toward the optimization of energy production by sea-based farms (Lopez-Ruiz et al., 2018).

Infrastructure Design and Development of Mechanical and Electrical Elements

The development of the ocean energy sector also needs innovative infrastructures and components that are capable of enduring the severe marine environmental stresses, making facilities less prone to faults and more cost-efficient, and guaranteeing their constant operability. Connected sectors such as marine construction, shipbuilding and electric power system design and operation would then envisage invaluable opportunities for growth, as they can re-adapt technological solutions developed in different contexts and partly re-orient their business and capitalize their experience (Ellabban et al., 2014; Magagna and Uihlein, 2015a,b; Borthwick, 2016). Both large enterprises and SMEs would in fact acquire new skills and capabilities by cooperating with cutting-edge research, confirming and enhancing their capacity of offering innovative, high-value solutions. On the other hand,

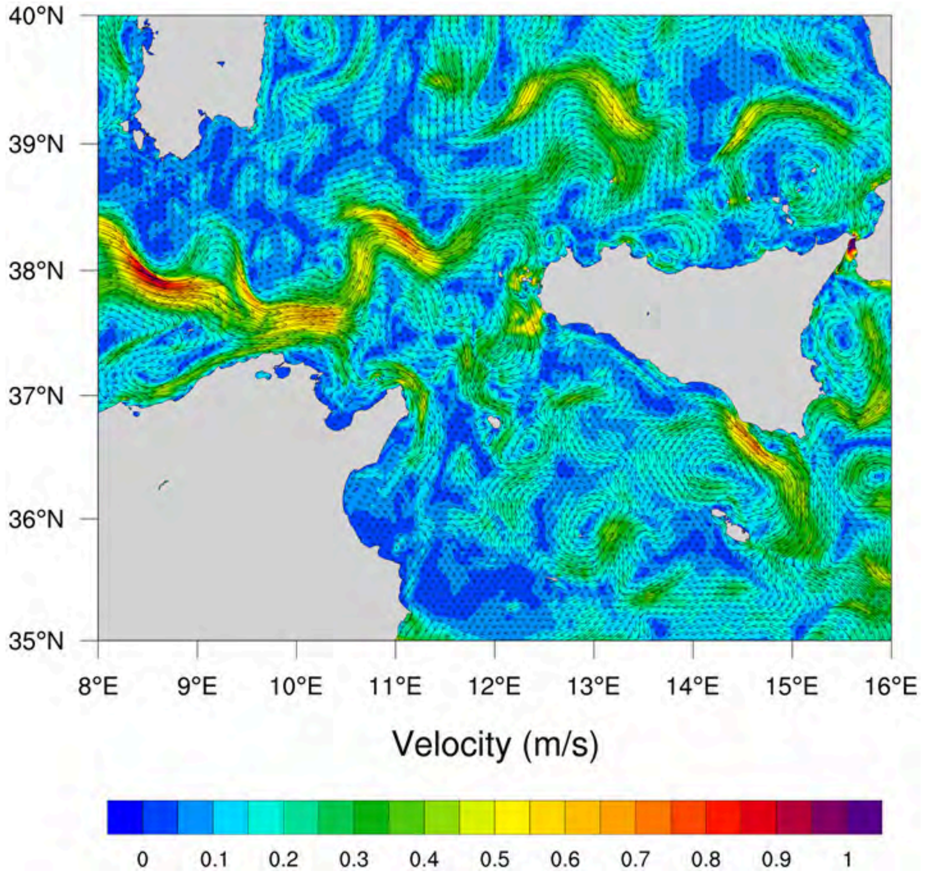

FIGURE 3 | Forecast of currents in the Sicily Channel and at the Strait of Messina.

academic research would largely benefit from the ability of established private firms to stay in a competitive market, and consolidate partnerships for the industrial roll-out of their concepts (Appleyard, 2017; European Commission, 2017c).

To give an outline of the variety of potentially connected sectors, either in the supply chain or in research and development, it is here worth considering:

- The Oil & Gas sector and the Shipyard & Shipbuilding industry, specialized in the construction of drilling platforms, floating platforms and offshore supply and cable laying vessels, and capable of delivering the economic assessment of the different phases in the lifetime of a floating structure, from construction to deployment;
- The electronics industry, offering innovative energy storage solutions and batteries for marine offshore applications, e.g. those based on the thermal and fluid integration of Proton Exchange Membrane (PEM) fuel cells and Metal Hydride hydrogen storage (prototype 1, completed), and on the electric and fluid integration of Electrolyser and RES[1] plus Metal Hydride storage for hydrogen production and storage (small scale prototype 2 – under development) (Lamberti et al., 2015);
- Companies providing cost effective solutions for onshore construction as well as hands-on experience in all areas of offshore geotechnics. Typical projects include offshore platforms, subsea structures, pipelines, floating structures, whose feasibility study is accompanied by quantitative risk assessments covering the full range of marine installation, and including the hydrodynamic and sea-keeping analysis of floating units, their mooring analysis, ship handling/maneuvering simulations, and the analysis of mechanical components (e.g., static and dynamic stress analysis, structural thermal coupling, vibration and fatigue analysis);
- Companies providing innovative and durable materials for submerged structures (e.g., new coatings and alloys);
- Manifacturing companies offering bearings, ballscrews and Electro-Mechanical Actuators (EMAs) and PTOs for the aerospace, industrial and energy sectors;
- Companies specialized in the design and production of Electro Submersible Pumps and turbines, whose performance under variable flow conditions is crucial in the low-energy wave conditions typical of the Mediterranean Sea;

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[1] Renewable Energy Source

- Companies developing unmanned underwater robotics for the monitoring and surveillance of the infrastructures at sea;
- Companies offering integrated cable-less communication solutions for the Internet Of Underwater Things (IOUT), which open new possibilities for the installation and monitoring of infrastructures (FP7 Project SUNRISE).

Many of these enterprises have further consolidated their technical competences and contributed to the technological development of the ME sector by participating, in collaboration with potential customers and leading R&D institutions, to several regional, national and international research projects (Sannino and Pisacane, 2017).

Experimental Infrastructures

During the development of ocean energy converters from their first conceptual modeling to their deployment, scale prototyping and testing is crucial to correctly re-direct the design process. Small and medium scale prototypes are tested in wave flumes and wave tanks, where specific sea states can be artificially created, and power production and device survival assessed. For the correct downscaling of the system, the wave tank/flume features need to be taken into account, so as to construct the prototype according to the characteristics of the facility that is going to be used.

While universities usually offer facilities of limited size for limited applications, many specialized centers offer research infrastructures that include world-class towing tanks and flume tanks, simulating complex testing environments for wave, tidal, offshore wind energy systems. The MARINERG-i Project has recently been launched with the aim to create an integrated European Research Infrastructure, designed to facilitate the future growth and development of the Offshore Renewable Energy sector, in the framework of the European Strategy Forum on Research Infrastructures (ESFRI).

In addition to traditional infrastructures offering testing opportunities in laboratory conditions, the Natural Ocean Engineering Laboratory (NOEL) of the University of Reggio Calabria (UNIRC) provides a unique testing infrastructure in the marine environment, where field tests can take advantage of the dedicated sensors and data acquisition center, and be carried out with the support and assistance of specialized personnel (www.noel.unirc.it).

DEDICATED POLICIES

The EU SET Plan

The Strategic Energy Technology Plan (SET-PLAN) is part of a new European energy Research & Innovation (R&I) approach designed to accelerate the transformation of the EU's energy system and to bring promising new zero-emissions energy technologies to market. The SET-Plan intends to accelerate the development and installation of low-carbon technology. It attempts to enhance new technology and bring down prices, by coordinating Member States research efforts. It also aims to enhance project funding. The SET-Plan includes the SET-Plan Steering Group, the European Technology and Innovation Platforms, the European Energy Research Alliance, along with the SET-Plan Information System (SETIS). Within the SET-Plan organization, dedicated Working Groups (WGs) were created in 2017 for both ocean energy and offshore wind, which recently issued specific Implementation Plans, delineating priority actions to foster future developments (SET Plan, 2018a,b). Due to the different stages of development of ocean energy and offshore wind technologies, recommended actions clearly differ as to targeted objectives, relevant policies and funding sources foreseen, especially as regards the relative weight of public and private commitment. In particular, the offshore wind industry target reduction in the levelised cost of energy (LCoE) declared in the NER300[2] programme to less than 10 ct€/kWh by 2020 and to less than 7ct€/kWh by 2030 was reformulated by the WG, which indicated the even more ambitious objective of zero subsidy cost level, as a result of improved the performances along the entire value chain (SET Plan, 2018b). Less constraining targets are set for offshore wind farms in deep waters (>50 m), whose more costly substructures need to be considered as integral parts of the whole system, with expected LCoEs of less than 12 ct€/kWh by 2025 and less than 9 ct€/kWh by 2030 (SET Plan, 2018b).

On the other hand, the implementation plan delivered by the SET-Plan Working Group "Ocean Energy" (SET Plan, 2018a) aims to speed up the development of wave and tidal energy in Europe. The WG is composed of 10 EU Member States: UK, Italy, Spain, France, Belgium, Portugal, Germany, Ireland, Cyprus, Sweden. Stakeholders also joined the WG, represented by the relevant Government Agencies, Regional representatives, industry sectors representatives, research associations and the education sector.

The agreed common targets for the ocean energy sector are:

- Bring ocean energy to commercial deployment,
- Drive down the levelised cost of energy,
- Maintain and grow Europe's leading position in ocean energy and
- Strengthen the European industrial technology base, thereby creating economic growth and jobs in Europe and allowing Europe to compete on a global stage.

The WG also agreed on setting quantitative targets for the LCoE for tidal stream and wave energy:

The LCoE for tidal stream energy should be reduced to at least 15 ct€/kWh in 2025 and 10 ct€/kWh in 2030. Wave energy technology should follow the same pathway through convergence in technology development and reach at least the same cost targets maximum 5 years later than tidal energy: 20 ct€/kWh in 2025, 15 ct€/kWh in 2030 and 10 ct€/kWh in 2035.

Substantial reductions in LCoE will need to be obtained through a combination of development and deployment to ramp up 'learning by doing' and learning by innovation. Substantial improvements in technology performance and operational efficiency combined with mass production will deliver the necessary cost reduction and performance improvements of both tidal and wave technology. Overall the WG recognized that the combination of both step changes in innovation and considerable

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[2] NER300 Programme: https://ec.europa.eu/clima/policies/lowcarbon/ner300_en

volumes of ocean energy devices need to be installed to achieve these aims.

National Policies and Lessons Learnt

European countries exhibit different degrees of participation in knowledge creation, diffusion and demonstration in marine energy technology, face different barriers to innovation activities and adopt different solutions for the removal of the factors hampering marine energy deployment (OES, 2017; SET Plan, 2018a). According to (SET Plan, 2018a), only France, Spain, Italy and Cyprus have prioritized action in the OE sector and allocated public funding, while only Italy and France have implemented government incentives in the form of feed-in tariffs (OES, 2017). In the offshore wind sector, where higher Technology Readiness Levels have been reached, national research and innovation programmes are usually limited to technologies up to TRL 7, while financial support provided by Member States to higher TRL technologies need to comply with the EU's State aid rules (SET Plan, 2018b).

In general, considering the whole European landscape, the UK, Ireland and the Nordic countries were early movers in the ME industry, and initiated an intense process of knowledge creation, whereas other EU countries are lagging behind, with limited investments that are mainly expected to be overcome by intensification of knowledge diffusion through EU funded projects and programmes (Corsatea, 2014). Among the latter, Italy has been trying to fill the gap and coordinate a national effort to gain visibility for its well-established activities in the sector (Sannino and Pisacane, 2017).

Even in the most advanced countries, however, policymakers were faced with the necessity to refine the policies in support to numerous and diverse product innovations, in order to get technologies closer to the market (Magagna and Uihlein, 2015b. In order to reduce the high cost of marine energy technology, "nursery markets" were accordingly created to provide opportunities for the infant industry to develop (e.g., publicly supported centers providing the infrastructure needed for the successful demonstration of marine devices). The UK is certainly a leader in this respect, while France and Sweden have started implementing public funded projects, and Germany is pursuing the involvement of multi-technology private companies (Corsatea, 2014).

In all countries, public support has been recognized as a crucial factor for early-stage research on marine energy technology, as it stimulates private investment, although national targets are apparently insufficient to create a long time horizon for private investors, due to the weak stringency and stability of national policies. As marine energy technology still faces significant cost constraints, stable mobilization/allocation of public resources is anyway needed for its further development. The birth of a policy community involving technology developers and marine industry, also involving intermediate levels of decision-making, is now necessary to foster the necessary positive environment for the development of ME innovation activities, enhancing synergies among participants (Borthwick, 2016; European Commission, 2017c). Tighter teamwork of all the relevant actors and more constraining targets would in fact foster market acceptance of the technology and be an effective innovation catalyzer and disclose existing potentialities (Corsatea, 2014).

Mediterranean countries are now entering the ME sector and transposing the EU directives in the matters of both energy policy and marine spatial planning. National legislations are therefore being designed, as well as adequate policy instruments. In the light of past experiences, the importance of networking and of the prospective role of large-size clusters of stakeholders has been acknowledged, resulting in specific initiatives (e.g., the Italian Technological Cluster for Blue Growth) and in public support to EU funded projects for the regional exploitation of ME technologies (Sannino and Pisacane, 2017). Nevertheless, authorization procedures must still comply with the complex legislation in force as to the protection of the environment, of the landscape, and of cultural heritage, and obtaining consent for the installation can be very complex, as it is necessary to ensure the involvement and coordination of all the authorities and tive bodies that represent and protect the different and diverse public interests involved (deCastro et al., 2018). Although streamlining authorization procedures has been timely recommended (SOWFIA, 2013), as well as the adoption of rigorous metrics to evaluate and monitor technological progress and environmental compatibility (European Commission, 2017c; OES, 2017), there is still a need to o accommodate some very different legal obligations arising not only from domestic law and EU law but also from international law, and EU Member States have to seek new forms of cooperation according to their needs and must be forced to effectively transpose the EU Directive on Maritime Spatial Planning into their national legislation and to establish transnational regional structures to face cross-border issues (Martinez Perez, 2017; Salvador et al., 2018).

Dedicated Regional Development Projects

The Interreg MED Programme, which is part of the European Territorial Cooperation (ETC) objective of the EU Regional Policy, was initiated with the ambition of contributing to the long-term development of the Mediterranean area and of strengthening transnational cooperation among 57 regions in 10 different EU member states and 3 candidate countries (MED Programme, 2015). In 2016, the EU Interreg-MED Programme launched the horizontal project InnoBlueGrowth - "Horizontal Communication & Capitalization project for Innovation in Blue Growth at Mediterranean level" (https://blue-growth.interreg-med.eu/), with the aim to implement concrete actions for the creation of cohesive stakeholders communities in strategic investment areas. Among the modular projects of InnoBlueGrowth, PELAGOS and MAESTRALE are specifically dedicated to marine energy. In particular, the PELAGOS Project (https://pelagos.interreg-med.eu) aims to define a management and coordination system among the participating countries (Greece, Italy, Portugal, Spain, Cyprus, France, Croatia), connecting the different components of the Quadruple Helix (i.e., the public sector, the business community, the higher education institutions and civil society) that represents the linkages and the potential conflicts between knowledge production and knowledge use in the field of marine energy. Its scope is to facilitate the deployment of targeted technological solutions and products that are tailored to the characteristics of the Mediterranean environment. It addresses both the request for adequate information and support expressed by the several direct stakeholders in the ME value chain, and the demand for economic, environmental and societal sustainability coming from private and public bodies and citizens. In the framework established by the EU directives in the matters of Regional Policy, Maritime Spatial Planning and Blue Growth, PELAGOS will establish a permanent Mediterranean Cluster of stakeholders to sustain macro-regional strategies and connect key actors of the Marine Energy sector (e.g., technology and service providers, large enterprises, power distributors, financial operators, policy makers, Non-Governmental Organizations (NGOs) and citizens), thus enhancing trans- national cooperation and the internationalization of efforts in the development of new marine based technologies that are both safe and economically feasible. It will support technology transfer and knowledge sharing, and stimulate the development of high-tech and sustainable infrastructures, so as to generate economic growth, to enhance the security of energy supply, to foster competitiveness, and to increase the demand of high-quality professionals in new sea careers. PELAGOS will implement Pilot Actions at both regional, national and transnational level, that will illustrate and provide services, tools and methods tailored to the needs of Small and Medium Enterprises (SMEs) and help highlight the actual obstacles and limitations to the development of the ME sector, at the same time identifying joint opportunities in key market sectors such as tourism & leisure, aquaculture and shipbuilding.

The role of trans-national clusters in creating a favorable environment for collaboration, and in enhancing technological development and economic growth through the sharing of facilities and tools among stakeholders, is a consolidated pillar of EU policy (European Commission, 2008, 2017c; ECO, 2016). In 2016, EU Directorate General Growth launched the European Cluster Collaboration Platform (ECCP), an action of the Cluster Internationalization Programme for SMEs funded under Europe's programme for small and medium-sized enterprises (COSME). The ECCP provides networking and information support for clusters and their members, aiming to improve their performance and increase their competitiveness through trans-national and international cooperation, and to build cluster bridges between Europe, its neighboring countries and the world (https://www.clustercollaboration.eu/).

On the other hand, the MAESTRALE Project (https://maestrale.interreg-med.eu) intends to lay out the basis for a Maritime Energy Deployment Strategy in the Mediterranean, concerted across partners from Italy, Spain, Croatia, Greece, Cyprus, Portugal, Slovenia, and Malta. Starting by making a survey of innovative existing technologies, hindrances and potentials in participating countries, it aims to widen knowledge sharing among scientists, policy makers, entrepreneurs and citizens and to prompt concrete actions and investments. Project partners will cooperate to detect maritime renewable energy potentials in participating countries as a function of their geographical, legal, technological, economic and social contexts. Environmental sustainability, technological innovation and public acceptance are specifically addressed, as well as possible adverse impacts on marine ecosystems. The main output of MAESTRALE will be the creation of Blue Energy Labs (BEL) in each participating region. BELs will include local enterprises, public authorities, knowledge institutions and citizens and will outlive the project to support future blue energy policies and plan concrete strategies for blue growth. Pilot actions are being implemented to raise awareness among local stakeholders, to increase social acceptance and to reduce the inherent uncertainties in impact assessments, thus augmenting the feasibility and effectiveness of interventions.

National support to such initiatives, as well as the inception of similar efforts at the national/regional level, and the complementary implementation of adequate financial support instruments, would definitely contribute to further expanding the ME sector, and to the implementation of solutions tailored for the different national contexts (European Commission, 2008). In particular, transfer of scientific information and exportation of best practices to countries of the South Mediterranean can be achieved through the joint efforts of MEDENER (the association of national agencies for energy efficiency and renewable energy), OME (the Observatory for Mediterranean Energy) and ADEME (Agence de Maitrise de l'Environnement). Such organizations already cooperate in sustaining the Mediterranean countries along their energy transition path, and in helping them to fulfill their ambitious national and regional objectives. The implementation of a regional platform to enhance knowledge exchange on energy efficiency and renewable energies would effectively reinforce Euro-Mediterranean cooperation in the field (MEDENER/OME, 2016), and complement the industrial cooperation effort undertaken through the ECCP.

SUSTAINABILITY

The sustainability of marine energy in general is constrained by economic, environmental, and societal issues (Copping et al., 2014; Bonar et al., 2015; Borthwick, 2016; Copping, 2018). As it is still far from being fully deployed, its impacts are likewise largely to be assessed, as well as the potential adverse effects. Mitigation measures are also still to be designed. While economic constraints are primarily due to the relative high LCOE of marine electricity (induced by higher capital and recurrent costs), to the stability of government subsidies, and to market volatility, reliable information on environmental and societal issues is largely missing, as well as the indirect economic impacts implied (Kerr et al., 2014). As a consequence, public responses to proposed renewable energy developments critically depend on the specific technology and location, and are influenced by a wide range of factors. Regulatory and consenting procedures, for instance, have not been clearly defined yet and still represent a significant barrier to the upscaling of tested infrastructures (European Commission, 2017c). This is also due to the existing uncertainties about their cumulative effects, which are still too large to convince managers and policy makers to ease their administrative scrutiny (Bonar et al., 2015; Borthwick, 2016; Willsteed et al., 2018). As a matter of fact, the development of

Marine Energy is part of an ongoing large-scale strategy for the exploitation of marine resources, namely the Blue Growth, that also includes a variety of possibly conflicting economic activities such as commercial fishing, shipping, aquaculture, dredging, spoil-dumping and oil and gas exploitation. The question of how to regulate the complex interactions of all the involved economic sectors, at the same time preserving (or, when appropriate, conserving) the environment has just been posed, and the "data-rich, information-poor" (DRIP) paradox regarding the assessment of potential modifications of the benthos is yet to be escaped, in particular as to crucial marine ecosystem services (Wright, 2015; Wilding et al., 2017).

Environmental Considerations

Accounting for the cumulative environmental impacts of Marine Energy installations is no longer deferrable since any artificial ocean structure can cause changes to the marine environment, both adverse and beneficial (Willsteed et al., 2017). The debate as to the potential impacts of offshore installations on the marine wildlife (biotic components) is still on-going, the conclusion being sometimes very controversial and not always based on scientific evidence or accurate reference environmental data (Wilding et al., 2017). The propagation of uncertainties through the predictive models used to estimate power extraction and its impact on the marine ecosystem is often overlooked, as well as the impact of device-device interactions, while field data is difficult and expensive to obtain, and current knowledge of the relevant processes involved still partial (Borthwick, 2016). It is likely that the long-term ecological side-effects of marine power plants and device farms will not be fully known until information is available from post-installation monitoring campaigns but, far from being an alibi, this consideration should prompt extra efforts and funding to preventively broaden our knowledge as to how ME devices alter the local flow hydrodynamics, with consequences on critical processes and properties, such as sediment transport, littoral drift, sea quality, biodiversity and food availability (Bonar et al., 2015; Borthwick, 2016).

In general, potentially disruptive interactions between the devices for marine energy conversion and the environment have not been ruled out. This is all the more true for the sensitive Mediterranean environment, where their installation might cause changes at a scale large enough to alter the provision of crucial ecosystem services, in particular as regards fisheries and biodiversity (Bray et al., 2016). The alteration of trophic linkages might change the distribution of fish, birds and mammals, a hypothesis that strongly demands the development of new and more appropriate metrics to be proved false before political consensus is gained around the installation of ME farms (Wilding et al., 2017). From this point of view, basin-wide analyses and theoretical considerations are insufficient, and they can only serve as a non-constraining reference for more stringent tests, accounting for the specific characteristics of prospective installation sites and technologies, on which resources should be concentrated. Metrics of change should be designed that can be unambiguously linked to ecosystem function or service provision, mainly when strongly non-linear effects are expected to be triggered. Innovative long-term monitoring techniques should also be implemented to sustain the development of predictive ecosystem models aiming to support transparent, auditable and timely decision-making (Wilding et al., 2017).

Compared to other forms of ocean energy (e.g., wave and tidal power), offshore wind energy seems to be comparatively more developed from both the technological and environmental point of view. However, Offshore Wind Farms (OWFs) have been fully operative for a relatively short period, and the research on their potential environmental impacts is therefore also limited. Moreover, current assessments of the effects of existing OWFs in Northern European Seas may not be applicable to the Mediterranean, and site-specific analyses are needed before large-scale offshore wind energy exploitation is initiated (Bray et al., 2016). The experience gained from onshore wind farms can only very carefully be extended to the case of OWFs, and for particular cases, such as the effects on bird migrations.

Environmental impacts should be assessed all along the operational life of a plant, as well as during the construction and decommissioning phases. Current assessments usually rely on three strategies:

(1) Gathering existing experience from relevant/similar activities;
(2) Implementing simulation models, and;
(3) Conducting ocean and environmental monitoring/surveys during the planning, the construction and the operational phase of the offshore plant, which is the most important (though expensive) action for an effective environmental impact assessment study. Water quality and pollution indicators should be derived and analyzed, together with the associated impacts on benthic, sea mammal, pelagic, and bird communities. Ornithological surveys may be conducted on the sea, resting and migrating birds, as well as sea mammal surveys on cetaceans and seals. The surveys should be extended onshore to assess the potential impact of on-shore stations and power transfer cables on the surrounding environment.

It is often argued that device foundations and support structures could act as artificial reefs improving biodiversity (but they might also attract invasive species) and that the interdiction of trawling within the concerned area, might be beneficial for the marine flora and fauna, but adverse effects of biofouling such as higher sedimentation rates and eutrophication have not been thoroughly investigated, nor have the consequences of the possible use antifouling chemicals. Also, the effects of prolonged exposure to noise, electromagnetic radiation, and habitat exclusion on marine animals are still to be assessed (Bray et al., 2016).

Social Acceptance

Societal acceptance is generally connected to employment prospects, esthetic concerns, stakeholder involvement, and the wellbeing of communities (Borthwick, 2016). Most of these aspects are not immediately quantifiable in terms of monetary costs or repayments, and an unbiased socioeconomic impact assessment must therefore also account for apparently intangible goods, such as the cultural and esthetic value of landscape or environmental quality. The latter not only define and interweave the multiple, intimate relations between local communities and their natural environment, but also provide vital economic advantages in the form of avoided and replacement costs, as well as of factor income, which are often only appreciated long after their disruption.

Attempting to assign monetary values to non-consumptive public goods and to their functions presents several challenges (Fausold and Lilieholm, 1996). They might even be impossible to accurately calculate, as certain intangible values lose their significance in the process. However, when evaluating the trade-offs and alternatives that are to be proposed to the public, a multidisciplinary effort must necessarily be implemented to account for the parallel economy of the commons, in the context of a mature participatory decision-making process that weighs the social and economic consequences of development and conservation (Newig, 2007; Pomeroy and Douvere, 2008; Portman, 2009). Such an approach is indeed mandatory in view of the social resistance to offshore installations that has been growing in some local communities (e.g., along the Italian Adriatic shores), and of the active role played by local representative bodies in the authorization process, which can lead to project rejection or anyway to costly delays. As a matter of fact, despite the documented widespread support of renewable energy exploitation (European Commission, 2007), on several occasions local communities oppose the installation of plants. The Not-In-My-Backyard (NIMBY) syndrome is probably responsible for this apparent contradiction between public acceptance at the local and the national level, so that individuals favor the proposed interventions only if they are implemented away from their own community (Vazquez and Iglesias, 2015). However, the multifaceted social attitudes and preferences toward complex and strategic matters such as energy production, cannot be fully accounted for by the NIMBY syndrome, and strongly depend on age, education and social rank (Kontogianni et al., 2013; Westerberg et al., 2015). Public efforts must therefore be implemented to inform and involve citizens in participatory decision-making processes, illustrating necessary trade-offs and possible alternatives (Cormier et al., 2013). In particular, inconsistencies and gaps between the proposed management measures, the risk criteria adopted and the level of risk accepted by society need to be identified, while the public must be fully aware that decisions have to be taken by the competent authority on the basis of probabilities and uncertainties (Cormier et al., 2016). Transparent communication and timely stakeholder involvement in a risk-based management approach (Stelzenmüller et al., 2018) would help find a balance between over-regulation (i.e., regulations that are too stringent with respect to the expected risk), and insufficient regulation unnecessarily exposing citizens and economic operators (GRM, 2017).

Economic Opportunities and Constraints

In the Mediterranean area, the development and implementation of offshore renewable energy technologies is expected to stimulate innovation and investment in innovation, and to reinforce the competitiveness of local and regional economic activities traditionally connected to the maritime and marine sectors or engaged in the high tech sector. Operation and maintenance costs are in fact expected to represent a considerable percentage of the future cost burden (Rademakers et al., 2009), and the intellectual property of efficient installation, operability and connection, and in general of cost-effective monitoring and management solutions will definitely represent an invaluable asset on the global market (Magagna et al., 2016). As product development comprises all the levels of the value chain, from R&D to final deployment, several competitive advantages would arise from the coordinated development of all the connected technologies, sustaining the creation of high-tech, sustainable infrastructures in cohesive investment areas and the establishment of efficient transnational business networking and collaborative R&D (European Commission, 2014).

The creation of new jobs can therefore be expected at the local, national and continental scale, adding to the already growing demand for highly qualified professionals in the EU eco-industry. As ME technologies are still at an early or intermediate stage in potentially competitive countries, the chance exists for EU countries to occupy market niches that are still to be conquered and to establish a strong market position as a technology exporter (Magagna et al., 2016).

The national perspective, however, is not sufficient to bring ocean energy technologies to the market, due to the high investment costs. Access to financial resources from international funding bodies need to be facilitated in order to help the domestic industry players achieve the “critical mass” that would speed up the industrial roll-out of products. The continuous and consistent participation of experts from Mediterranean countries in international initiatives needs to be guaranteed, and their competences and interests adequately represented in EU governing bodies (Communication From The Commission To The European Parliament, 2014; Corsatea, 2014; Magagna and Uihlein, 2015a,b; Ocean Energy Forum, 2016; European Commission, 2017c).

From the point of view of actual implementation constraints, the development of the ME sector can be hindered by conflicts with traditional maritime sectors (e.g., shipping, fishing activities, tourism) that are not always spatially compatible (European Commission, 2015). Potential conflicts clearly exist between marine energy deployment and maritime transport (e.g., increased potential risks to the safety of navigation due to higher traffic density in transit areas and shipping lanes and visual limitations), fisheries (e.g., fishing restrictions in the security zone around energy farms, gear type restrictions for the protection of submarine cables connecting energy farms to the onshore distribution grid, and potential depletion of stocks around individual sites), tourism (e.g., limited access to sea space for leisure purposes and low social acceptance) and environmental protection.

According to the available studies, however, impacts on tourism and leisure activities can be negative, positive or negligible, depending on the implementation phase of the offshore installations. In particular, temporary disruption to the tourism sector is expected during the construction and decommissioning phase of an offshore park, while during the operation phase the main threat to tourism appears to be undesirable visual intrusion, which is worst in clearer air and sunshine. Other impacts can be minimal provided mitigation measures are implemented. On examining whether potential visual nuisances can be compensated by associating reef-recreation to offshore plants or by adopting a coherent environmental policy, a study specifically devoted to installations in a Mediterranean environment indicated that age, nationality, vacation activities and loyalty to holyday destination influence the public's attitudes toward compensatory policies (Westerberg et al., 2015). No data are available for sites of particular historical interest and/or located in particularly beautiful landscapes, which are not always included in officially protected areas. It is to be noted, however, that while disamenity costs decline as the distance from the coast increases, transmission, construction, and maintenance costs typically rise with distance, therefore posing the crucial question of optimal trade-offs in the economics of near shore marine energy plants (Global Insight, 2008).

Residential property values can be negatively impacted by the presence of ME installations due to the disamenity costs of visual impacts, which might be compensated by lower property taxes. The latter, however, would result in lower property tax revenue for the country. In addition, impacts on the tourism sector would affect commercial property values (i.e., summerhouse rentals) in coastal areas (European Commission, 2007).

On the contrary, aquaculture activities are likely to profit from business ventures with the ME industry, provided these are managed on a case-by-case basis, and projects are jointly developed on the basis of adaptive management, rather than separately pursued as sectorial targets (Christie et al., 2014).

Direct positive impacts on local and large-scale economic sectors (e.g., construction, electrical and mechanical engineering, manufacturing activities, marine transport, professional services for the assembling procedures and accommodation services) are also liable to arise during the construction, the operation and the decommissioning of plants, while their operative life would lead to indirect benefits on the local district economy, thanks to the expenditures of the employees and to the continuous demand for local services, including accommodation services. Local taxes could be derived by property and excise taxes paid to the corresponding municipalities by workforce and enterprises during the construction, operation and decommissioning phases, while state taxes would include income and sales taxes paid by workforce and enterprises (Deloitte, 2012). The imposition of corporate, local and regional taxes would cause a corresponding increase of revenues through the direct, indirect and induced increase of GDP and employment.

The uncontrolled coexistence of different sectors competing for alternative uses of sea space is a primary factor of suboptimal economic development and of negative cumulative impacts on the environment. The EU Directive 2014/89/EU on Maritime Spatial Planning, by establishing a framework for the harmonization between environmental legislation, legislation on marine renewable energy, fisheries regulations and the Integrated Maritime Policy, justly aims to set the conditions for the sustainable spatial management and coherent planning of sea areas and for the cross-boundary cooperation of stakeholders and authorities.

CONCLUSIONS

The global energy system is changing, as it faces an ever-increasing demand driven by rising living standards, and the enhanced environmental awareness of civil society. In the power sector the energy mix is being redefined, and renewables largely satisfy the demand growth. Affordable, secure and sustainable energy systems are expected to progressively integrate a variety of diverse energy sources and to substantially rely on distributed generation. The EU Commission proposed a long-term vision to tackle the challenges posed by the decarbonization of the European energy system, and a package of binding policies (climate and energy package) has been implemented and reformed, to overcome distributional obstacles and enable burden sharing among member states.

In this framework, marine energy holds a great potential, although still requiring faster cost reduction. Larger demonstration projects should be facilitated in order to sustain its development from basic and applied research to its final commercial deployment, also to enable a comprehensive assessment of the impact of plants on the environment and on local and regional economies. As a matter of fact, despite the encouraging resource availability and technological development, enabling conditions for the ME sector are still to be created for the Mediterranean area, and the risk that local contingencies might limit the opportunities for development is still to be averted.

The creation of transnational clusters of specialized suppliers and research institutes would definitely contribute to the success of the Mediterranean marine energy industry, by providing tailor-made technological solutions for both the improvement of devices and adequate environmental monitoring. In the medium run, it would support technology transfer and knowledge sharing, and stimulate the development of high-tech and sustainable infrastructures in cohesive investment areas, thus concurring to generate economic growth, to enhance the security of energy supply, to foster competitiveness, and to increase the demand of high-quality professionals in new sea careers. Concerted action between Mediterranean countries would also accelerate the implementation of effective Maritime Spatial Planning strategies, and allow the harmonization of solution and regulations.

In the framework of the European Transnational Cooperation Programme, on-going projects are currently exploring innovative strategies to transform the aspirations of the marine energy sector into operational actions and agendas to be implemented in the Mediterranean region. On the other hand, the Horizon 2020 Research and Innovation Programme provides specific funding for the development of research and roadmaps at the continental level, that can help reach the targets agreed in the EC Declaration of Intent (European Commission, 2017a). Both the on-going and foreseen actions are expected to enhance coordination between Member States and the EC and to sustain the development of a structured path to the gradual implementation and commercial viability of marine energy technologies. The widest possible range of connected stakeholders is expected to be involved in the process, through knowledge and information sharing initiatives, also with the aim of filling the existing gap between Northern and Southern Europe. Technological solutions suitable for the Mediterranean environment could then be exported to North African and Middle East countries, as part of the EU declared intent to cooperate with third countries to meet their EU 2020 targets (Renewable Energy Directive 2009/28/EC).

Constant monitoring and updated mapping of the different activities that are currently being undertaken across Europe is recommended, in order to avoid duplication and realize the full synergy potential of different actors, either sharing high product or market affinities or facing common governance and administrative issues. The optimization of the use of funds for the marine energy sector is also a priority, and financial solutions tailored to the Mediterranean sub-national, national and regional contexts should be envisaged and scaled up as appropriate. Mobilization of investments, both public and private, is imperative to achieve scale and scope. An overall policy framework is therefore needed, that is capable of supporting investment-led development in the area, while balancing the need for attractive risk-return rates with the need for affordable and sustainable energy production. To this end, agreed technical, environmental and financial metrics need to be designed in order to allow the objective comparison of different technologies, and transparency and accountability needs to be guaranteed all along the implementation, operation and decommissioning of plants in the real environment.

The forthcoming years will be crucial in unlocking the potential of marine energy in the Mediterranean, through the cumulative impact of targeted research, continuous support to industrial development and deployment, and the streamlining of administrative procedures and funding instruments.

AUTHOR CONTRIBUTIONS

GP and GS conceived the work. GP wrote the manuscript with support from GS, AC, MS, and AC made the Figures. All authors designed the review and contributed to the final manuscript.

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Experiences in Developing Tidal Current and Wave Energy Devices for Mediterranean Sea

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In the last years, the interest for renewable energies has shown a continuously increasing trend, in search of a convenient and sustainable source alternative to carbon and fossil fuels, also due to government incentive systems, as can be seen for example in the objectives proposed by the EU 2020 target. In such context, marine energy sources are particularly attractive, both for the high conceptual available resource and for some specific technical characteristics, such as a more predictable behavior with respect to other sources like wind energy. The work here presented resumes the experience gained over more than 20 years of activities conducted at Department of Industrial Engineering of the University of Naples "Federico II," in collaboration with research consortium Seapower scrl, in the field of ocean renewable energies. The work refers to several case reports related to different projects in which the research group has been involved. Two main energy sources have been investigated, namely tidal currents, and wave energy, through the development, among others, of two different projects reported in this paper:

- GEMSTAR: a submerged floating tidal current hydrokinetic turbine system (an evolution of GEM turbine)
- PIVOT: a wave energy converter (WEC) based on a pivoting buoy

GEMSTAR is a project which is at Technology Readiness Level (TRL) 7 being the first prototype tested in real field while PIVOT is at TRL 5 since the full-scale prototype has been tested only in controlled environment. In any case both projects are still in development, evolving to more mature technology levels. The article reports the two case studies related to the above-mentioned systems at the present development stage along with the resource assessment of both energy sources in Mediterranean area.

Keywords: tidal current energy, hydrokinetic turbine, floating marine turbines, wave energy, pivoted buoy conversion system

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TIDAL CURRENT ENERGY CASE STUDY: A PRELIMINARY ASSESSMENT ON TIDAL CURRENT ENERGY RESOURCE IN THE STRAIT OF MESSINA

In the last few decades, the technologies to exploit the kinetic energy flux in regions of extreme tidal current provided very interesting results. Several conversion systems have been designed and, in some cases, installed or are undergoing full scale testing in a pre-commercialization stage. The development of "green" offshore power plants is particularly challenging in countries facing oceans where the greatest wave and tidal energy potential is found, but it appears to be still relatively slow in semi-enclosed sea as the Mediterranean. In this context a detailed marine energy assessment becomes a priority, in order to maximize the potentiality of area still economically valuable, but where lower amounts of energy are available (Liberti et al., 2013).

This is especially true for countries like Italy having relatively long coastlines. Nonetheless, in literature, there are only some production estimates for the Strait of Messina, placed in the broader context of the estimation of marine energy resources in Europe.

The choice of the Strait of Messina is very attractive both for the prototypes deployment and for the establishment of production farms of medium and large scale, due to the average high currents and suitable meteorological and oceanographic conditions (see for example El-Geziry et al. (2013), which also indicates possible environmental impacts of marine energy systems). Other locations exhibit less attractive characteristics, such as the lagoon of Venice where lower values of maximum water currents and greater interference with the navigation reduce the cost effective project to develop tidal energy current farms. The channel of Bonifacio, between Sardinia and Corsica, also shows interesting energetic features, but it is less suitable as its severe meteoceanographic conditions and deep waters can cause installation and maintenance issues.

In 2013, a study, summarized in this paragraph, has been performed by Coiro et al. (2013), in cooperation with the Italian research institution ENEA, with the aim to assess an overall estimation of the possible energy potential available in the Strait of Messina. The main purpose of this work was to provide site-specific production estimates associated with the use of marine current energy, considering various possible devices and geometric, environmental, and navigation limits. In this study some simplifying assumptions are adopted. To have comparable estimates of the different tidal current devices, it is assumed that all the deployed units have the same maximum power equal to about 1 MW. Available current information is analyzed to define the average current energy potential and to address the problem of its exploitation. Geometry assumptions have also been conducted, considering that geometry is a strong limit to the tidal farm efficiency and extension. Anyway, such study neglects some specific siting issues (for example eventual presence of obstacles related to device mooring), giving only a general energy potential estimation.

Several tidal energy devices are considered, assuming some performance parameters.

For a device in an open water flow, as discussed later in this paper, the performance can be described with sufficient approximation by a cubic power curve:

$$P = \frac{1}{2}\rho V^3 S C_P$$

where ρ . is the average density of the water, V is the current speed, S is a reference surface and C_P. is the power coefficient, a measure of the efficiency of the current device (Stoddard and Eggleston, 1987).

In this paper, four different current turbines have been considered:

- MCT SeaGen (a);
- Kobold (b);
- GEM (c);
- Verdant Power (d).

For technical specifications of considered devices, refer to Turbine (2012), Coiro and Nicolosi (1998), Coiro et al. (2009), and Reinecke et al. (2011).

In order to have comparable estimates, it was assumed that all the individual units have the same maximum power of 1 MW. The dimensions of the structures were in a first approximation proportionally scaled to the diameter of the turbines. The actual dimensions could affect the density of installation (i.e., the maximum achievable number of turbines per km^2) and therefore the overall production at a given site. The implementation details and the consequences on the feasibility of individual farms were considered negligible in this general production estimate.

In lack of detailed information for all the systems and in order to have uniform assumptions for all the considered devices, an assumption has been made on the electrical conversion efficiency. A total efficiency of the transmission line equal to 80% has been taken into account, as representative for the global electric conversion system (generator, conversion systems, and transmission of energy). Considering the power coefficient, C_P., as representative of the conversion from current kinetic energy to mechanical available energy, the overall efficiencies reported in **Tables 1**, **2** have been considered.

Moreover, some assumptions on space occupation have been made, details are provided in Coiro et al. (2013), and some specific possible installation areas (**Figure 1A**) have been considered, within the Strait zone, taking into account also limitations due to local naval traffic.

TABLE 1 | Power coefficient and total efficiency assumed for the selected current turbines.

Device	Power coefficient	Total efficiency
MCTSeaGen	0.46	0.8·0.46 = 0.37
Kobold	0.30	0.8·0.30 = 0.24
GEM	0.75	0.8·0.75 = 0.60
Verdant power	0.34	0.8·0.34 = 0.27

TABLE 2 | Annual energy production assessment according to selected current turbines-Method of farms.

Device	Density (unit/km^2)	Power (MW)	Annual energy (GWh)
MCTSeaGen	40	263.2	175.0
Kobold	36	150.1	100.2
GEM	23	235.2	155.2
Verdant power	16	103.1	67.9
Mean annual production			124.6

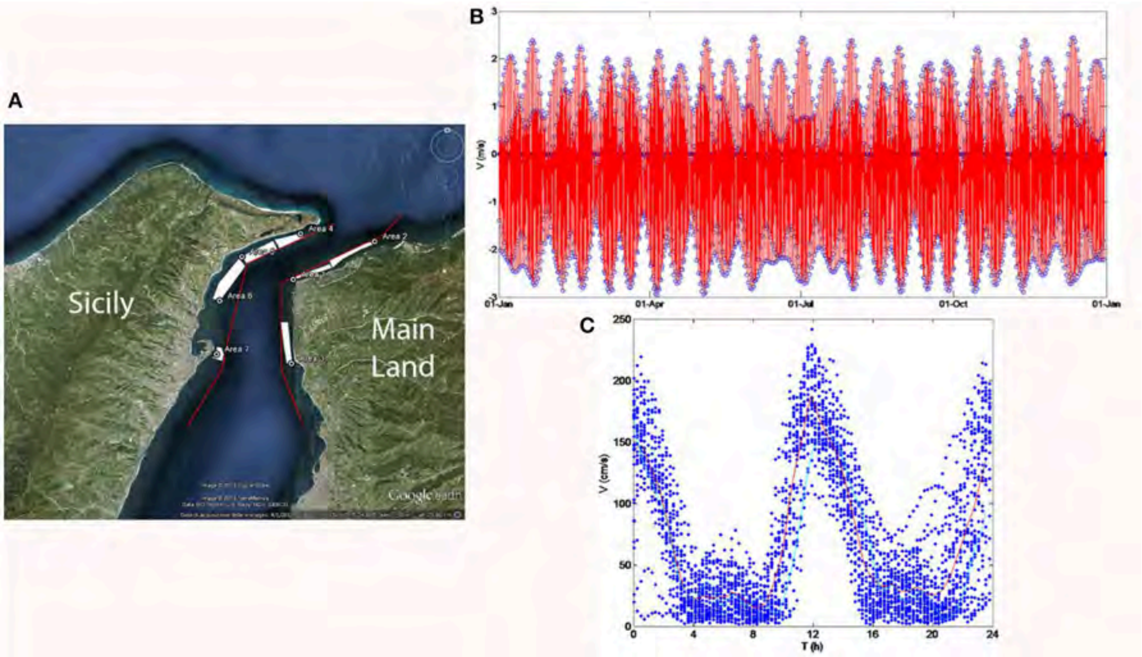


FIGURE 1 | Strait of Messina installation areas **(A)**. Typical yearly time history of current velocity **(B)** and superposition of several daily current speed profile highlighting a daily peak sequence pattern **(C)**. Data are related to two different sites of the Strait: **(B)** reference site *Punta Pezzo*, **(C)** lower speed site *Punta S. Raineri*.

With all the above indicated assumptions, an estimation of the overall energy, potentially available for the different considered devices, has been obtained.

Tidal Current Estimation

Production assessment is generally based on site-specific current measurements. Design data for the present analysis were based on the tide tables of the Strait of Messina, for the year 2004 (Marina, 2003). In general tide tables are referred to a specific reference site where information is provided on slack water and maximum expected currents (both flood and ebb). In particular, the reference location for the Strait of Messina is Punta Pezzo (38°14′00″N; 15°38′ 00″E).

From the available data it was possible to reconstruct the time series of current magnitude at Punta Pezzo throughout the year, as shown in **Figure 1B**. For a more detailed current prediction and consequently power assessment, data related to the peaks and to the calm have been interpolated, adopting an hermitian cubic interpolation to preserve the shape. A typical pattern is evident in the area, formed by the succession of semi-diurnal cycles, with approximately monthly variation of the local peaks. In particular, four peaks happen per day with two direction inversions. The peak speeds vary throughout the year according to typical luni-solar tides but the current is always slightly higher in the descending direction (from Tyrrhenian Sea to Ionian Sea).

Assuming Punta Pezzo as the reference site, it is possible to determine tidal time (slack and maxima) and peak values in some secondary locations of interest. In particular, it is possible to assume a linear relationship as

$$V' = V_0{}' + rV_c$$

where V' is the velocity in the secondary location, V_c is the velocity at the reference site, r is an appropriate site-dependent scaling factor, $V_0{}'$ is an empirical offset. Admiralty tide tables give the local peak current speed in some known secondary locations, assigning the related correction factors (Vercelli, 1925).

Furthermore, on-site current measurements may provide information at additional locations. In particular a SonTek Argonaut XR ADCP was installed at a water depth of about 20 m (**Figure 1C**), from the 17th of March to the 20th of April 2010, in proximity of Punta S. Raineri (Messina). These data have been assumed representative for Villa San Giovanni and S. Raineri site, where information was missing from Marina (2003). In general, two main daily peaks are present.

Using the reported data, it was possible to derive near surface peak velocity at secondary locations.

The Method of Farms

Among the possible approaches to available potential estimation, in this study the so called method of farms has been considered.

With the method of farm, the productive potential of a site occupied by several devices is assessed by the occupation density dependent on the overall dimensions of the system as assumed in the present work.

From a practical point of view, it is assumed that farms are installed in feasible areas of limited size not too far from the coast, to avoid interference with naval operations and in order to facilitate installation and maintenance operations. The bathymetric contour line of 50 m is taken as the minimum achievable water depth for the installations. This depth, in reality, is characteristic of each specific system and such value has to be considered as a first guess only. The maximum water depth at the site is also a limiting factor, related to the complexity of installation and operation. Increasing the depth of the site means increasing the installation and maintenance costs. In the present study we assumed an indicative maximum limit of 150 m water depth.

Table 2 shows the potential production rate, obtained by adding energy production for all the suggested areas of installation, under the above stated assumptions and with rated power rescaled to the value of 1 MW to obtain comparable results. The estimated results are only a fraction of the total theoretically energy available in the current, as a consequence of the restriction to plant space occupation imposed in order to comply with practical operational constraints.

All the considered devices show promising results, at least according to available data. However, the specific cost of the selected turbines should be carefully evaluated. The cost can be significantly different between one system and the other regardless of their production capacity. In particular, the cost of installation and maintenance must be taken into account as well as any possible impact on navigation and fishing. In other words, the final criteria to select a tidal turbine with respect to another, for the installation in a specific site, are driven by factors that can totally reverse the order of choice due to the mere criteria of the energy production assessment. Detailed knowledge of production units and their characteristics, as well as a preliminary current assessment in the specific installation site are necessary for final evaluation.

TIDAL ENERGY CASE STUDY: GEMSTAR, SUBMERGED FLOATING HYDROKINETIC TURBINES

GEMSTAR System Configuration

GEMSTAR system is an evolution of GEM system but, in what follows, we will also refer to the original GEM system. It is composed by a tethered floating structure, supporting two hydrokinetic turbines, with the ability of self-alignment with current stream. It may be equipped with a self-towing winch, which is capable of setting the desired operating depth. Operating underwater, it has a limited impact on navigation. The system is moored at a single point on seabed, allowing the rotation of the floating structure in response to current direction change and may reduce maintenance cost and simplify deployment operations: by releasing the winch mooring cable, the system may be raised at surface for easier maintenance. A CAD drawing of the GEM configuration is shown in **Figure 2**.

The system is sustained by the buoyancy provided by a streamlined axial-symmetric floating body, placed at the top of the structure. Stability and oscillation damping are improved by means of tail fins mounted on the floating body. Two generators are installed on board and mounted on the turbines shafts through a gearbox. Each generator is electrically controlled by an inverter, both for grid connection purposes and in order to attain optimal working conditions at different current speed. Suitable control logic is also needed to pursue optimal operating conditions. The power connection is provided by means of a power cable, passing along the mooring cable and extended up to an on-shore grid connection point.

The three bladed rotors have been developed at the University of Naples and designed to reach a high efficiency in a relatively wide operating conditions range, using a properly designed airfoil section shape to avoid cavitation. The turbines have been intensely tested both in wind tunnel and towing tank experimental campaigns. In a possible configuration a diffuser, also developed at the University of Naples, is placed around each turbine with the aim of enhancing the energy conversion process by increasing the mass flowing though the turbine swept area. After further investigations, a solution with bare turbines (without diffusers) will be considered in the next GEMSTAR device for a cost effective implementation of the system.

The development of the system started in 2005 and, after preliminary numerical analyses and design work, many experimental tests have been performed on different systems characterized by different scales. In 2005 tests were performed on the bare rotor turbine model with 1.2 m diameter. Coiro et al. (2006). Bare and shrouded turbine performances were compared after a series of tests performed in in the years from 2008 to 2010 (Coiro et al., 2009). The complete floating system was tested in two test campaigns on a 1:20 scaled model (2010) and on a 1:8 scaled model (2011) (Scherillo et al., 2011). A full-scale prototype with 3 m diameter rotor was manufactured, deployed and tested in 2012 (Coiro et al., 2012).

The main results of the experimental test campaigns, performed at different project stages, are reported in the following paragraphs.

Bare and Shrouded Turbine Experimental Tests

In order to characterize the behavior of the system in different operating conditions, experimental tests were performed in the towing tank on isolated turbine as well as on two different scaled model of the full GEM system. A first experimental campaign was carried out on a single isolated, reduced-scale hydro-turbine – which is the main component of the GEM system—with, and without a shroud. In fact there have been a large number of papers regarding shroud effect on bare turbine, see for example (Igra, 1981; Van Bussel, 2007; Polagye et al., 2011; Shives and Crawford, 2011) but a real and complete cost-effective analysis has probably never been performed.

After a first set of tests performed in air in the wind tunnel facility of the Department of Industrial Engineering of University of Naples, a second session of experimental tests has been completed in the towing/wave tank belonging to the same Department and the experimental results will be reported in the following paragraphs.

General Definitions

Prior to presenting tests data, some useful definitions of dimensionless quantities are recalled here. These coefficients are widely used further in this paper to discuss about the power generation system characteristics of the GEM.

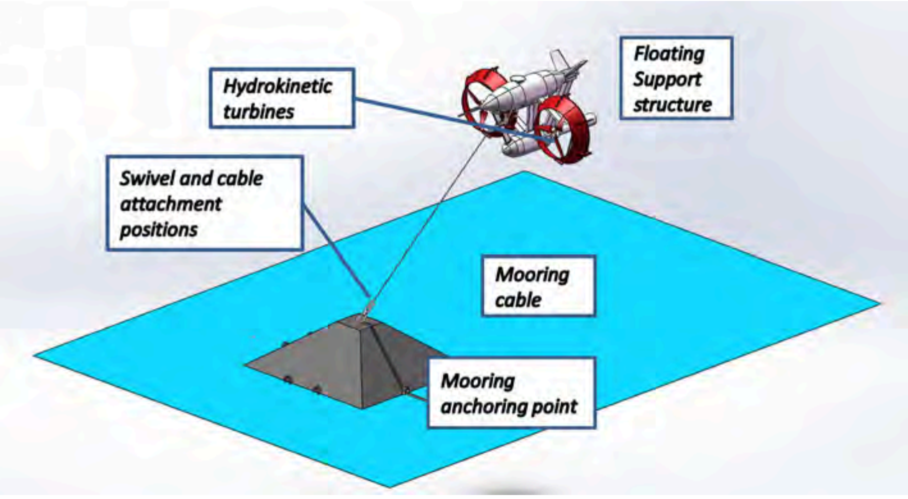


FIGURE 2 | Schematic view of GEM configuration.

In general, a turbine is a device that works at a given rotational speed Ω when immersed in a fluid stream of speed V. The desired effect is the establishment of a torque Q that keeps the blades in rotation and brings about the generation of a mechanical power

$$P = Q\Omega$$

An important state variable of the turbine is the Tip Speed Ratio $TSR = \Omega R/V$, i.e., the tip speed ΩR non-dimensionalized with respect to the current speed *V, R being the turbine radius*. The power coefficient (or turbine's efficiency) is defined as

$$C_P = P/(0.5\,\rho V^3 A)$$

where P is the power generated (measured or estimated), V is the asymptotic speed of the fluid stream (in this case, the steady-state traveling carriage speed), A is the area of a reference surface, and ρ is the water density. Similarly, the torque coefficient is defined as

$$C_Q = Q/(0.5\,\rho V^2 A\,R)$$

where Q is the torque (measured or estimated), at the turbine hub. Finally, the thrust coefficient has the following expression:

$$C_T = T/(0.5\,\rho V^2 A)$$

where T is the turbine thrust, that is the axial force developed by the device immersed in the flow and functioning at a given TSR. The area A in the above definitions is always taken coincident with the bare rotor disk surface area, both for the bare turbine and for the diffuser-augmented one. This is important when comparing performance of different solutions in terms of efficiency.

Model Set-Up

Support structure and actuation system

An initial test campaign has been performed on a single isolated turbine to characterize the behavior of the power conversion system prior to the installation on the floating system. The turbine was mounted on a submersed pole connected to the towing tank carriage by means of a support structure capable of placing the turbine shaft at the desired depth. During tests the towing cart was operated at a constant speed simulating a given relative current, the turbine shaft was actuated by a controlled motor in order to achieve the desired rotational speed and operating conditions.

The assembly consists of a hollow tubular steel mast of length of 2.46 m whose circular section has an external diameter of 114 mm and inner diameter of 108 mm and it could rotate around its axis in order to test the device with a fixed yaw angle respect to the oncoming water current. A frame built by several welded tubular square sections fixes the tubular mast in a vertical position.

Measurements have been made using a torque-meter of 226 Nm (2,000 lbf-in) of full scale range, with an accuracy of ±0.1% FS. Also, a load cell with 5 kN FS was installed at the end of the transmission shaft to measure compressive or traction loads produced by the rotor. A ducted turbine configuration, i.e., with a diffuser (shroud) placed around the turbine, has been developed and tested in order to study the possible increase in conversion efficiency. Basically, the shroud is an annular diffuser with a streamlined cross section. A high lift airfoil has been used for the cross section shape of the shroud.

A controlled motor is set up to control the desired rotational speed, a torque-meter measures the turbine torque, and load cells measure separately the axial forces experienced by the turbine and by the diffuser immersed in the flow.

Figure 3A represents a picture of the test set-up installed in towing tank, with the support structure for the shrouded turbine

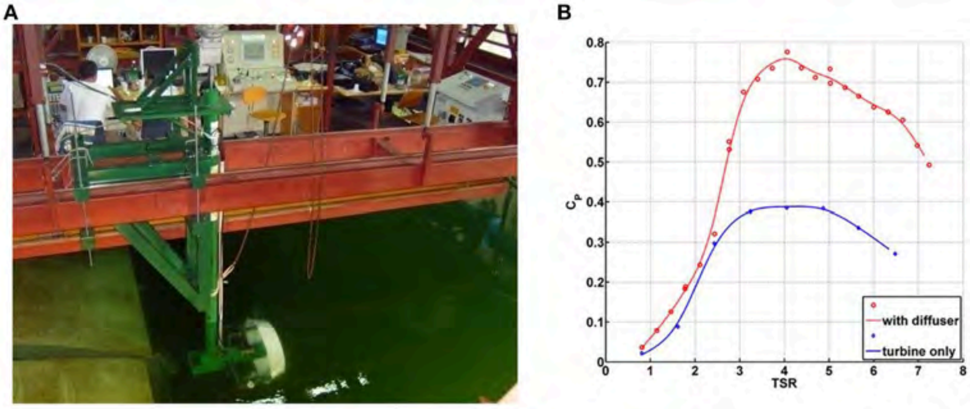


FIGURE 3 | Single turbine test system mounted on towing tank carriage **(A)**. Power coefficient for single isolated turbine. Comparison between bare and ducted turbine ($\phi = 26^\circ$). Relative speed 2.0 m/s **(B)**.

able to rotate around its vertical axis to test the device in both axial and yawed flow conditions.

Shroud and turbine geometry

The shroud is realized as an axially symmetric revolution body generated by an airfoil shape set to a proper inclination angle. A characteristic angle associated to the shroud geometry is the angle ϕ formed by the chord of the airfoil-shaped annular cross section of the shroud (taken with a radial plane) and the turbine axis. Two geometries of streamlined shrouds have been tested; these geometries had the same annular cross section, i.e., the same airfoil shape, but with different airfoil chord angles, $\phi = 23^\circ$ and $\phi = 26^\circ$, respectively.

The tested turbine had a diameter of 0.6 m and a chord length of about 0.05 m at 75% radius span and was coupled in some tests with a shroud. In the case of the shroud with maximum inclination angle (26°), an exit diameter of 0.812 m was used. The diffuser throat section was slightly larger than the turbine disk (0.62 m diameter).

Tests on single turbine

Power coefficient. The main results of the tests on the turbine are reported in terms of non-dimensional coefficients. Preliminary numerical and experimental results show that, between the two considered shroud geometry the most effective in terms of power coefficient increase is represented by the configuration with higher section angle $\phi = 26^\circ$. Such shape has been considered for further analyses and tests. It is worth to specify that blade pitch angle has been kept always fixed without any attempt to optimize its value in order to increase the maximum efficiency, since the main goal of the tests was the investigation on diffuser installation effect on bare turbine performances. The Reynolds number, based on airfoil chord and on relative airfoil velocity, shows a significant variation across the operating test range, mainly due to the variation of rotational speed. For a flow velocity of 2.0 m/s, assuming a reference chord length equal to the blade chord at 75% radius span, the Reynolds number of the representative blade section spans the approximate interval between 1,20,000 and 7,30,000. The effect of the diffuser on turbine apparent efficiency over the whole range of *TSR*'s is shown in **Figure 3B**. The maximum power coefficient reaches an almost double value with respect to the case of bare turbine. **Figure 4A** reports the effect of yaw misalignment on C_P, clearly showing a reduction of conversion efficiency at increasing yaw angle.

It may be noted that the apparent value of the C_P exceeds the Betz limit, with the assumed value of the reference area (turbine disk area). If the exit area of the diffuser is used as reference for the definition of power coefficient, the maximum value is limited to a lower value.

Thrust coefficient. A comparison of thrust coefficient plots vs. TSR is reported in **Figure 4B**. They are relative to different turbine configurations (bare rotor, ducted rotor with $\phi = 23^\circ$, ducted rotor with $\phi = 26^\circ$). The values of C_T are relative to the thrust acting on the rotor only. These data are consistently evaluated by taking the reference area A as the frontal area of the bare rotor disk. It is observed that in presence of the diffuser the rotor features a sensibly higher thrust coefficient with respect to the bare rotor case. This experimental result does not agree with the hypothesis made in some studies reported in literature (see for example Van Bussel, 2007), who claims that the thrust on the rotor remains the same even if it is ducted, but the observed power performance increment, on a ducted turbine, is essentially due to the extra mass flow through the rotor. However, further investigations and validations of numerical and experimental analyses may be useful on this topic.

For the design of GEM system, the estimation of thrust acting on the diffuser supports has also an important role. The diffuser only thrust coefficients (C_{Ts}), referred to the swept area of the rotor [$C_{Ts} = T_s/(0.5\, V^2 A)$], have been measured and estimated as function of *TSR* for two shrouded turbines with different diffuser geometries ($\phi = 23^\circ$, $\phi = 26^\circ$). It is observed that the diffuser thrust coefficient reduces almost linearly with increasing *TSR*. For the 23° shroud, C_{Ts} varies across the explored TSR interval, ranging from a value of about $C_{Ts} = 0.92$ at TSR $= 0.8$, to a value of $C_{Ts} = 0.66$ at TSR $= 5.7$. Such behavior may be due

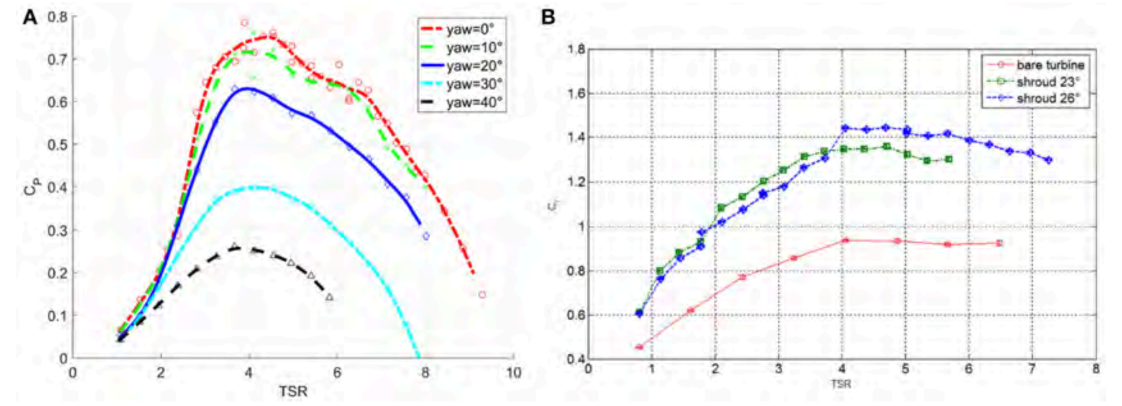


FIGURE 4 | Effect of yaw misalignment on ducted turbine ($\phi = 26°$) on measured power coefficient. Current speed 1.5 m/s **(A)**. Comparison of measured rotor thrust coefficients for 3 different configurations (bare rotor, ducted rotor with $\varphi = 23°$, ducted rotor with $\varphi = 26°$). Current speed 2.0 m/s **(B)**.

to a flow reattachment on the diffuser inner side promoted by the turbine induced flow. A similar trend may be observed for the 26° shroud configuration, with higher C_{Ts} values, ranging approximately from $C_{Ts} = 1.12$ at TSR = 0.81 to $C_{Ts} = 0.78$ at TSR = 7.2.

An important observation, from the design point of view, is related to the significant increase in thrust on the turbine-diffuser assembly with respect to the turbine only configuration.

Tests on full model in small scale

GEM tethered model set-up. In this section the main results of towing-tank tests on a reduced-scale model of the entire GEM system are presented. These tests were mainly aimed at characterizing the steady-state conditions and the related power production performance, and to study the stability and the dynamic behavior of the whole scaled system in different possible operating conditions; for example, some off-design conditions were also examined, such as those caused in real situations by an abnormal shut-off of one turbine.

In the GEM system design two counter-rotating turbines are mounted at the sides of the main floating body. The model used in the tests is scaled by 8 times with respect to a possible real-scale installation of the GEM, and is shown in **Figure 5A**. It consists of a floating submerged system made up of two bodies: the upper body serves to produce the necessary buoyancy force, while the lower body accommodates instruments and auxiliary devices. The upper body is also equipped with two fins forming an angle of 45° with the longitudinal plane of symmetry. A "V tail" configuration has been used for the tailplanes with the aim to improve the necessary lateral stability of the system and to allow the regulation of the body's pitching trim at stabilized advancing speeds, while reducing the possible interference with turbine wake. Different tail configurations have also been tested throughout the campaign.

The GEM scaled test model had an overall length of 3.55 m with a turbine axes distance of 1.13 m and an height of 1.84 m. At zero carriage speed the turbine axis was set at 1.65 m below water surface, while the final axis depth is dependent on carriage speed; a schematic of the forces acting on the system is illustrated in **Figure 5B**. The tethering cable arrangement in steady flow is an important aspect of the tested device. In the towing tests, an immersed steel frame structure fixed with the running carriage simulates the seabed single-point anchorage (represented by point A in **Figure 5B**). The model is connected via the cable to the running anchorage point. A winch located in point A allows to release or to tighten the cable and, consequently, to position the model at the desired depth in the tank.

Characterization of the submerged tethered system. During the tests, the following data are monitored and measured:

(i) Torque and angular velocity of the left-hand-side turbine, from which the total output power is estimated, assuming symmetrical operating conditions;
(ii) Mechanical tension on the tethering cable, measured by a dedicated load cell;
(iii) Trim of the GEM system with respect to a reference frame fixed to the tank floor, by means of an inertial platform.

As seen from the schematic shown in **Figure 5B**, in steady-state condition, the equilibrium is guaranteed by the cable tension force T_C, the net buoyancy B (buoyancy force minus weight), and the total horizontal force F_H.

Based on the cable tension load and on the knowledge of the buoyancy, the total horizontal drag developed by the whole system may be estimated, which in non-dimensional form is expressed by the total resistance coefficient:

$$C_D = \frac{F_H}{\frac{1}{2}\rho V^2 S_{ref}}$$

where S_{ref} is a properly chosen reference area. For this application the assumed reference area is $S_{ref} = 2\,A$, i.e., twice the turbine disk area. The cable traction T_C balances the vector sum of total drag F_H and the buoyancy B.

Experimental values of power and torque coefficients plotted vs. TSR are shown in **Figures 6A,B**, respectively. While the data

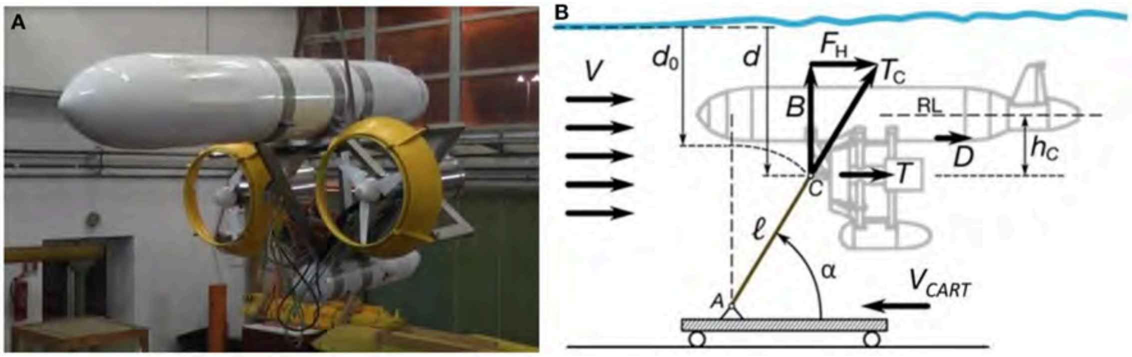


FIGURE 5 | The GEM reduced-scale model tested in the towing-tank. Scale 1:8 **(A)**. Schematic of the GEM system in a steady-state condition, immersed in a current V (due to the advancing carriage speed V); the equilibrium involves the cable tension force TC, the buoyancy B, and the total horizontal force FH **(B)**.

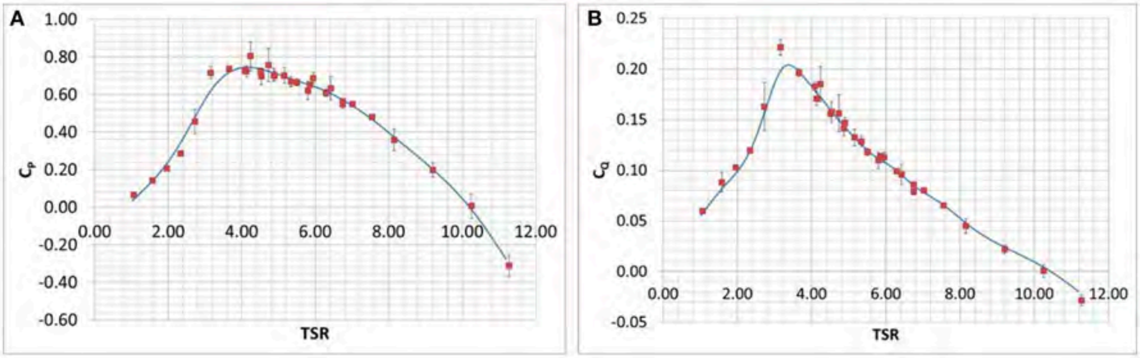


FIGURE 6 | Measured power coefficient averaged values. Turbines with shrouds, V = 1.5 m/s **(A)**. Measured torque coefficient averaged values. Turbines with shrouds, V = 1.5 m/s **(B)**.

in **Figure 3B** are relative to a single isolated turbine, the latter graphs are referred to the complete small-scale GEM model. In the same figures, fitting curves of C_P and C_Q are also reported. The scattered values of C_P and C_Q are extracted by averaging from the power and torque measured signals sampled at a frequency of 500 Hz, for different constant rotational speed of the turbine rotors and at a fixed towing carriage speed $V = 1.5$ m/s. The uncertainty levels indicated on these plots are taken as three times the standard deviation of the sampled values. The two plots reveal that the maximum non-dimensional torque, $C_{Q,\max} = 0.22$, occurs at a value of $TSR = 3.15$, which, as expected, is not the same TSR at which the maximum C_P occurs.

The maximum efficiencies of (reduced scale) GEM, measured in the two cases of shrouded and bare turbines, have been compared, considering the values of TSR at which the maxima occur as well. An approximate maximum C_P value of about 0.4 has been observed for the bare turbine at $TSR = 4.0$, while the shrouded turbine showed a maximum C_P of about 0.74 at $TSR = 4.17$.

Although a high scattering of test data may be observed, the data obtained from the GEM scaled model tests seem to confirm the results obtained for the isolated turbine, that is, the presence of diffusers nearly doubles the maximum efficiency. It has to be noted that, due to data scattering, some difficulties are encountered in the estimation of the optimal C_P and TSR.

Full Scale Prototype Tests

Experimental tests were carried out on a full-scale GEM prototype, designed to produce 20 kW of power at a nominal current speed of 1.5 m/s. During the field tests, GEM off-design operating conditions have been measured as well. This prototype has been developed, built and installed in a test site in the Venice Lagoon, Italy. The test campaign was supported partially by a consortium of companies operating in the Italian Veneto Region and partially by the Veneto Regional Authority.

Test Plant Configuration

Prototype general data

The first prototype has been installed in the Venice lagoon, near Forte Sant'Andrea, with a seabed depth of about 25 m. The system operated at a depth of about 15 m. In **Figure 7A** a picture of the large-scale prototype is reported. Operational characteristics and other features of the system are summarized in **Table 3**.

Starting from the information gathered in the preceding research steps, a prototype plant was designed and built-up with the objective to operate in a site with 1.5 m/s speed, generating

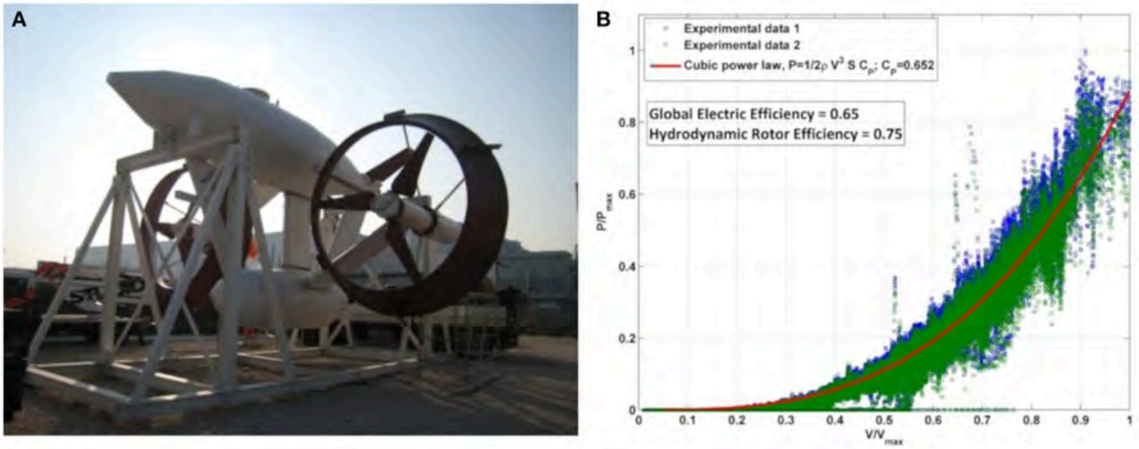


FIGURE 7 | GEM large scale prototype **(A)** and measured total electrical output power (normalized with respect to maximum measured power) vs. normalized current speed **(B)**.

TABLE 3 | GEM prototype geometrical data.

Turbine diameter:	$D_t = 3.08$ m
Diffuser throat diameter:	$D_g = 3.10$ m
Diffuser exit area diameter:	$D_e = 4.08$ m
Overall length:	$L = 9.2$ m
Overall height:	$H = 5.2$ m
Overall width:	$S = 10.4$ m
Weight:	(Overall weight including ballast weight) $W = 16{,}100$ kg (Steel/composite structure only) $W = 10{,}700$ kg
Net buoyancy force:	$B = 51{,}000$ N
Horizontal thrust (on the overall system estimated at 1.5 m/s):	$T = 45{,}000$ N
Working rotational speed:	(Turbine shaft at 1.5 m/s) $\Omega = 38$ rpm

a nominal total power of 20 kW, with a depth operating range between about 9.8 m (without current) and about 15 m. The turbine has a diameter of 3.08 m, with about 7.45 m^2 swept area for each rotor. The adopted manufacturing solution uses carbon-fiber for the turbine blades and of glass-fiber for the diffuser and for the tail-planes, while steel structures are used for the floating body and the connection frame. Turbine blades and diffuser design are based on the results of previous aerodynamic research studies.

Measurement equipment and main observed data

The GEM system full-scale prototype has been equipped with a set of devices for measuring several operating parameters: mainly, system trim and generator power production data. The data have been recorded onboard and transmitted via radio to a remote server. An acoustic speed sensor (ADCP) was installed in proximity of the GEM mooring point in order to measure current speed (the mooring point is about 25 m below the free water surface and its horizontal distance from the GEM). This device allowed the reconstruction of the whole velocity profile of the current, from seabed to water surface.

During the tests, the GEM sideslip (or yaw) angle β, i.e., the rotation angle around the GEM vertical axis, the current direction δ with respect to the North, and the averaged actual current speed measured by ADCP were acquired.

Power production results

The power production has been measured for both installed turbines. In **Figure 7B** the total measured power is reported vs. the measured speed, in order to determine the device power curve. These data are relative to a single cycle of constant incoming flow direction, i.e., when the current flowing direction δ is almost constant. The data in **Figure 7B** are non-dimensionalized using the maximum value of velocity observed during a single cycle (V_{max} is about 1.35 m/s, slightly lower than the device rated velocity of 1.5 m/s) and the maximum measured power for a single turbine. The test campaign presented many challenges and the data show a rather wide dispersion. Data dispersion is also partially due to a number of trials performed to set up and optimize the maximum power tracking control procedure.

A binning procedure has been used in order to better analyze the power performance: it consists in dividing velocity and power measurements into small intervals (bins), for each bin an average value of velocity and power can be extracted. Thus, power production data are grouped into velocity bins over which an arithmetic mean has been performed. This is the same procedure used for determining wind turbine power curve.

A rough estimation of global power coefficient may be obtained by comparison between cubic and binned curves: the maximum overall power coefficient $C_{P\ max}$ is within the range

$$C_{P\ max} = 0.6\ \div 0.65$$

also including mechanical and electrical efficiencies, i.e., efficiency from water current to electrical wire.

Consequently, supposing a generator efficiency of approximately 0.9 and a mechanical gearing efficiency of about 0.9, it can be claimed that, approximately, the shaft power coefficient is within the range $0.76 \div 0.8$, which is in good agreement with previous model towing tank testing.

Tests have proven the suitability of the system to operate in nominal conditions and the capability to convert efficiently the energy of the flow in mechanical and electrical energy. In particular, the use of ducted diffusers with rotor shroud of optimized shapes has proven to augment power generation capability with respect to the simple bare turbine solution. Nonetheless increased structural complexity and higher thrust levels due to the installation of diffusers have to be accounted for, in the overall evaluation of the shrouded configuration. This has led to GEMSTAR, second generation of GEM, in which, among other evolution, the diffusers have been removed for a cost effective installation to reduce the Levelized Cost of Energy (LCOE).

The full scale tests on a GEM prototype seem to prove the feasibility, reliability, stability and efficiency of the system. Further research studies will aim to the development and validation of an accurate simulation model capable to design a GEM system for higher rated power. Three hundred kilowatt GEMSTAR prototype will be deployed in Messina Strait in 2020.

WAVE ENERGY CASE STUDY: PIVOT, PIVOTING BUOY WAVE ENERGY SYSTEM

A second test case is considered in relation to possible marine energy exploitation in the Mediterranean area: a wave energy converter, named PIVOT, based on a pivoting buoy. In principle such kind of device may be adapted to the integration with different types of PTOs. In the actual development of the system it has been integrated with a linear PTO based on the recirculating ball-screw technology developed by Umbra Group s.p.a., a world leading producer of bearings, ball-screw systems and electromechanical actuators.

In the field of wave energy, a number of different solutions has been presented. The presented device may be classified as a wave actuated body oscillating under wave action around a fixed hinge. Several research activities have been presented in literature on similar topics. The subject of wave actuated bodies has been extensively studied in literature. Point absorbers in heave, for example, represent a common type of wave energy converter (WEC) and many analytical studies (see for example Falnes, 2002) as well as numerical and experimental researches have been reported (see for example Vantorre et al., 2004; Hager et al., 2012). The concept and modeling of hinged WECs has been explored for example in Marquis et al. (2010), Hansen and Kramer (2011), Hardisty (2012), and Ionescu and Ngwenya (2014).

A Preliminary Resource Assessment

Several analyses about wave energy resource on the Italian coastal areas may be found in literature. For example, Iuppa et al. (2015) reports a survey of some site along the Sicilian coast. Here, a brief survey of some results is reported in relation to a site investigated for the study of a possible installation of the system in an on-shore configuration.

The site location is close to Civitavecchia port on a breakwater structure. Available data for the assessment are obtained by a numerical model for wave climate estimation (Bargagli et al., 2011). Data were supplied by the Italian research institution ENEA.

Available data report, with a 3 h sampling interval, the time histories of the following wave climate characteristics, which represent the sea state conditions:

- Significant height, H_s (m)
- Peak Period, T_p (s)
- Mean Period, T_z (s)

Time histories data of the measured quantities are available over an observation period of 10 years (2001–2010).

An overall scatter matrix, which reports the occurrence frequency of a discretized set of sea states as a function of significant wave height and peak period, may be obtained by post-processing time histories data (**Figure 8**).

System Operating Principle

The system consists in a point-pivoted buoy that is put in oscillation by the incoming waves. The buoy is hinged through supporting arms to a fixed structure. Another hinge, placed on the oscillating arms, provides the connection with the ball screw based electro-mechanical generator, in such a way to allow generator rotation according with the buoy oscillation. The rotational motion of the pivoting buoy is transformed into the translational motion transferred to the PTO. The PTO, by means of a ball-screw mechanism, transforms the linear motion of the piston in the rotational motion acting on the generator. The ball-screw mechanism and the generator are integrated in a whole device.

A schematic representation of the operating principle of the system is reported in **Figure 9A**.

Numerical Model

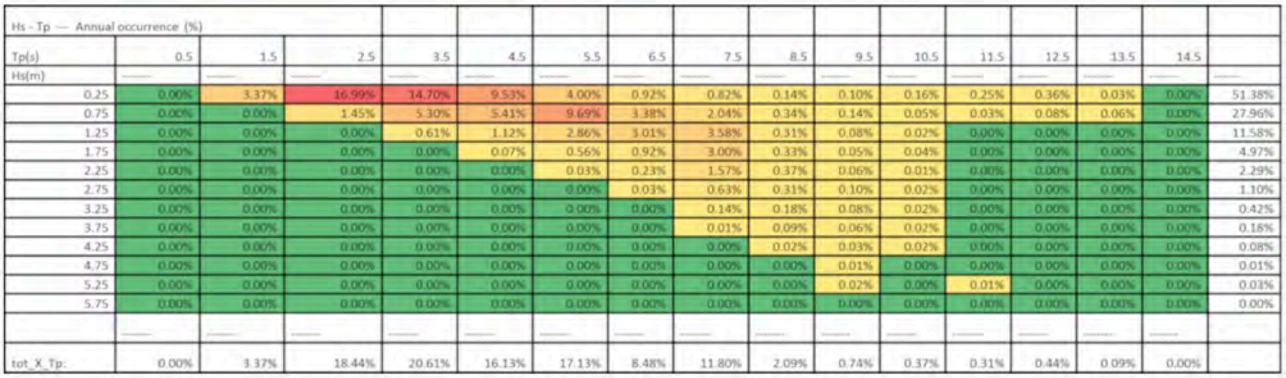
A numerical model based on potential flow theory has been developed, using existing computational codes, in order to analyzed the wave-body interaction in the examined cased.

The dynamic behavior of the system may be described to a first order of approximation by the use of a simple equivalent 1DOF equation that represents the equilibrium of moments around the hinge axis:

$$I\ddot{\theta} = M_{ext} + M_{rad} + M_0 + M_{PTO}$$

where:

- I is the rotational inertia around the hinge axis accounting for the hydrodynamic added mass also;
- M_{ext} is the external moment due to waves excitation forces (diffractive and Froude-Krylov forces);
- M_{rad} is a term accounting for the radiation force, which should be corrected for viscous contribution;



Hs - Tp — Annual occurrence (%)																
Tp(s)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	
Hs(m)	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——
0.25	0.00%	3.37%	16.99%	14.70%	9.53%	4.00%	0.92%	0.82%	0.14%	0.10%	0.16%	0.25%	0.36%	0.03%	0.00%	51.38%
0.75	0.00%	0.00%	1.45%	5.30%	5.41%	9.69%	3.38%	2.04%	0.34%	0.14%	0.05%	0.03%	0.08%	0.06%	0.00%	27.96%
1.25	0.00%	0.00%	0.00%	0.61%	1.12%	2.86%	3.01%	3.58%	0.31%	0.08%	0.02%	0.00%	0.00%	0.00%	0.00%	11.58%
1.75	0.00%	0.00%	0.00%	0.00%	0.07%	0.56%	0.92%	3.00%	0.33%	0.05%	0.04%	0.00%	0.00%	0.00%	0.00%	4.97%
2.25	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.23%	1.57%	0.37%	0.06%	0.01%	0.00%	0.00%	0.00%	0.00%	2.29%
2.75	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.63%	0.31%	0.10%	0.02%	0.00%	0.00%	0.00%	0.00%	1.10%
3.25	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.14%	0.18%	0.08%	0.02%	0.00%	0.00%	0.00%	0.00%	0.42%
3.75	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.09%	0.06%	0.02%	0.00%	0.00%	0.00%	0.00%	0.16%
4.25	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.03%	0.02%	0.00%	0.00%	0.00%	0.00%	0.08%
4.75	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
5.25	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.00%	0.01%	0.00%	0.00%	0.00%	0.03%
5.75	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	
tot_X_Tp:	0.00%	3.37%	18.44%	20.61%	16.13%	17.13%	8.48%	11.80%	2.09%	0.74%	0.37%	0.31%	0.44%	0.09%	0.00%	

FIGURE 8 | Wave scatter matrix for a Tyrrhenian sea site, near Civitavecchia, derived from sea state time histories (2001–2010, ENEA numerical model).

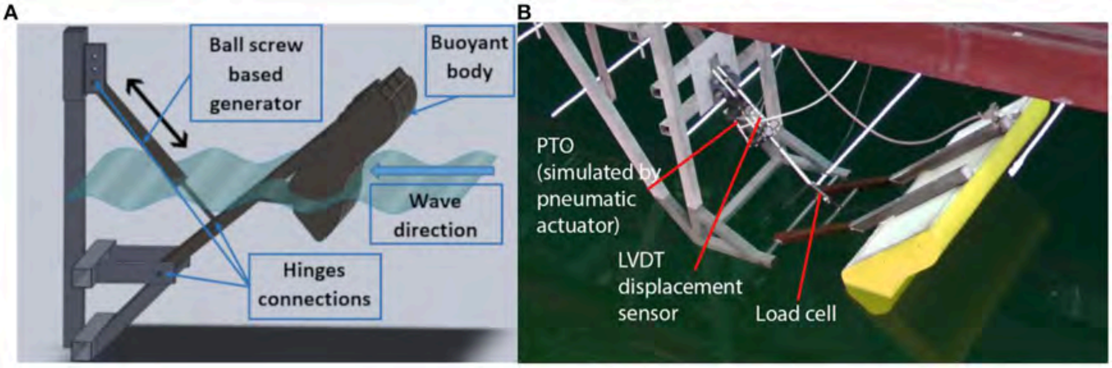


FIGURE 9 | PIVOT WEC system operating principle **(A)**. PIVOT WEC system small scale test model set-up **(B)**.

- $M_0$is a term related to hydrostatic stiffness;
- M_{PTO} is the moment due to the point pivoted power take-off device (PTO);
- θ is the inclination angle of the support arm of the body.

The definition of the radiation and excitation terms are related to a classical approach to the wave-body interaction problem, based on potential flow theory. Using such diffused approach, the simulation of wave-body interaction is decomposed in the solution of different boundary value problems, assuming that a superposition principle may be applied. The potential solution is written as the sum of different terms: (a) the undisturbed wave field (related to Froude-Krylov forces), (b) the perturbation field due to the presence of the body (related to diffraction forces), (c) the radiation field due to the wave radiated by the body motion in a steady free surface (related to radiation forces expressed in terms of added mass and radiation damping). Each problem is solved separately with its own boundary condition. Some details may be found in Berteaux (1976) and Faltinsen (1990). The solution procedure is based on a boundary elements method, which allows obtaining the hydrodynamic coefficients to define each of the contribution to the wave-body interaction forces. A time domain solution is further performed to solve for the effective dynamic response of the system.

A suitable control system has to be implemented in the PTO device, in order to ensure that the force response of the device comply with a given control law. The selected PTO system was controlled so as to produce a force response proportional to velocity variations, according to the following relation:

$$F_{pist} = KV_{pist}$$

where K is an adjustable gain, F_{pist} is the PTO force acting on the oscillating piston of the PTO, and V_{pist} is the elongation velocity of the piston. The gain coefficient K may influence the overall behavior of the system in response to wave action and may affect power conversion performances. F_{pist} defines the contribution of the PTO to the dynamic equilibrium of the system.

The model takes into account only the shaped buoy, neglecting the effect of the oscillating support arms.

Test on Reduced Scaled Model

In order to better understand the physical behavior of the system a set of tests have been performed on a scaled model of the system, in an approximately 1:5 scale ratio with respect to expected larger scale prototype. A picture of the model set-up is reported in **Figure 9B**. Detailed results of the tests have been reported in Coiro et al. (2015). An experimental test campaign was performed in the towing tank facility available at the Department of Industrial Engineering, of the University of Naples. This facility has a wave generator capable of producing waves with variable frequency and amplitude. A moving wall wave generator is placed at one end of the basin. The wave generator is able to reproduce different sea states, and its operating limits are reported below:

- Operating frequency interval: ~0.35–1.2 Hz
- Maximum wave height: ~0.6 m (also depending on frequency)

To characterize the power production performance of the system, the absorber is equipped with a potentiometer and it is linked to the buoyant body by means of a load cell: power is then indirectly measured as the product of force times velocity. Wave elevation is measured by means of ultrasonic probes and the movements of the buoyant body around its equilibrium position are primarily measured by the potentiometer mounted on the piston during wave testing (for some specific purposes, during the tests, other displacement measuring equipment have been used, such as a laser distance measuring system). Then, all these measurements are collected and compared with numerical results.

The PTO device has been simulated for the major part of the test campaign by means of a pneumatic actuator. The actuator is driven by an analog control system, which apply the chosen linear control law and allow the variation of the force-speed gain to modify system response. The control system takes as input the measurements of the load cell and of the potentiometer and implements a feedback control algorithm to ensure the appropriate instantaneous force response actuating the controlled valves of the pneumatic piston. At the same time the controller provides an output signal for the estimated piston speed.

Two testing configurations were developed and studied during the experimental analysis, with different position of the hinges relative to the water free surface. In both configurations, the simulated PTO device is almost perpendicular to the supporting arms, but in one configuration the support arms are horizontal, while in the other one the arms have an inclination angle. The inclined arms configuration has shown better results in the performed tests. Such behavior is probably related to the possibility to exploit both the vertical and horizontal wave force actions, while for the horizontal arms model only the vertical component is effective in practice.

Several different types of test have been performed, the main results are related to the estimation of system response and power output.

Numerical potential flow data compared to experimental tests have shown to be in relatively good agreement with respect to natural frequency and wave frequency for max power (mean and instantaneous), but the value of the power from simulations is almost double than experimental one. Part of this issue is probably related to an overestimation of the velocity, and thus of the force at the absorber, in the simulations, since no viscous effects were introduced. A much better agreement between numerical and experimental results may be observed for large scale prototype, as reported below indicating that the influence of viscous effect is much larger for reduced scale prototype than larger one.

Optimization Based on Potential Flow Simulation

A numerical optimization procedure has been implemented in order to search a suitable system configuration for a given sea condition. To perform the optimization, the commercial code ModeFrontier, by ESTECO SpA, has been used in cooperation with Umbra Cuscinetti SpA.

The assumed sea state is extremely simplified and is assumed to be representable by a monochromatic wave of given frequency and amplitude. This approach has been chosen for design purposes in order to reduce the amount of simulation time, during multiple simulation runs, and the complexity of an irregular sea state. It has to be noted, however, that this is a strong approximation and that the effect of irregular waves may have a significant impact on the final effective power output.

The optimization process has been applied to a system with the dimension of a possible real scale prototype, with a width fixed to 5 m, a length of about 3 m and a submerged volume of about 4 m^3. The width of the buoy was fixed to account for possible limitation on the available installation site and/or on the number of installable systems.

In the search process, for every examined configuration, a shape is generated and an initial equilibrium condition is found. With respect to this equilibrium condition a linearized hydrodynamic analysis is performed. A surface mesh is generated for the geometry, which is split into two parts distinguishing between diffractive (underwater) and non-diffractive elements. The radiation and diffraction problems are solved to obtain the related hydrodynamic coefficients (added mass and radiation damping, for radiation problem, and diffractive forces coefficients) for just the frequency of interest. Assuming a regular monochromatic wave, in the analysis of the radiation forces the convolution method, more proper for irregular seas, has not been used and the radiation forces have been estimated using the response amplitude operators and the hydrodynamic coefficients related to the prescribed incoming wave frequency.

A time domain simulation is then performed using the linearized coefficients previously estimated for the frequency of the incoming wave, together with a non-linear estimation of the hydrostatic and Froude-Krylov forces, which are calculated at each integration time-step considering the actual wetted surface. During time simulation the mechanical non-linearity due to the effect of the hinge and of the pivoting generator piston are taken into account. Power output is estimated by post-processing time simulation results.

The following parameters have been accounted for in the optimization process:

- Body mass (related to submerged volume at initial equilibrium condition)
- PTO force-speed gain
- Body shape

The position of the center of gravity is assumed to be constant together with the assumed principal moment of inertia. Only the overall mass of the body is changed through the optimization process.

The geometry of the PTO connection, involving the length of the support arms and the position of the piston attachment points, is leaved unchanged. A linear PTO control law is chosen, defined by the value of the gain relating speed and generator required force.

With respect to the shape of the body, only the cross-section shape is varied, leaving unchanged the transversal length in order to fulfill possible size constraints (for example, due to the available site extension). A B-spline curve, defined by 15 coefficients, is used to parameterize the cross-section shape of the body. In order to reduce the number of optimization parameter, only 3 coefficients are varied, changing only the forward part of the body, which is supposed to be more influent in determining the interaction with the incoming wave. It has to be noted that some problems may arise using such approach and sometimes unfeasible configurations are generated. Reducing the number of parameters may have a positive effect on such issue.

RANS Simulations

Several Unsteady Reynolds Averaged Navier-Stokes (URANS) simulations were performed on the buoy configuration, using the commercial code StarCCM+, with similar assumptions as for the potential flow model. These simulations were made to try to take in account viscous effects due to buoy movements into water. Due to symmetrical properties of the problem, only one half of the real physical water tank was reproduced. In the simulated wave tank, the buoy can rotate around a hinge due to wave's actions. Different computational grids were tested and one was chosen which assure the better combination of accuracy and CPU time. In general, grids have a background and a superimposed grid (overset grid approach), which allows the buoy floating movements: the buoy is completely contained in the overset grid (**Figure 10A**). Each URANS simulation run for about 30 s of simulation time, requiring about 2 days on a 64 CPUs device. Different turbulence models were also tested and k- ω model was chosen. During simulations, data about hinge rotational angle and center of gravity (CG) position were recorded and used to evaluate mean and max available power. In the URANS simulations, effects of PTO device were also accounted for, in a way similar to that used in the potential flow simulations.

Several analyses have been performed, both on the small scale and on the full-scale system model. A summary of some results is reported in **Figure 10B** in terms of oscillation amplitude as a function of incoming wave frequency with no PTO load. A large overestimation of predicted oscillations using potential flow theory may be seen in the case of the small-scale model, particularly around the peak frequency. On the contrary, very good accuracy can be seen regarding CFD numerical results. This situation is particularly true for small scale models while for larger model the differences between the two approaches tends to vanish, as shown later in the paper, indicating that viscous effects play a more important role for small-scale model test.

The larger computational costs of the CFD suggest its use for detailed analyses of specific cases of interest, while for optimization purposes the potential flow approach seems to be more indicated. Despite the lack of accuracy in predicting the exact value of system response, the potential flow model is able to capture the overall trend of system behavior and to compare alternative configurations, requiring smaller computational resources.

Large Scale Prototype

After the first small scale test campaign, aimed to focus the main issues and the overall system behavior and to simulation model set up, a larger model was developed, in cooperation with Umbra, within a research program supported by WES organization (Wave Energy Scotland).

Figure 11A shows the large scale model mounted on the dynamometric cart in the naval towing of the University of Naples.

The model was optimized for a regular wave condition with 0.24 m wave amplitude and 0.35 Hz frequency. Some modifications to the direct results of the optimization have been implemented in the final design, to optimize integration with the PTO and for constructive reason, simplifying the shape in areas, like the rearward part of the body, with lower impact on hydrodynamic performances.

The developed numerical model was enhanced where needed also taking into account the information gathered in the first run of tests.

The prototype buoy shape and dimensions, given the operating conditions, were chosen comparing several solutions obtained using the developed shape optimization numerical procedure.

Final manufactured configuration was slightly changed for manufacturing reasons and for better coupling with ball-screwing based electrical generator.

The main results of the tests were the system power output and the conversion efficiency.

A resistor bench has been used to define a control law for the generator force response. Electrical load was changed by setting the bench electrical resistance value.

An approximate linear relation between force and velocity is established using an adjustable electrical load by means of a resistor bench (real relation shows also a variation with piston speed for a fixed electrical load).

The system was equipped with a load cell and a potentiometer (LVDT type) on the piston in order to measure force and displacement (and velocity by differentiation) to estimate mechanical input power. Moreover, 4 tri-axial load cells were used to estimate the forces exerted by the wave directly on the buoy in order to evaluate the efficiency of the buoy.

Wave characteristics were monitored by multiple capacitive wave gages system (8 in total) in a suitable array arrangement, to capture eventual directional patterns and to study wave reflections.

For the highest tested wave amplitude (0.24 m with 0.35 Hz frequency) a mechanical peak power of about 6.5 kW has been observed, with an average mechanical power of about

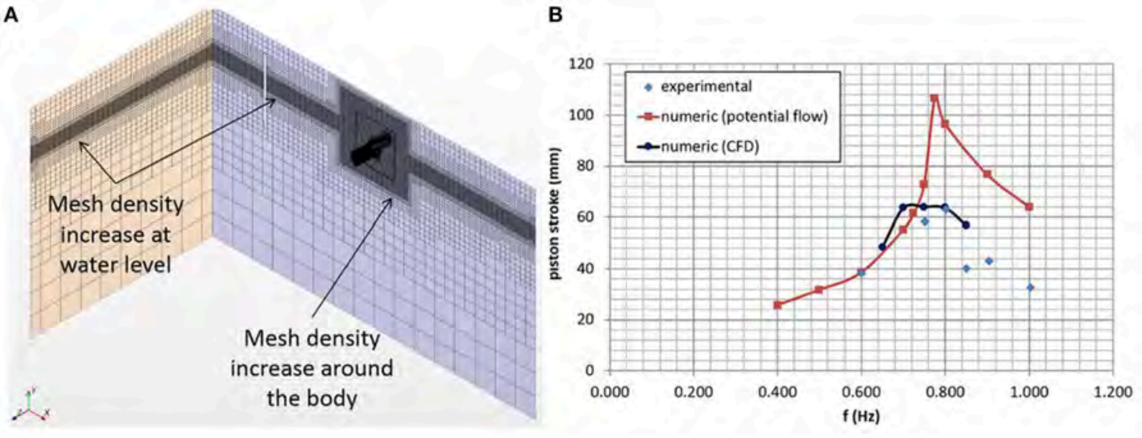


FIGURE 10 | CFD model computational grid **(A)**. Comparison of potential flow, CFD, and experimental results in terms of piston oscillation amplitude as a function of wave frequency with no PTO load **(B)**.

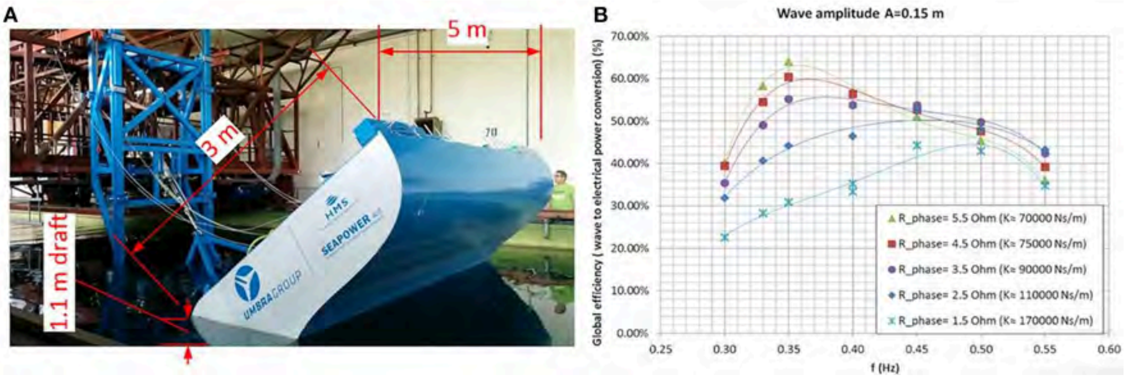


FIGURE 11 | Wave tank experimental test on large scale model **(A)**. Global conversion efficiency in regular wave tests, as a function of wave frequency for different electrical resistance load. Wave amplitude 0.15 m **(B)**.

2.6 kW. Based on wave available power, a buoy mechanical conversion efficiency of about 74% may be estimated in this specific condition. In the same conditions the measured average electrical power output reached a value of about 2.0 kW, with a PTO efficiency of about 77% leading to an overall efficiency of 69%.

It has to be noted that a significant dependence on wave frequency has been observed, as expected for a resonating behavior. The power production rapidly decreases away from the power production peak frequency (about 0.35 Hz, but variable with the PTO damping). **Figure 11B** shows the global conversion efficiency (wave-to-wire), in percentage, as a function of wave frequency for different electrical resistance and for 0.15 m wave amplitude. The global conversion efficiency is defined as the ratio of the electrical power output to the average power transported by the wave, thus accounting for both the conversion efficiency of the buoy and the generator electrical efficiency.

Typical measured and computed time histories of piston oscillation velocity and output power are reported in **Figures 12A,B**, under a wave condition with 0.2 m wave amplitude and 0.35 Hz frequency. A good agreement may be observed at least for this specific case, although it has to be noted that some slightly larger differences appear for some conditions over the whole range tested.

Reported data are related to tests in regular waves. It has to be noted that, considering irregular sea states with possible large variation in instantaneous surface elevation, conversion efficiency and power output may be significantly reduced. One of the most relevant issues observed with the tested device is the possible very large difference between the average and peak power output and forces on the PTO. Such issue requires further studies in order to define and implement a proper control strategy to mitigate, if possible, the peak-to-average power ratio.

Tests in irregular wave conditions have also been performed. **Figure 13A** shows the large difference observed between maximum and average power for Pierson-Moskowitz spectrum sea states with 0.25 m significant height and different peak frequency. Finally, **Figure 13B** reports the global efficiency in the case of irregular sea states. Two spectrum models are considered, JONSWAP and Pierson-Moskowitz, both showing a

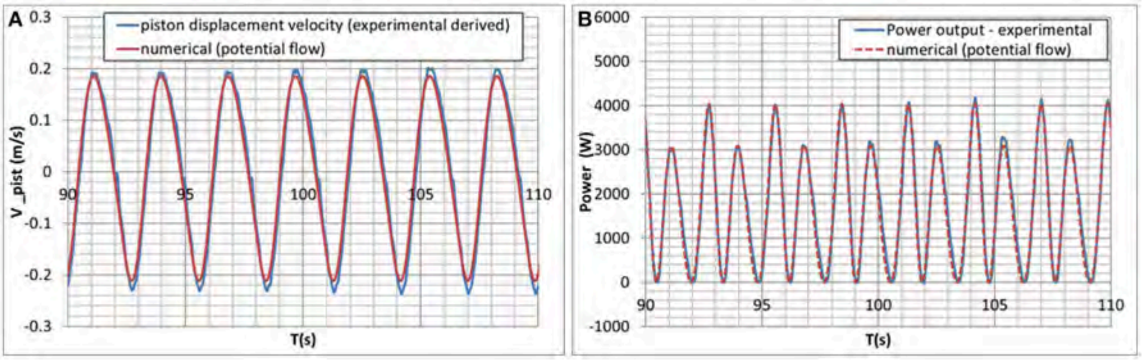


FIGURE 12 | Numerical (potential theory)—experimental comparison. Piston velocity time histories **(A)**, instantaneous power time histories **(B)**. [A = 0.20 m, f = 0.35 Hz, K = 90,000 N/(m/s)].

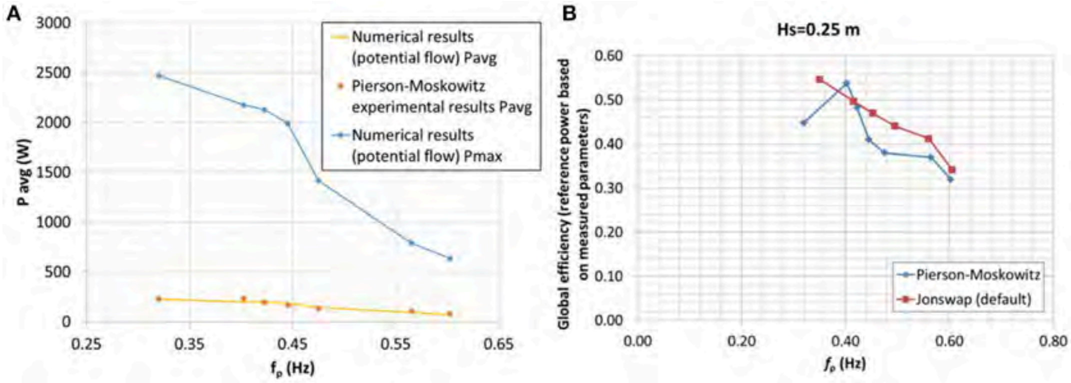


FIGURE 13 | Comparison between measured average and max mechanical power for irregular sea states, for constant significant height (H_S = 0.25 m) and variable peak frequency (Pierson Moskowitz spectrum) **(A)**. Global measured conversion efficiency, for irregular sea states **(B)**.

slight reduction of performance with respect to the regular sea state case.

A further development of the project is planned after laboratory tests. In particular, a prototype to be tested in marine environment is currently under construction for the deployment on a breakwater in Civitavecchia harbor. For a 5 m wide device, with the wave climate at Civitavecchia (see par. 3.1), the estimated annual energy production is equal to about 14,000 kWh/year. It has to be noted that the planned tests are aimed at the evaluation of the overall system behavior in real environment and only a limited set of operating conditions over a limited time extent will be considered for the initial test, thus potentially limiting the effective harvestable energy.

CONCLUSIONS

A brief review is presented of the experience gained over several years of applied research in the field of marine energy performed at Department of Industrial Engineering of University of Naples in cooperation with non-profit research consortium SEAPOWER scrl participated by the same University. Both tidal and wave energy have been considered and several Mediterranean installation sites have been explored. Promising results have been obtained, although some problems still need further investigations. Two case studies have been presented.

In the case GEMSTAR tidal device, a floating submerged turbine system at TRL 7, problems may arise in the design of the mooring system and structural optimization, as a consequence of the high loads due to turbine thrust and required buoyancy. Further undergoing studies are involving blade shape optimization also in connection with the generator control strategies aimed to reduce costs keeping blades pitch fixed to reduce global system capital cost and O&M.

The PIVOT WEC system at TRL 5, also shows promising possibilities for low energy sites typical of Mediterranean Sea, even if some issues are still under investigations. A problem for this type of device is related to the strong dependence of the response on the sea state frequency, which may require site specific optimization and may yield poorer energy production performances. Moreover, the problems arising from the large difference between average and peak response requires further undergoing studies, which will involve strategies aimed to upgrade the PTO to smooth out the large differences between maximum and average output power and also to optimize the control strategy. Issues with survivability in storm conditions need also further investigations.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Disaggregating the SWOT Analysis of Marine Renewable Energies

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Energy transitions require strategic plans that minimize inefficiencies and maximize energy production in a sustainable way. This aspect is fundamental in the case of innovative technologies based on marine renewable energies. Marine renewable energies involve problems and advantages which imply a reconceptualization of marine space and its management. Through an holistic SWOT analysis the main strengths, weaknesses, opportunities and threats are highlighted in this paper, considering social, economic, legal, technological, and environmental dimensions. We disaggregate the SWOT analysis for marine renewable energy technologies in order to create an overview of pros and cons for every dimension and better identify specific hotspots and possible solutions in different fields.

Keywords: marine renewable energy, energy transition, marine space, sustainable development, policy making, energy planning, MAESTRALE project

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INTRODUCTION

Nowadays one of the main issues facing all Countries is climate change and its associated global warming. In Rogelj et al., 2016, the Paris Agreement was signed to keep global average temperature below 2°C (Paris Agreement, 2016).[1] To mitigate climate change, the decarbonisation pathway is an essential step toward reducing CO_2 concentration in the atmosphere. In this perspective, the European Union has set three main targets to be achieved by 2030, which imply a 40% reduction in greenhouse gas emissions compared to 1990 level, at least the 27% of clean energy production from renewable sources, and 27% of energy savings (https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy).[2] Such an ambitious plan necessarily requires a transition from fossil to renewable energies.

Alongside more traditional renewable energy sectors, such as photovoltaic or onshore wind, innovative solutions for exploiting renewable sources are emerging, namely Marine Renewable Energies (MREs). MREs are "a form of renewable energy deriving from the various natural processes that take place in the marine environment" (Abad Castelos, 2014). Technologies that convert kinetic and chemical potentials or thermal properties of seawater are involved in the MRE definition. Generally, these devices convert kinetic energy from tidal currents or wind-driven waves, or exploit the potential energy deriving from the rise and fall of sea levels due to tidal range, or the temperature and chemical potential gradients, respectively, between surface and deep water and salt concentration (Pisacane et al., 2018). These sources of energy are usually named ocean energies

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[1] UNFCCC. Adoption of the Paris Agreement. Report No. FCCC/CP/2015/L.9/Rev.1

[2] European Commission.2030Energy Strategy.Available from https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

and derive from waves, tides, marine and tidal currents power, thermal and salinity gradients. Together with the already mentioned ocean energy sources, MREs include offshore wind and algae cultivation. Several prototypes to exploit MREs already exist and show different technological features concerning the design, the functioning principle on the basis of the source exploited.

As Wright (2015) argues, MREs are laying the foundations for a new "industrial revolution" based on oceans, seas and their exploitation and industrialization. For this reason, the promotion and development of MREs have several implications and would require a re-conceptualization of marine spaces and a deeper investigation of the impacts in terms of social, economic and environmental sustainability (Wright, 2015). These evaluations are necessary to avoid social or economic conflicts, preserve and protect fragile natural ecosystems and ensure the sustainable development of this energy sector considering the three pillars of sustainability. With the aim of gaining awareness of the main advantages or disadvantages that MRE technologies could lead with their installations, a SWOT analysis (the acronym stands for "Strengths, Weaknesses, Opportunities, and Threats") has been produced using a transdisciplinary approach. Indeed, the SWOT analysis allows to identify the main factors that may hamper or contribute to the development of the MRE sector. The SWOT analysis has already been applied in the literature to establish problems to face or possible policies to implement in order to promote an energy transition. Terrados et al. (2007), applied the SWOT analysis to redesign the regional energy system in the province of Jaén, a region in southern Spanish, demonstrating that the SWOT analysis has been a successful tool for energy planning and for the elaboration of policies. Similarly, Markovska et al. (2009) applied SWOT as a baseline to diagnose the Macedonia energy system and lines of action for more sustainable development.

The scope of this study is to provide a schematic knowledge framework for the development of the MRE sector. The paper focuses on tidal, current, wave and offshore wind technologies which have in common a quite similar development pathway. The knowledge framework is established through the elaboration of a SWOT analysis on the potential implications of the development of MRE.

Through a disaggregation process, all factors that may influence exploitation of the MRE are divided into five main subcategories: social, economic, legal, technological, environmental, with the aim of acquiring a holistic perspective. The results are expected to address the implementation of guidelines for the development of the MRE in different marine regions and, focusing on possible gaps or obstacles, promote discussions within the political and scientific community, also involving entrepreneurs, citizens and other stakeholders.

The final output of the SWOT analysis will identify:

- The main impactful factors for the development of MREs;
- The factors that can be influenced by innovative and programming policies;
- The possible policies to implement.

As baseline for this study we have used information and knowledge collected by MAESTRALE, an InterregMed project mainly dedicated to investigate the potential development of the MRE sector in the Mediterranean area. MAESTRALE is based on a transdisciplinary approach and analyzes MREs from different perspectives.

MATERIALS AND METHODS

The SWOT analysis refers to a kind of analysis designed for strategic planning processes of small and medium-sized enterprises (Houben et al., 1999). However, some research experiences show that the SWOT analysis is also a powerful tool to analyze the national energy sector for sustainable energy development (Terrados et al., 2007; Markovska et al., 2009). The aim of the SWOT analysis is to allow decision makers to design the qualitative structure of a process or system, identifying changes that will strategically and consistently improve it by maximizing strengths, reducing weaknesses, exploiting available opportunities, and avoiding threats (Fertel et al., 2013). On one hand, strengths and weaknesses are factors which exert pressure within a system; on the other hand, opportunities and threats are determined by the external environment. As intrinsic factors, strengths and weaknesses are manageable; opportunities and threats are external and less manageable (Dyson, 2004; Phadermrod et al., 2016). In particular, strengths are resources or capacities that stakeholders involved in the field can use to progressively develop MREs; weaknesses are limitations which may hamper MRE diffusion. Opportunities and threats are favorable or unfavorable (contextual or external) situations to face (Karppi et al., 2001). In general, SWOT underlines strengths upon which to build a strategy or weaknesses to eliminate in order to achieve established goals; at the same time, it also points out opportunities to exploit or threats to mitigate (Karppi et al., 2001).

In this study, the SWOT analysis has been performed to understand the main internal and external forces which can hamper or encourage the deployment of MRE, with a special focus on Italy.

The analysis follows a framework divided into five main subcategories or dimensions in order to investigate social aspects, economic and funding tools, legal background, technological features, environmental and ecological dimension together with the energy potential. This disaggregation enables a wide overview of what MRE technology implementations imply under different viewpoints (dimensions).

The analysis is based on a literature review in the five different dimensions and also make use of the support tools developed in the MAESTRALE Project (MASTRALE Project Deliverable, 2018). Moreover, it takes into account the results from a questionnaire designed to measure the social acceptance of citizens and a participatory approach through meetings attended by key stakeholders and experts in the field of MRE in the Tuscany region.

RESULTS AND DISCUSSIONS

Tables 1–5 present a survey of the factors belonging to different SWOT compounds. In particular, information has

TABLE 1 | SWOT analysis of social factors.

Forces	Internal	External
Social	Strengths New job positions	Opportunities Public support Development of an ecological citizenship
	Weaknesses Social and recreational activities overlapping Visual landscape impact Risk of noise	Threats Uncertainty in social-political acceptance Uncertainty in community acceptance

TABLE 2 | SWOT analysis of economic and funding factors.

Forces	Internal	External
Economic and funding	Strengths Major energetic independence Major control of resources by communities To share the ownership of the renewable technological park Lower price volatility	Opportunities European funding Interministerial Italian decree to incentive renewable energies through public funding
	Weaknesses High financial and investment costs Start-up risks Lack of competitiveness Possible overlap of economic activities	Threats Early stage of the MRE market Lack of market acceptance

TABLE 3 | SWOT analysis of legal factors.

Forces	Internal	External
Legal	Strengths Institution of a national cluster for the Economy of the Sea	Opportunities 2017 Italian National Energy Strategy supports the transition toward a renewable energy system European Directives are useful to promote a legal framework
	Weaknesses Slow existent procedures to obtain permissions and authorizations	Threats Italian law sees gaps in the regulation of MRE installations Overlapping competences between different political actors Delays in the implementation of European directives

TABLE 4 | SWOT analysis of technological factors.

Forces	Internal	External
Technological	Strengths Increasing number of Italian R&D studies in MRE technologies Already existent infrastructures onshore or nearshore	Opportunities Knowledge transfer among Mediterranean research centers and universities
	Weaknesses Technological designs require more studies Resources estimation in Italy is incomplete	Threats Unexpected and extreme phenomenon Risk of survivability High sea depth

TABLE 5 | SWOT analysis of environmental and MRE potential factors.

Forces	Internal	External
Environment and MRE potentials	Strengths Good geographic position Good energy potentials Stability in time and predictable potentials	Opportunities Climate change mitigation Better air quality Increasing of biodiversity
	Weaknesses Scarce and not homogeneous resource potentials on national level	Threats Risk of changing hydrodynamics Risk for life under water Risk for life above water (i.g birds) Risk of noise

been disaggregated into five sub-categories in order to highlight specific topics to be faced and discussed. The next paragraphs are devoted to present sectoral specificities.

In the next paragraphs, items highlighted in the tables are presented as crucial aspects to be faced when dealing with the implementation of any MRE plants in Italy.

Social Aspects

The creation of new job positions (strength) is a positive social consequence of MREs. Communities can locally grow and develop through new specialized works. This factor may increase the public support of politicians and citizens.

Internal problems concern social and recreational activities overlapping (weakness) i.e., the possible interference between different activities, such as fishery, beach tourism, sailing, diving, shipping. Nevertheless, limitations to these other activities can be opportunely managed. Moreover, the possibility to exploit MREs as touristic attractions or hubs for the regeneration of marine ecosystems remains an open issue.

The visual landscape impact (weakness) is a huge challenge to solve. Offshore wind farms, or huge overtopping technologies may dramatically change the shape of a territory increasing, at the same time, conflicts between communities and developers.

Simultaneously, the risk of noise (weakness) during the construction phase or the functioning of technologies may represent a critical obstacle.

The choice of the site is therefore crucial. For example in some cases feasibility of new installations is higher in industrial ports than in touristic harbors. Potential visual or acoustic pollution in natural areas or in places close to residential areas has to be taken into account.

Considering the possible threats, there are uncertainties regard the social acceptance of these technologies. The social acceptance of MRE technologies could be low when the installation process is real since possible problems or fears could arise. Three sub-dimensions, namely socio-political, market and community, can be identified (Wüstenhagen et al., 2007). In this paragraph only the socio-political and the community acceptance will be briefly considered. The market acceptance will be introduced in the following section.

At this date, uncertainty in social-political acceptance (threat) is a critical issue for MRE implementation. Wüstenhagen et al. (2007) describe the socio-political acceptance as a wide concept that involves stakeholders and policy makers at supra-local and national level. The socio-political acceptance could be estimated observing the presence of policies enhancing market and community acceptance, or encouraging the establishment of financial procurement systems or spatial planning systems that stimulate collaborative decision making (Wüstenhagen et al., 2007).

Italy is not yet pro-active in supporting the installation of MRE plants. For example, considering The Regional Environmental And Energy Plan (PAER) of Tuscany, it is evident that the energy strategy by 2020 does not consider as possible exploitable renewable sources the MREs, preferring, on the other hand, hydroelectric, geothermal, photovoltaic or onshore wind technologies (Regione Toscana., 2013). Similarly, the regional energy plans of Lazio and Liguria do not include MREs (Regione Liguria, 2014; Regione Lazio, 2017).

Uncertainty in community acceptance (threat) refers to a local dimension and local stakeholders with interests in a given area (Wüstenhagen et al., 2007). Estimating community acceptance may be difficult because it should not be assumed that citizens are ready to accept a technology in their territory. The siting decision may impact on community acceptance and the more a technology directly affects the community, the stronger the social opposition can be. This effect is commonly known as the NIMBY effect (not in my backyard). NIMBY refers to protectionist and oppositional attitudes adopted by community groups when unwelcomed project are developed in their neighborhood (Dear, 1992). It is affected by multiple variables such as for example, physical features, the proximity of a technology and the temporal dimension considered (Devine-Wright, 2005). Research on social acceptance of wind farms conducted by Warren et al. (2005) has shown that proximity to the installation site has a negative impact during the design phase of a technology, whereas the trend changes after construction when the technology is operational. The results of this study on onshore wind farms are probably also expected in the case of offshore wind farms. However, the first studies on the social acceptance of MREs, such as tidal and wave devices, show a positive social acceptance of these technologies (Devine-Wright, 2011; Heras-Saizarbitoria et al., 2013). This demonstrates that social acceptance cannot be taken for granted, but appropriate strategies and policies can contribute to turn social acceptance into a strength.

Although socio-political and community acceptance shows uncertainties, public support (opportunity) seems to be favorable. Public support depends on general factors that can influence the opinion of local communities, progressively improving the feasibility of interventions (e.g., social acceptance, technological and economic feasibility, etc.).

The literature shows a high level of public support for renewable energies in Europe and UK (Toke, 2005); in general, the social context is favorable to the development of MRE technologies. In order to gain preliminary information on the public support of Italian citizens, a questionnaire was produced to elicit perceptions from the civil society. The questionnaire was circulated on the Web through social media and face to face interviews. The results of this preliminary survey showed that the sample of respondents counts 353 units, of which 92% come from Tuscany, and 58% of them live near the sea (0–10 km). 77.8% of the respondents were in favor of the construction of MRE plants in their territory with a vote of more than 8 (on a scale from 1 to 10) and 92.6% with a vote higher than 6.

Moreover, the development of an ecological citizenship (opportunity) is another important consequence of the diffusion of MREs. Ecological citizenship is defined as a continuous social process through which individuals and groups commit themselves to broaden their rights through the recognition, representation and participation of ecological practices or reasoning (Islar and Busch, 2016). In this perspective, territories close to the sea can exploit MREs and start a process of energy transition on a local scale that implies the direct and proactive involvement of local communities. The emblematic case of Samsø is an excellent example of how renewable energies can encourage the development of an ecological citizenship based on shared responsibilities and good behavior (Islar and Busch, 2016). The inhabitants of Samsø have been actively and directly involved in the energy transition process and now share ownership of renewable energy facilities, thus enjoying economic benefits.

Economic and Funding Aspects

The advantages of the development of the MRE sector lie in a major energetic independence (strength). Territories close to the sea with high potential may increase the diffusion of indigenous and renewable sources obtaining a major energy independence (IRENA Report., 2014).

In addition, MREs guarantee a major control of resources by communities (strength) and the possibility for communities to share ownership of the renewable technological park (strength). Again, Samsø is an example of how a small island community can produce energy by increasing its independence and earning revenue (Islar and Busch, 2016).

Also a lower price volatility (strength) may be a possible advantageous output as these marine renewable sources are decoupled from geopolitical interests or crisis (Pireddu, 2015). This leads to greater price stability, which is more independent of exogenous shocks. Nevertheless, one comment needs to be made. Due to climate change, there may be an increase in extreme events and damage to technologies. In this way, price volatility would not decrease.

In the economic field, there are many weaknesses that require strategic management. High financial and investment costs (weakness) are the primary cause of these delays in the commercialization of MRE technologies (Magagna and Uihlein, 2015). Investors are usually reluctant to invest in the MRE sector as technological feasibility and survivability increase risks more than traditional renewables (Leete et al., 2013). This condition drives toward the "valley of death," defined as a critical financing gap where "available funding is not sufficient to scale up from prototype to full scale deployment" (Leete et al., 2013, p. 867). Thus, since private finance is still reluctant to invest in MREs, there is a need to produce public policies and incentives to support this technological push phase.

The previous factor is strictly related to start-up risks (weakness). Indeed, for example, investors may spend huge money resources in project or installation that risk to not be implemented or that will have lower revenues.

The lack of competitiveness (weakness) is another huge obstacle to overcome. The competitiveness between several technologies is measured by the Levelized Cost of Energy (LCOE). The LCOE is measured as a ratio between the total lifetime cost of an investment and the cumulated generated energy by this investment (Pawel, 2014). The total costs are discounted at equal points of time (Ebenhoch et al., 2015). From a study conducted by Astariz et al. (2015), it is possible to observe that the LCOEs of MREs, such as offshore wind (165 €/MWh), tidal (190 €/MWh) and wave energy (325 €/MWh) are much higher compared to more traditional resources(average 46 €/MWh) based on fossil fuels.

These conditions have led to two main conclusions: the deployment of MREs is still too expensive and their technological development is only possible through public funding and financial support.

Besides, possible overlaps of economic activities (weakness) may further increase the incompatibilities of MREs with other economic sectors. Seas and oceans have important economic functions linked to tourism and the maritime industry. The total value of goods and services produced by maritime activities in Italy is €43 million, equal to the 3.5% of the GDP and provide occupation for 835.000 employees (UNIONCAMERE., 2016). Looking at these numbers, it is easily understandable that MRE technologies could not be installed everywhere and that a structured maritime spatial planning should be promoted by decision-makers and authorities with the aim of reducing possible conflicts with local communities and, at the same time, increasing synergies between activities.

The main threats concern the energy market. The early stage of the MRE market (threat) needs special attentions. According to Magagna and Uihlein (2015), ocean technologies prototypes based on tide and wave sources are more developed than osmotic and thermal gradient converters which still are in a research and innovation phase. Considering wave and tidal devices, the latter is more advanced. Indeed, tidal technologies are in a phase of market push mechanisms (Magagna and Uihlein, 2015) that is due to the early commercial stage; the need of incentives or specific funding programs to have any chance is fundamental. Likely, a market pull condition, referring to an advance commercial phase involving private investors, will take some years to be achieved. Among all the technologies, the wind offshore seems to be the most mature one thanks to its heritage from onshore wind.

Besides, there is a lack of market acceptance (threat). The market acceptance refers to the market capacity of responding to a new technology supporting and favoring it (Wüstenhagen et al., 2007) through possible tools, such as incentives, subsidies or funding. As said, in Italy there are available funds for promoting renewable energies, but these tools are not restricted to MREs. The consequence is that money resources are spent in more competitive technologies.

Although the possible issues, the European Union provides European funding (opportunity) in order to reduce some of the weaknesses mentioned. EU is aware that MRE technologies can be developed only through the creation of a stable and advantageous economic environment. For this reason, EU provides financial support to increase capacity building and knowledge transfer in the MRE sector. For instance, at the moment some of the main funding come from Horizon 2020 (https://ec.europa.eu/programmes/horizon2020/), InterregMed (https://interreg-med.eu/) Programmes.

Also considering the national dimension it is visible a more availability of funding. An Interministerial Italian decree to incentive renewable energies through public funding (opportunity), (D.M. 23/06/2016),[3] was produced by the Italian Government and it increases the number of available funds for renewable energies. In total 5.8 billions of euro per year was released to invest in renewable energies, except for photovoltaic (http://www.sviluppoeconomico.gov.it/index.php/it/normativa/decreti-interministeriali/2036874-decreto-interministeriale-23-giugno-2016-incentivi-fonti-rinnovabili-diverse-dal-fotovoltaico).[4]

Legal Aspects

The national legal background within which MREs should be developed is slow in the elaboration of well-established laws that regulate the development of MRE technologies.

Certainty, the institution of a national cluster for the Economy of the Sea (strength) established by the Ministry of Education, Universities and Research through the Decree N. 1610/3 in August 2016 is a step forward. Within the competences of this technology cluster is included the need of promoting MREs. The decree contains the main guidelines to develop project within the cluster and the stakeholders working in the field of MREs can

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[3] Ministero dell'Istruzione, dell'Università e della Ricerca. (2016). Decreto Direttoriale 3 agosto 2016 n. 1610. Avviso per lo sviluppo e potenziamento di nuovi 4 cluster tecnologici nazionali. Available from http://attiministeriali.miur.it/anno-2016/agosto/dd-03082016-(3).aspx

[4] Decreto interministeriale. (23 giugno 2016). Incentivi fonti rinnovabili diverse dal fotovoltaico. Available from http://www.sviluppoeconomico.gov.it/index.php/it/normativa/decreti-interministeriali/2036874-decreto-interministeriale-23-giugno-2016-incentivi-fonti-rinnovabili-diverse-dal-fotovoltaico

directly take part to initiative to promote the sector. The cluster is in a beginning phase, thus, it will require some more time to be incisive, however, it could have a key role for developing the right basis of MREs and it will be a good tool to create a network.

Slow existent procedures to obtain permissions and authorizations (weakness) to install MRE technologies do not encourage developers. It could happen that bureaucracy may obstacle these installations due to complex and several procedures. Moreover, there are not specific authorization for these devices as emerges from the screening of the Italian Jurisprudence documents and rules. Thus, the major legal risk is to face blocks which bring to discourage the developers and to abandon the project.

Besides, Italian law sees gaps in the regulation of MRE installations (threat). Since MRE technologies are innovative, a specific regulation for these devices does not exist. Some open issues regard the property rights in the maritime environment, the main procedures to follow for their installation and the bureaucratic applications. The State regulatory uncertainty is one of the most thorny barrier for the development of the ocean energy sector (Leary and Esteban, 2009).

The overlapping of competences between different political actors (threat) is dangerous on a procedural level as well. The territorial sub-divisions in Regions and Municipalities and the special Regional Autonomies, sometimes, increase overlapping of competences and juridical conflicts. For instance, due to Constitutional Law 3/2001[5] which modifies the Constitution's Title V, Regions gained a competence for regional energy policies and efficiency. The result is that there is not an homogeneous legal framework for the development of a MRE sector on a national level. This fragmentation may hamper the installations of technologies creating confusion and deadlocks.

In addition, delays in the implementation of European directives (threat) slow down the formation of legal stable conditions. For example, in 2014 the European Parliament adopted the Directive 2014/89/EU[6] on the establishment of a maritime spatial planning. Italy ratified this directive but its effective implementation is still on the way. However, the right management of areas and activities is fundamental to create synergies and harmony between MREs and other sectors. This is a threat since Italy could fall behind with respect to the European guidelines and criteria slowing down the development process which is already quite slow.

The 2017 Italian National Energy Strategy[7] supports the transition toward a renewable energy system (opportunity). It has clearly improved the objectives set in the 2013 edition. An effective transition to renewables and the abandonment of fossil fuels, except for natural gas, is a promising feature. Nevertheless, MRE technologies are not explicitly mentioned in the National Strategy, with the exception of (hypothetical) off-shore wind farms. This may be a symptom of political carelessness or lack of priority in the development of MREs; anyhow a specific role is assigned to innovation and experimentation of new solutions.

Contrary to the Italian measures, the European Directives are useful to promote a legal framework (opportunity) that will advances MREs and their installations in marine ecosystems. The document "Blue Growth Opportunities for marine and maritime sustainable growth" shows that one of the objectives of Blue Growth concerns the development of Blue Energy (as it is called the energy sector that exploits marine renewable energy), which has "the potential to improve the efficiency of the collection of European energy resources, minimize the land use needs of the energy sector and reduce greenhouse gas emissions in Europe" (COM(2012)494 final, p.7).[8] The development of a MRE scenario is a priority goal to be pursued and its importance is also reiterated in the Communication "Blue Energy—Action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond" (COM(2014) 15 final) issued by the European Commission. The Communication promotes the development of MREs and, at the same time, encourages the implementation of new laws since "[...]ocean energy will benefit from a clear, stable and supportive policy framework to attract investment and develop to its potential" (COM(2014) 15 final). The basic directive for the development of MREs still is the Renewable Energy Directive (Directive 2009/28/EC[9]) which promotes the use of energy from renewable sources on the basis of the targets and criteria set out in the document. These directives directly encourage the development of MREs development. Other directives provide the main guidelines to be respected when MREs are installed in marine ecosystems. For instance, the Marine Strategy Directive (Directive 2008/56/EC[10]) directly affects the quality of sea and oceans by promoting the achievement of good environmental status in the marine environment, while, the aforementioned Maritime Spatial Planning Directive (Directive 2014/89/EU) organizes spaces and activities in order to manage in a sustainable way the activities which occur in marine areas, with the aim to avoid contrasts between the various competing interests. Alongside these legal documents, the Habitats Directives (Directive 92/43/EC[11]) and

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[5] Servizio Studi Ufficio ricerche sulle questioni regionali e delle autonomie locali a cura di Marcelli, F. (2001). La legge costituzionale 18 ottobre 2001, n. 3. Available from http://piattaformacostituzione.camera.it/application/xmanager/projects/piattaformacostituzione/file/EventiCostituzione2007/files/Dossier_n.270.pdf

[6] Europa. (2014). Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. Official Journal of the European Union L 257/135.

[7] Ministero dello Sviluppo Economico. (2017). Italy's National Energy Strategy 2017. Available from http://www.sviluppoeconomico.gov.it/images/stories/documenti/BROCHURE_ENG_SEN.PDF

[8] Europa. (2012). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Blue Growth opportunities for marine and maritime sustainable growth. Brussels, 13.9.2012, COM(2012)494 final.

[9] Europa. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union L 140/16.

[10] Europa. (2008). Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European L 164/19.

[11] Europa. (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities No L 206/7.

its Natura 2000 network must not be forgotten as essential tools for the preservation of protected areas.

Technological Aspects

Italy is proactive in the development of the MRE sector as shown by the increasing number of Italian R&D studies in MREs technologies (strength). Several Universities, such as the Polytechnic University of Turin, The University of Florence, the University of Tuscia, the University of Naples Federico II, the Mediterranean University of Reggio Calabria and research centers, such as ENEA and CNR are working for developing and improving ocean energy (Sannino and Pisacane, 2017). At national level there is an active group of experts that supports research and innovation concerning these technologies.

Already existent infrastructures onshore or nearshore (strength), such as harbors, wharf and offshore platforms may embed MRE technologies, such as wave-to-energy plants. In the case of extensions of existing docks or breakwater systems, these solutions can be easily implemented through an additional investment with promising payback time.

However, technological designs require more studies (weakness) since technologies based on MREs have not discovered yet their full potential and resistance within the marine environment. The operational experience in marine technologies date back to the end of ′90 and it regards small-scale testing of marine technologies prototype (Mueller and Wallace, 2008). Thus, the operational experience is mainly based on simpler and small devices tested in controlled environmental condition. Simulating sea states and extreme events during the testing phase enables developers to better understand if devices can operate under water in hard conditions and if the design software is adapted to reach a good energetic performance.

Resources estimation in Italy is incomplete (weakness). There is a lack of studies on potentials and this does not allow a clear knowledge of MREs and technology implementation.

The main technological obstacles once that the devices are installed are due to the intrinsic features of marine ecosystems.

For example, unexpected and extreme phenomenon (threat), such as strong storms which could destroy the technology or some components and simultaneously increase the risk of investors.

Thus, the risk of survivability (threat) of technologies due to the environment in which they are installed is one important factor to consider. The survivability is defined as "the ability of a marine energy system to avoid damage, during sea states that are outside of intended operating conditions, that results in unplanned down time and the need for service" (Brown et al., 2010). Extreme wave, wind and current events may destroy or damage technological component of devices. Also, in ordinary condition the marine environment can induce corrosion and structural stresses (Mérigaud and Ringwood, 2016) which require maintenance operations.

Moreover, technologies may be influenced by the high sea depth (threat). In the Mediterranean depth puts some constraints, especially for the installation of off-shore wind turbines. In Sicily and Sardinia, sea depth is higher than 30 m within a few hundred meters from the coast. This hinders the installation of fixed wind towers and calls for innovative solutions, such as floating wind turbines (Van Haaren and Fthenakis, 2011; Rosenauer, 2014).

Neverthless, the knowledge transfer among Mediterranean research centers and universities (opportunity) is currently increasing in the field of MREs and this is an opportunity to fast the MRE process development and improve the adaptation of these innovative technologies to the environment. This process is encouraged also by the European Union programmes.

Environmental and MRE Potential Aspects

Good geographic position of Italy (strength) surrounded by seas with more than 8,000 km of shores and 458 small islands in its territory. This allows for identifying many opportunities for the development of MREs considering the extension of coasts, number of harbors and other maritime infrastructures.

Good energy potentials (strength), even though the average power is lower than that of oceans or the Northern Sea, there are some advantages, such as lower intensity of extreme events, higher frequency and continuity. Regarding offshore wind, the major source intensities are located close to the two main islands. For example in west Sardinia, the annual mean wind speed is about 5.4 and 4.9 m/s while, in Sicily, close to the Messina strait, the annual mean wind speed is about 5.7 m/s (European Centre for Medium-Range Weather Forecasts, 2015). Wave energy is directly related to wind. From studies conducted by Iuppa et al. (2015), higher potentials are located in the south-western coast of Sardinia (9.05 kW/m) and more moderate potentials close to Sicily (4,75 kW/m). The areas with the greatest potential in terms of marine tidal currents are close to the Venice Lagoon, to the Strait of Bonifacio in Sardinia, while the most promising site is the Strait of Messina in Sicily (Sannino and Artale, 2011).

Stability in time and predictable potentials (strength) characterize the MRE Italian situation. This aspect allows to develop and test technologies for a definite environment with features known.

Scarce and not homogeneous resource potentials on national level (weakness) are nevertheless observed in most of the Italian marine environment. In particular, marine currents are generally low. In the Tyrrhenian Sea the average speed is lower than 1.0 m/s whilst, observing the already existent prototypes and technologies, turbines usually need a stream speed of at least 1.5–2 m/s to operate efficiently.

Among threats and opportunities, the major aspect to consider concerns the possible negative or positive impacts of these technologies on the environment.

Risk of changing hydrodynamics (threat) is a possible negative impact of MRE devices, especially for plants with huge dimensions. These technologies in some way can calm the sea creating a slow "recirculation" process (Pelc and Fujita, 2002) limiting the transport of gases, nutrients and food to sedentary organisms (Shields et al., 2011).

Risks for life under water (threat) exist with some wave or tide technologies due to the possibility to inhibit or limit physiology, nutritional behaviors, migration habitudes, etc., of fishes or other living species due to the presence of devices and consequently cause their death (Pelc and Fujita, 2002).

Risk for life above water (threat) is mainly related to the interaction between offshore wind and birds. Offshore farms may hamper birds, and if they are installed along a migratory route the possible impacts increase (Sun et al., 2012).

Risk of noise (threat) is possible during the phase of construction and during the activity of the technologies. Some species may be particular sensitive to noise and suffer it avoiding the area (Gill, 2005).

Climate change mitigation (opportunity) is the general objective of promoting new initiatives and innovation in the MRE sector. The Ocean Energy Europe[12] estimated that 100 GW can be obtained by ocean energy industry (exploiting waves and tides) by the end of 2050. This would be enough to provide electricity for 76 million of European citizens. The contribution of every single installation in the Mediterranean area is difficult to estimate yet, but any pilot initiative or test is highly desirable.

A better air quality (opportunity). Fossil fuels may be progressively substituted by cleaner energy production systems, such as MRE technologies. Especially in islands, where most of the electricity is produced locally by thermoelectric plants fueled by heavy oil or diesel, air quality is often compromised and the exploitation of MREs can be a definitive solution.

Increasing of biodiversity (opportunity) emerges as a positive impact from literature. MRE technologies may work as artificial reefs favoring the concentration of nutrients and thus fish concentration (Pelc and Fujita, 2002). Moreover, the presence of technologies would likely forbid the navigation in their proximity and therefore create a sort of protected area for reproduction of species.

The SWOT analysis reveals the main advantages and disadvantages of technologies based on MREs. Among opportunities, general political and social enthusiasm has a good impact on the development of renewable energies, in general, and marine renewable energy technologies, in particular. Such a condition may be virtuous because political action could orient investments toward the development of renewable energy technologies generating people's consensus that, in turn, can further corroborate policy and management choices in that direction. The political and legal support toward renewable energies has a double dimension which derives from the European directives and the national energy strategy simultaneously. The growing interest in MREs is also demonstrated by the increase in public and private studies in MRE technologies and in the number of pilots and prototypes realized. Research and innovation studies are conducted with the aim of maximizing the opportunities created by MREs.

At the same time, the MRE sector shows important issues to solve for pursuing an efficient strategic plan.

As we already said, social acceptance should not be taken for granted. Especially in a pre-construction phase, citizens tend to be more skeptical about a plant and they show a major resistance. Heras-Saizarbitoria et al. (2013) proposed a review of articles in literature dealing with social acceptance. From their work it emerges that variables, such as perceived benefits, information, low visual impact, procedural justice and trust, and local community involvement have pivotal role in addressing citizens toward the acceptance of a technology. Thus, strategies may be thought from these starting point.

For instance, more reliable relations could be created by participatory and inclusive processes established *ad hoc* to allow citizens to express their opinion and acquire knowledge about technologies. In fact, knowledge may clarify and solve doubts and fears, stimulating positive debates. According to Disconzi (2011), information plays a crucial role in the acceptance of wave and tides technologies. By means of a questionnaire, Disconzi noted that the three most important strategies for wave technologies regard the importance of being informed about the utility of these technologies to reduce the GHG emissions, the importance of being informed by communication tool and the opinion of scientists. Other strategies can be pursued, in this sense because communication of the potential benefits for the community may generate a higher level of acceptance of citizens.

Legal, economic, funding and technological issues are mostly related with each other, and synergies between several actors involved are fundamental. Leete et al. (2013) investigated the main factors that investors consider fundamental when investment plans have to be decided. Investors clearly express the requirement to have a consistent and predictable regulatory support background and, at the same time, financial support mechanisms and confidence in the technology functioning. Indeed, a clear framework of rules to regulate technologies which exploit MRE is not mature yet. This instability creates uncertainties in the private finance and an unwillingness to invest in MRE projects. This aspect lead to delays in the technological development which is only supported by public funding. As mentioned before, the Ministerial Decree (D.M. 23/06/2016) for renewable energy establishes a huge amount of money to enhance the development of new technologies. However, it does not specifically direct money to the MRE sector. The result is that funds are mainly used for more competitive technologies. In short, MREs are in a critical stage now: on one hand, there is the need to develop the technologies in order to improve their efficiency and durability, decreasing at the same time the high initial costs; on the other hand, the high initial costs and the lack of funding inhibit technological innovation and drive investors toward more competitiveness alternatives. Nevertheless, it is demonstrated that investing in these technologies will improve the learning curve in MREs. Adopting a microeconomic point of view, the learning curve is used as an empirical method to understand what are "the effect of learning on technological change [. . .]" (Jamasb and Kohler, 2007, p. 2) and it measures the learning effect in terms of "reduction in the unit cost (or price) of a product as a function of experience gained from an increase in its cumulative capacity or output" (Jamasb and Kohler, 2007, p. 2). Thus, the learning curve can be considered as an experience curve that measures the ability to reduce costs by virtue of cumulative experiences in producing and deploying a unit of product (MacGillivray et al., 2014). This means that investing in R&D activities will entail a learning by doing process that creates the right basis to improve the learning rate of the technologies

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[12] Ocean Energy Europe. Europe needs ocean energy. Available from https://www.oceanenergy-europe.eu/ocean-energy/

decreasing their costs and improving their technological features at the same time (Jamasb and Kohler, 2007; Esteban and Leary, 2012). Thus, funding are necessary to implement R&D activities and later shift MREs from a market push to a market pull phase.

A clear legal framework is a fundamental condition for MRE development. In Ireland in 2014, an Offshore Renewable Energy Development Plan (OREDP[13] was published. The OREDP is a sort of manual whose aim is to give guidelines to increase the development and the deployment of MREs. It encourages the collaboration and the share of information between several stakeholders trying to affect the governance, the maritime spatial planning and thus the test sites, the creation of economic support tools, the collaboration between companies, research centers and experts, and the environmental monitoring (https://www.dccae.gov.ie/documents/OREDP%20Interim%20Review%2020180514.pdf).

Creating political and legal necessary favorable pre-conditions for the MREs installations, the OREDP also introduces some preliminary market support schemes. The adoption of the OREDP can contribute in increasing the chance of investments in MRE sector, giving positive signals to investors and resolving potential issues.

Strengths, weaknesses, opportunities and threats are all linked with each other. If we consider all the investigated dimensions or sub-categories it may happen that what is considered as a strength in one dimension it is actually a weakness in another. Thus, it is important to properly manage the implementation of the MRE sector in order to reduce possible conflicts pursuing a path that better satisfies the general well-being according to the sustainability concept.

CONCLUSIONS

The article aim was to identify and study factors that can hamper or encourage MRE sector development, with a focus on the Italian context. The SWOT analysis has proved to be a good tool for investigating on MREs adopting an holistic approach. Indeed, factors involved in the development of MRE technologies have been divided into several dimensions in order to encompass all the possible social, economic, legal, technological and environmental aspects. However, the main limit of SWOT analysis concerns the arbitrariness. The selection or the exclusion of factors may depend on the perspective of the analyst. In order to avoid as much as possible this risk, a review in literature on MREs was done aiming at pointing out the main impactful factors across several dimensions. Another limit that SWOT analysis could experience concerns a possible loss of information or compensation processes when the information is aggregated. To alleviate this problem the disaggregation seems to be a possible solution since it allows to narrow the search to specific disciplines considering more detailed information.

The SWOT analysis reveals important outputs for the several dimension.

- Considering the social aspects it emerges that major issues concern the social acceptance of technologies. However, good transparency, communications and participatory policies may contribute in creating cohesion between the several stakeholders involved. Generally, the public support toward renewable energies is high, and for this reason also MREs could be seen positively by citizens and decision makers. An important aspects to consider is the location of technologies in order to not interfere or disturb with the recreational activities or the seascape.
- In the economic and technological field, it is possible to affirm that economic challenges stem from the increase in investment costs due to risk factors that projects face and the lack of competitiveness of MREs compared to more conventional fossil sources or more traditional renewable energies, such as photovoltaic or wind onshore. Although in Italy several research centers are promoting MRE technologies by developing innovative prototypes, the lack of subsidies, incentives or sectorial policies increases uncertainties. This condition is caused both by the early stage of MRE market and by a lack of market acceptance of MREs. The advantages bring by MREs are several in the economic field. Local control of indigenous resources together with the chance of sharing the ownership of the marine technological park, can increase the energetic independence of communities reducing price volatility. Besides, thanks to European funding, MRE could have an initial economic support. However, with the aim of stimulating the growth of the MRE sector, policy makers should introduce more economic incentives or subsidies or funding to the market. In particular, they should be explicitly oriented toward MREs to avoid investments focusing on more competitive technologies.
- A weak legal framework without clear and defined rules and laws for the deployment of MREs discourages investors. In particular, the slowness of existent procedures for obtaining permits and authorizations create delays and losses. This situation is even worsened by overlapping responsibilities between different political actors. Nevertheless, the European Union is trying the give cohesive guidelines to all Member States in order to facilitate the legal development of MREs. Also on a national dimension, in recent years, more efforts have been done to implementing renewable sources in general, and more specifically, the last year, a cluster for the Economy of the Sea was designed and now is taking shape. Reducing the legal uncertainties through sectorial laws on MREs, or simplifying the bureaucracy procedures, could be a first starting point to increase the optimism of MRE investors.
- From a technological point of view, the MRE sector seems to be promising as several research and design studies are carried out by many private and public actors and a good knowledge transferring is occurring at the Mediterranean level. However, more technological design studies and better mapping of resource potentials should be implemented. The major technological threats stem from the risk of survival due to extreme environmental phenomena, or from the environmental characteristics of marine ecosystems, such

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[13] Government of Ireland. Offshore Renewable Energy Development Plan (OREDP). Interim Review. May 2018. Available from (https://www.dccae.gov.ie/documents/OREDP%20Interim%20Review%2020180514.pdf)

as the high seas, which could prohibit the installation of technologies.

- Considering the environmental aspects, Italy shows good and stable energetic potentials in specific areas close to Sardinia and Sicily. For example, the annual average wind speeds close to Sicily and Sardinia are considered exploitable. Similarly, tidal currents in the Strait of Messina or in the Strait of Bonifacio have been found strong enough to be deployed. The possible environmental impacts regard risks for life below or under water and risk of altering the marine ecosystem. However, with a maritime spatial planning strategy and thanks to environmental evaluations, these possible impacts could be reduced by identifying areas which present low risk impacts. On the other hand, the opportunities which derive from the technologies may give a huge contribution in the mitigation of global warming, reducing the CO_2 emissions, and improving the marine environment quality.

Technologies based on MREs are promising and require a good planning. Economic, legal and technological factors are particularly relevant for the MREs sector. Since these three dimensions are connected, it is important to design a comprehensive path to act simultaneously on weaknesses and threats.

AUTHOR CONTRIBUTIONS

GG performed the SWOT analysis and wrote the draft paper. MG, FP, NM, and GS supervised the social, economic, and environmental chapters and co-authored the paper. MM and FV supervised the legal part and co-authored the paper.

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REVIEW
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Marine Renewable Energy Clustering in the Mediterranean Sea: The Case of PELAGOS Project

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The main ideas presented in this work are an outcome of the Interreg MED project PELAGOS (Promoting innovative nEtworks and cLusters for mArine renewable energy synerGies in Mediterranean cOasts and iSlands). Since Blue Energy development is at its very beginning in the Mediterranean Sea, the aim of the paper is to present and discuss in depth the key-issues for a Marine Renewable Energy (MRE) cluster development in the Mediterranean and reveal its necessity for the commercial and sustainable development of Blue Energy in the area. This cluster is expected to stimulate the relevant Blue Energy sectors under the perspective of smart and sustainable growth. A healthy cluster is based on an efficient cluster policy. The main policy constituents (innovation, legislation and financial frameworks) are discussed taking into account the interrelated characteristics that are expected to specify the commercial development of MRE in the area. Key issues that can contribute to the establishment and acceleration of deployment of the related technological innovation are identified, and existent hindrances and challenges encountered in MRE sector are determined. The importance of solid financing instruments and strong collaborations among interested stakeholders is also highlighted for the viability of the MRE cluster. Finally, as an example of the cluster activities at a national level, the Greek Hub for Blue Energy is introduced. In this respect, aspects in terms of its structure and the services provided to its members are analyzed.

Keywords: marine renewables, Blue Growth, value chain, Greek Hub for Blue Energy, clusters, financial policy, innovation

INTRODUCTION

The topic of renewable energy sources (RES) is an ever popular subject especially in an economic environment where fossil fuels have a leading role. Renewable energy is usually unlimited, conditioned to appropriate management, and, consequently, sustainable and drastically reduces greenhouse gasses emission. The clean and renewable energy resources of the world Ocean can be exploited in several ways. Therefore, the necessity for marine renewable energy (MRE) development is evident. The main types of MRE are offshore wind energy and ocean energy (sometimes called also Blue Energy[1]) that comprises energy from waves, tides/sea currents and thermal and salinity gradients; see (European Commission, 2014; Borthwick, 2016). Ocean energy

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[1] The terms Blue Energy and Marine Renewable Energy will be used indiscriminately in this work.

is included in the five sectors of Blue Growth strategy that have a considerable potential to boost economic development and provide new sustainable jobs (https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en). Offshore solar, marine biomass and ocean geothermal energy can be considered as emerging MREs.

According to Appiott et al. (2014), offshore wind energy (OWE) is the most mature type of MRE regarding technological development, policy frameworks, commercialization and installed capacity. On these grounds, OWE is the most favorable type of MRE for the Mediterranean Sea (MS). Given the EU target of at least 27% energy generation share for RES by 2030, significant MRE development is expected to be achieved globally over the next few years. Although Europe is a global leader in MREs, current status in the MS is not yet favorable for reasons explained analytically in Soukissian T. H. et al. (2017). Probably, the most important problem refers to the different uses of the ocean space that induce challenges and conflicts of interest between stakeholders' activities and uses, and policy goals that can be resolved through mutual understanding, cooperation and efficient communication. Other hindrances as regards MRE development in the Mediterranean refer to the inadequate legal-regulatory framework, the financial instabilities encountered in some Mediterranean countries, as well as the lack of Marine Spatial Planning (MSP) and Integrated Coastal Zone Management (ICZM). MSP and ICZM are prerequisites for achieving sustainability and facilitating spatial demands by diminishing potential conflicts regarding the use of marine space. Within this framework the most competitive and influential public and private organizations related with the field of MREs should join efforts and form a transnational cluster under a common vision: to establish and promote Blue Energy (BE) sector in the MS and enable its potential in an integrated and environmentally sustainable way.

In this work, the design and development of an efficient MRE cluster formation at a Mediterranean level is analytically discussed. Special emphasis is put on the cluster policy and the corresponding innovation, legislation and financial frameworks. To this end, the interrelated and multifaceted socio-economic characteristics of the Mediterranean basin are also described. These characteristics represent the most significant parameters of the geographical context in which offshore energy projects are to be implemented. As it is analytically discussed in Soukissian T. H. et al. (2017) and Boero et al. (2017), MRE development should be designed in an appropriate way so as to achieve economic viability and environmental sustainability, trying to harmonize three vital frameworks, not always aligned: the engineering, the ecological and the socio-economic one. Various aspects of these frameworks are also presented in Rodriguez-Rodriguez et al. (2016), Bray et al. (2016), Soukissian et al. (2016). An initiative toward these directions is the newly formed PELAGOS Mediterranean cluster. This cluster is expected to stimulate smart and sustainable growth in the MS through the development of BE and to accelerate the exploitation of the relevant technological innovation in the market sector.

The structure of this paper is the following: In section MRE Potential and Status in the Mediterranean, the readiness level of MREs' technologies in the MS is reviewed in brief. In section Interactions Between Marine Renewable Energy and Marine-Related Economic Activities in the Mediterranean, the competing to the MREs uses of marine space are described (tourism, fisheries, maritime transport, and ports) and the relevant MRE value chain is presented. The next section Clusters' Key Issues for the MRE Sector in the Mediterranean introduces the idea of clustering and highlights the role of cluster policy as a tool for the efficient operation of the cluster. In section The PELAGOS Project and the Mediterranean Cluster of Blue Energy, the role of the PELAGOS Blue Energy Mediterranean cluster is described in detail. In the same section, the Greek Hub for Blue Energy (GH4BE), one of the national clusters that make up the PELAGOS cluster is presented, along with the activities and services that the GH4BE provides to its members. In the last section, some conclusions and guidelines are provided regarding the rational MRE development in the MS.

MRE POTENTIAL AND STATUS IN THE MEDITERRANEAN

An extended review of the current status, main problems and challenges of MRE technologies along with some general directions for MRE development in the MS is provided in Soukissian T. H. et al. (2017). In Pisacane et al. (2018) the unlocking of MRE potential in the same basin is also highlighted as a necessity not only for energy production and independence (mainly of coastal areas) but for technology development as well. In the same study, the importance of BE translational clusters is emphasized as regards best practices and exchange of knowledge. These issues are analytically discussed here in sections Clusters' Key Issues for the MRE Sector in the Mediterranean and The PELAGOS Project and the Mediterranean Cluster of Blue Energy. As presented in both studies, there are several low-carbon technologies associated with the marine energy sector that can play a significant role in the fulfillment of the EU climate objectives. Taking into account the particularities and characteristics of the MS (e.g., rich coastal ecosystems, intense tourism, etc.) and the maturity of the BE technologies, currently two forms of BE seem to be the most propitious ones: offshore wind and waves.

Although offshore wind is the most promising type with many consented projects, no considerable progress is expected before 2020. Based on the recent analysis of Soukissian T. et al. (2017) regarding offshore wind power potential (at 80 m above sea level) in the Mediterranean, it was shown that the Gulf of Lion and the Aegean Sea are the most favorable areas for offshore wind energy projects in terms of potential (with 1,050 and 890 W/m^2, respectively). Taking into account bottom depth suitability, additional candidate areas include the Adriatic Sea and the Gulf of Gabes. In Boero et al. (2017), the Aegean Sea is highlighted as an ideal place for the installation of offshore wind turbines if additional restraints are considered (e.g., distance to shore, existing grid connection, sea-floor sediments, etc.).

Wave energy technologies present a diversity of design concepts dependent on the water depths, locations and wave characteristics hindering their progress to a fully commercial stage. The mean annual wave energy flux in the MS has been estimated for different time periods and wave data sources by various authors; see e.g., Liberti et al. (2013); Karathanasi et al. (2015); Soukissian T. H. et al. (2017). Although the estimates for annual wave energy flux vary, the relevant assessments agree that the highest wave energetic area is the extended area between Sardinia and Balearic Islands, with around 9.5 kW/m according to Karathanasi et al. (2015). Other productive areas are the Levantine and the Ionian basins, the central-northern Aegean Sea and the area between Sicily and Tunisia.

The exploitation of offshore wind and wave energy is also at the center of attention of the recently released report (EC Directorate-General for Energy et al., 2018) of European Strategic Energy Technology Plan (SET Plan). Two out of eleven adopted implementation plans (IPs) refer to BE, namely: (i) innovative for global leadership in offshore wind, and; (ii) initiative for global leadership in ocean energy. SET Plan is looking to expand the contribution of offshore wind energy in the total power supply coming from wind, which is expected to be 240–445 GW by 2030. The implementation plan is mostly committed to make this type of energy cheaper and more competitive. Thus, innovation is deeply encouraged in an attempt to find cost-effective ways for installation, operation and maintenance works. For instance, for the period 2018–2022, 10 M€ is estimated to be devoted in digital transformation in order to improve energy yield. Forecasts for the period 2018–2025 anticipate that 350 M€ is going to be devoted in the construction of large turbines able to produce more energy and harvest wind in lower speeds. The second implementation act regarding ocean energy is focused on the creation of a supply chain that could take advantage of the most advanced ocean technology present in Europe aiming to generate jobs and wealth. This supply chain will need new infrastructures, logistics and installations, which should be preferably, placed near the energy sources. Implementation plan also works in the development of a cooperative mentality, as coordinated actions are required in fields related to: (i) certification and safety standards; (ii) standardization and creation of guidelines for the evaluation of wade and tidal technology, and; (iii) promotion of a system that shares open data. Investment needs for the proper implementation of the above acts are estimated to reach the amount of 1,240 M€ by 2030.

INTERACTIONS BETWEEN MARINE RENEWABLE ENERGY AND MARINE-RELATED ECONOMIC ACTIVITIES IN THE MEDITERRANEAN

The Scenery for MRE Development in the Mediterranean

BE is the current generation of renewable energies with the potential to become a new South-European industrial sector. However, the concentration of renewable energy installations is clearly identified in the North and Baltic Seas, and in the European coasts of the Atlantic Ocean. Many opportunities also exist in the Mediterranean basin and, following EU targets, action is needed in order to be revealed. A first step toward this direction is to highlight the anticipated interactions between MRE development and other activities in the MS. The MS is characterized by important economic activities (coastal tourism, fisheries and aquaculture, maritime transport, etc.) and thus, the strategy of MRE development should account for the potential conflicts and impacts that may raise.

In any attempt for MRE development in the MS, the preservation of the good status of coastal and marine ecosystems is of first priority. On the other hand, the range of interactions between MRE and other marine uses, and the cumulative impacts of their pressure to ecosystems are hard to be determined at a first sight; evidently, it is rational to reinstate the operating principles of the main maritime sectors targeting to sustainability and efficiency. These values and principles will hopefully portray the future actions of the first Mediterranean cluster being developed under the framework of PELAGOS project; see section The PELAGOS Project and the Mediterranean Cluster of Blue Energy. In this connection, a general guideline is enacted in advance in order to: (i) qualify and treat the exploitation of MRE as the most sustainable and healthy way to produce energy; (ii) regulate the conflicts of interest arising from the overlapping use of marine space; (iii) fairly compensate potential negative aspects of MRE installations and mitigate social oppositions. Since OWE will soon start developing in the MS, the co-existence of other activities with offshore wind farms (OWF) is a subject of discussion and specific recommendations are provided in a way that the aforementioned sustainability and efficiency can be attributed. Since the rational exploitation of MRE is the most sustainable and healthy way to produce energy, this can be achieved by harmonizing conflicting frameworks that are evident during the design of an OWF. The coexistence of OWFs with aquaculture is an indicative example: with the appropriate information campaigns, consultation activities and incentives, conflicts can be mitigated between the involved stakeholders. Additional examples are provided in the forthcoming sections.

In a study by WWF (Piante and Ody, 2015) regarding the marine-related activities taking place in the MS, the necessity for a long-term vision for sustainable development has been emphasized, built upon the Barcelona Convention. In February 2016, the revised Mediterranean Strategy for Sustainable Development (MSSD) for the period 2016–2025 has been adopted. This Strategy was formulated through an inclusive process that involved key regional and national stakeholders. One of its main aims was to identify the specific direction that should be followed for the wellbeing of tourism, maritime transport, aquaculture and other sectors, affecting and involving, directly or indirectly, MRE sector as well (see next sections). In principle, the degradation of ecosystems and loss of biodiversity, the insufficient legal instruments that support sustainable development and climate change adaptation (mentioned in the revised MSSD) should be also taken into account in offshore wind energy projects. For further information on MSSD and the Barcelona Convention, see (UNEP/MAP, 2016)[2], respectively.

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[2] United Nations Environment Programme. Available online at: https://en.wikipedia.org/wiki/Barcelona_Convention (Accessed Jun 29, 2018).

MRE and Tourism

In the Mediterranean region, tourism activities are connected with a variety of recreational and business purposes and are mostly coastal oriented with dramatic increases during July and August. According to World Travel Tourism Council (2015), Mediterranean tourism offers 11% of total employment and contributes by 11% to the regional GDP. As it is noted in Fosse and Le Tellier (2017), Mediterranean area is a favorable destination in terms of both international and domestic tourism (more than 300 million International Tourist Arrivals), with a forecast of 500 million by 2030. Nevertheless, major problems such as the economic leakage through the unbalanced distribution of tourism-generated revenues, and the overconcentration in coastal areas accompanied with negative environmental impacts cannot be neglected. These conflicts may be mitigated if the belief that competitive tourism must be based primarily on environmental sustainability is cultivated. According to the main framework of the MSSD 2016–2025, long-term targets and key guidelines should be followed in order to deal with the issues identified above. The good environmental status should be the milestone of the strategy, promoting a premium model of ecotourism where tourists are willing to pay in order to be familiar with the cultural and the environmental wealth of the Mediterranean coasts. Carefully selected islands could constitute preferred demonstration regions for any innovative MRE projects. The compatibility between MRE sources and sustainable tourism development in the MS has been studied in Michalena (2008). Potential negative effects of OWFs in coastal tourism and in particular the visual noise effects have been discussed analytically in Boero et al. (2017).

The potential beneficial interventions of MRE projects, many of which have already been successfully tested in ecotourism, are the following: (i) power supply of local authorities and other infrastructures (hotels) can be provided by MRE; (ii) MRE installations can be used as thematic parks attracting alternative tourism. The habitats developed under MRE installations can be served for diving purposes; (iii) exhibition centers, such as marine museums, aquariums, etc., can be constructed near the OWFs' areas. Evidently, all these possibilities should be taken seriously into account as they create positive externalities for the nearby communities.

MRE and Fisheries

As it is stated in Food Agriculture Organization of the United Nations (2016), fishing industry provides about 220,000 jobs (employed on fishing vessels) and is therefore considered a main pillar of the Mediterranean economy. In the same reference it is highlighted that commercial fishing remains a valuable coastal industry for many countries including Italy, Greece and Spain. The increased demand for sea space dedicated to future MRE developments will also impact this industry. Consequently, as De Groot et al. (2014) mention it is necessary to consider efficient ways in order to harmonize future MRE and fisheries co-existence. The diverse morphology of the basin is an important sustainability factor that regulates the fishing activity as well as the impacts of future MRE projects in the entire region. Fishing in the MS may take place on the continental slope, while, most usually, is concentrated in depths up to 400 m and in nearshore areas (Piante and Ody, 2015; Food Agriculture Organization of the United Nations, 2016). Therefore, the installation of OWFs is less likely to be in conflict with these activities. Nevertheless, each area has its own particularities, obstacles and difficulties as well as strengths and opportunities may vary depending the case. Potentialities and opportunities (e.g., no-fishing areas, artificial reef effect and alternative employment) must be carefully adopted and used against oppositions. See also (Boero et al., 2017) for a detailed discussion.

MRE and Maritime Transport/Ports

In the recently published review (United Nations Conference on Trade Development, 2018), the significance of the maritime transport is highlighted. Board ships are the main mean of transport, carrying 80% of global trade by volume that subsequently is being handled by seaports. As it is mentioned in Piante and Ody (2015), hundreds of these activities are taking place in the waters of MS and therefore maritime transport presence is intense in the area. Also, some indicative and self-explanatory numbers, regarding maritime sector in the area of MS, could be the 550,000 direct jobs provided and the noteworthy participation of 21 ports in the list with the 100 world top ports.

Maritime transport is not an opposing activity to MRE development; on the contrary, maritime transport sector with ports at its center is bringing revolutionary ideas in harnessing MRE sources. Following the maturation of OWE and taking advantage of the declining costs, ports have started to transform their infrastructures in a way to support OWE and the entire supply chain contributing thus to cost reduction and efficiency (Wind Europe, 2017). For instance, large available spaces, found mostly in the yard, can be either used as warehouses or for training purposes (staff, visitors, etc.). Furthermore, their location facilitates the transportation of large components, avoiding not only a huge transportation cost but also many other incurred risks related to transport. Moreover, a survey conducted by the European Sea Ports Organization (2016) revealed that 38% of port authorities are facilitators of renewable energy production in the port while 16% are even investing or co-investing in renewable energy production. Evidently, MRE can be used in ports for cold ironing[3] purposes, while ports are expected to play a key role in MRE development, as they are becoming breeding grounds for blue technological innovation.

Overall, MS space can be exploited in many efficient ways, if a certain MRE mentality is to be adopted in its activities. It is also essential to explore the nature of the value chain mechanism that governs these activities in order to estimate correctly the range of these opportunities.

The MRE Value Chain

Value chain analysis focuses on the examination of the core and supportive activities of a project in an effort to understand costs, locate the activities that contribute the most in the generation of

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[3] Cold ironing (ship electrification) is a procedure for providing electricity in ships while at berth. Cold ironing is an EU priority and the subject of the recently completed ELEMED project (https://www.elemedproject.eu/).

adding value, and differentiate the project from the competition. It facilitates the search for synergies among sectors of different, but related, market subjects while it also provides a measurement to the stakeholders, as regards the externalities developed among sectors to the local and regional economies. Thus, it sets a basis for discussion around controversial issues and targets that should be met in the future.

Considering a particular BE project, e.g., the installation of offshore wind turbines, the relevant value chain reflects most of the life cycle of the project: it goes from the design and preliminary assessment phase that includes resource assessment, environmental impact assessment studies, design of the infrastructure, permitting processes, etc., continuing with the manufacturing including feasibility studies, testing in scientific labs, etc., the installation (e.g., assembling of different components, transmission of infrastructures, etc.), the grid connection, the operation and maintenance of the farm, and the decommissioning phase. The intervention of other actions, such as interpretation of regulatory frameworks, financing plans, risk assessment, logistics, etc., need also to be considered for the efficient implementation of the offshore project. This extensive BE value chain analysis, along with the identification of potential key players in the field, leads to the pathways for clustering aiming at the prompt and rational organization of all actors that will be involved. These issues have been analyzed in the Interreg BLUENE project (http://www.medmaritimeprojects.eu/section/bluene).

CLUSTERS' KEY ISSUES FOR THE MRE SECTOR IN THE MEDITERRANEAN

Introduction to Clusters

In an environment where the demand for renewable energies, and especially of BE, is continuously growing, a new strategy plan is adapted in the EU member countries. The pillars of this plan are based on the synergies among different stakeholders involved in the BE value chain. The necessity of fostering teamwork and collaboration in and between companies and institutions has been described by many economists as the primordial factor that determines their competiveness and innovation level. In the case of BE market/value chain, it is evident that any collaborative scheme should be applied in an extended geographic scale/region.

According to the definition of Porter (2008), clusters are "*geographically proximate groups of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities.*" Cluster members could be suppliers, service providers, firms in related industries, universities and research centers, etc., that are competitors but at the same time cooperators. Clusters are considered the most practical and profitable formations under which a large variety of marine-related sectors could be implemented. Moreover, the idea of clustering is entirely harmonized with the vertical integration concept, which drastically changed the status quo of economy in the early 20's. Until today, it continues to dominate the majority of economic activities. Economies of scale, outsourcing plans and value adding activities are the most eminent features of its application. In an era where the shifting nature of competition is increasingly driven by knowledge and skills, clusters play a fundamental role in the dissemination of knowledge and innovation, and the accumulation of skills. In this way, clusters represent the dedication to expertise as a rational alternative to low cost labor and low quality solutions.

Cluster Policy

The Role and Importance of Cluster Policy

Usually clusters emerge spontaneously triggered by a major event, turmoil, necessity, etc. The question that arises here refers to whether this spontaneous creation of clusters, responding to market signals, should be left to develop naturally. In our opinion, the potential accumulation of benefits from positive externalities previously distinguished creates a strong rationale for cluster policy that should regulate the activities of a sustainable renewable energy cluster. Given that there is no international instrument to cope with all potential elements of energy governance in the context of a cluster (Steffek and Romero, 2015), it is more probable to face a multi-level governance system extending in overlapping areas (Goldthau, 2014) since (i) MRE's regulation is spread across various areas of international (and national) law; (ii) diametrically opposed interests are arising from the implementation of institutional arrangements, and; (iii) main actors in the RES landscape are often geographically widely dispersed and isolated as regards potential collaborations (Jaegersberg and Ure, 2017).

Recently, the orientation of clusters has been significantly altered. A "top down approach," defined as the situation where economic opportunities are driven to industries (small & medium enterprises/SMEs) with little existing business culture, is being adopted[4]. The renewable energy market with its dynamic changing business landscape is becoming more competitive and less predictable at the same time. Obviously, it becomes imperative for policymakers to be aware of existing obstacles and opportunities on time in order to create the conditions for the prosperity of a value added cluster.

Designing Cluster Policy

In macroeconomic level there exist, in theory, rational guidelines regarding issues that concern policies and strategies for the development of clusters (e.g., the diamond model; Porter, 1998, 2011). However, when this knowledge is to be applied in more dynamic conditions, we come across with deficiencies of the theory and resistances in its implementation. As it is noted in Atkinson and Audretsch (2008), the realization of economic value in clusters are affected by barriers and enablers on the ground.

The design and construction of cluster policy that confronts deficiencies could commence with the adoption of basic principles from a broader strategy in transnational level. Best practices already tested in a wider European extend, combined with the experience from the confrontation of recurring barriers

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[4] Note that in the past rich matrix of alliances and networking had been evolved within a small region between already tested and strong associations.

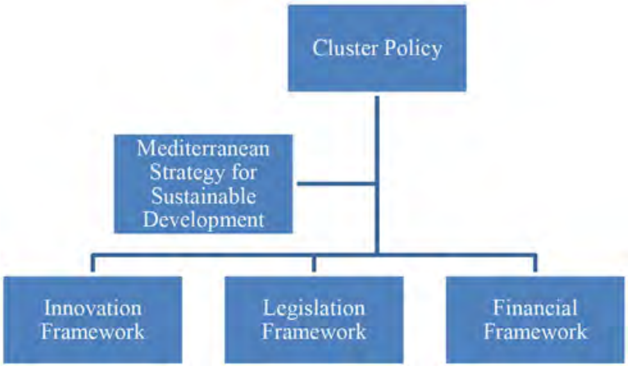

FIGURE 1 | Main constituents for a rational cluster policy.

identified in RES clusters, could provide useful guidance and should be seriously taken into consideration. For instance, MSSD could be used as a starting basis for the smooth assimilation of sustainable development into the corresponding strategies of the Mediterranean EU member states. The provision of its tools and suggestions, under which interconnected levels of government are operating, could be a huge assistance in the formation of the cluster policy. The framework, shown in **Figure 1**, is proposed as the backbone of cluster's policy formulation that will accompany any attempt for cluster establishment and maturation. Subsequently, useful lessons and experiences coming from recurring barriers will frame this scheme.

The general strategy perfectly aligned with the needs and the aim of a sustainable MRE project is the MSSD 2016–2025, which addresses important issues extending in the edge between "environment" and "development." It is anticipated that MSSD will establish and reinforce synergies between the activities of different stakeholders relevant with the BE value chain. It is also anticipated that MSSD will provide a common framework, in order to render efficient the implementation of sustainable development, (UNEP/MAP, 2016). In this connection, issues that should be addressed originate from sectoral, institutional and legal limitations, referring also to environmental aspects and socio-economic challenges. An overview of the current socio-economic and environmental impacts along with guidelines for the sustainable development of MRE in the MS is provided in Soukissian T. H. et al. (2017). These impacts should be considered before delving deeper into the policy perspectives of BE.

Recurring Barriers in Renewable Energy Clusters

In real world, recurring barriers are identified in the majority of clusters. In this work emphasis is put on SME-related issues considering their important contribution to job and wealth creation. A better understanding of the linkages between stakeholders is of critical importance in order to extract valuable conclusions for the design of cluster policy and functioning. As it is noted in Jaegersberg and Ure (2017), the identification of recurring barriers is clearly expressed through paradigms of different renewable energy clusters. This is necessary in order to understand the issues that arise in different contexts and highlight their value creation in clusters. Unfortunately, value creation is currently not receiving the appropriate attention from policymakers. Even some of the examined clusters are out of Mediterranean region, their contribution to define the first steps of cluster policy is decisive. The following examples are analytically discussed in Jaegersberg and Ure (2017).

The Baixo Alentejo PV cluster in Portugal adopted a "top down" approach in an environment lacking of real business culture and well-established networks of communication and coordination between the players. The most important difficulty was due to the restricted opportunities for SMEs to engage constructively with other stakeholder groups. The problems faced and the complaints raised by small-scale producers in their attempt to install solar products, when this was asked, can be summarized as follows: (i) Large enterprises and government shared power and influence; (ii) Bureaucratic issues combined with lack of transparency and safety; (iii) Lack of SMEs real representation in decision making; (iv) Universities and R&D institutions preferred to run research projects with large companies refusing at the same time to generate shared value from SME niche knowledge.

The Canadian Case in Alberta pictures the attempt of an early stage RES cluster to compete against well-established companies that produce electricity via fossil fuels in a supposedly liberalized electricity market. The reality, however, was quite different from the investors who tried to break the "monopoly" of fossil fuels. Incentives such as Feed-in Tariffs (FiTs) and quotas were absent in Alberta whereas neighbor regions were providing more favorable investment regimes. The differentiation in energy policies along with the cost efficient production of energy from oil and gas producers created harsh conditions for the cluster. The main problems that the involved SME's identified, referred mainly to the uneven level playing field, through unfair competition between RE and oil and gas companies, bureaucratic issues, shortage of long-term policy and of expertise in the sector of renewables, and the limited participation of SMEs in decision making procedures.

The German PV cluster faced recurring barriers of economic nature. The cluster was initially rapidly grown driven by the mechanism of FiTs and special funding programmes and Germany met a record rise in installations. According to EPIA (2012) Germany had the biggest PV share in a global level (24.7 GW capacity). A remarkable augmentation in the demand of solar panels though had a major effect in cost, enough to signal a governmental adjustment in the framework of FiTs. The majority of SMEs opposed to the change, stating that PV could not support itself without FiTs, as extra amounts of money directed to R&D incentives were indispensable. Combined with the increasing competition from China and low-labor countries, SMEs found themselves disproportionately penalized at the forefront of innovation. Eventually, there was a significant distortion of the market as a result of cheap imports and that Chinese companies took advantage of the less restrictive environmental standards and regulations, and the cheaper labor costs.

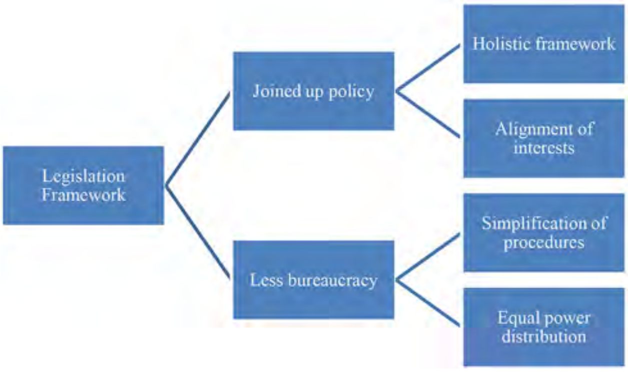

FIGURE 2 | Cluster policy: visualization of concept for legislation framework.

The Three Constituents of Cluster's Policy

Legislative Policy

In **Figure 2** the main necessities for an efficient legislative policy are summarized: (1) a joined up policy that should encompass a holistic framework, which caters the interest of individuals and the alignment of interest of the involved stakeholders, and (2) the minimization of bureaucracy, leading to simplification of procedures and equal distribution of power among the shareholders. Lack of joined up policy and bureaucracy resists tightly to any positive change due to deep rooted habits and mechanisms.

Clusters need to become accustomed with new ideas and business models in order to face key aspects of legislative issues concerning mostly the lack of joined up policy and the delays faced in its implementation. The most profound problem concerns the willingness of national and local authorities to adapt in these new business models, which make the whole process more cumbersome. Their arrangements, laws and actions are often hindering the smooth operation of necessary activities toward BE growth by causing conflicts of interest (overlapping issues, etc.). Another problem concerns the interests of disparate groups, often intensified in early stage clusters where the collaboration scheme involves different administrative bodies. In this direction, the efficient revision of national, and at a next phase transnational, policies and the integration of environmental, socio-economic, technical, and legislative considerations into a single holistic framework is necessary. Although harmonization and integration of regional, national and transnational policies is not easy, it is of crucial importance in order to mitigate the above-mentioned problems. A legislative and regulatory infrastructure aligning the different interests and point of views, and assessing all the political ramifications is complex to be designed and hard to synchronize. Realistic and necessary steps in facilitating a joined up policy that boosts MRE development in the area are the following: (1) governance support; (2) centralization and decreasing of the permitting bodies to the less possible number; (3) composition of a comprehensible document which summarizes and simplifies the licensing and permitting procedures, and; (4) countenance of activities that promote synergies among European stakeholders (improvement of regulatory frameworks, creation of platforms, coupling of private and public sector through partnerships). For a discussion on these issues see also (Soukissian T. H. et al., 2017).

Legislative gaps and delays of the kind described in the case of Portugal cluster constitute a considerable barrier to cluster performance. Cumbersome bureaucratic issues are frequently encountered during different stages in the implementation of a MRE project. Companies' efficiency is closely dependent on the degree they can surpass these issues. However, as it is noted in Garbe et al. (2012), the footprint of these issues may not be necessarily negative, as some organizational and geographical constraints are acting beneficially to some clusters.

A conclusion from the study of RES cluster cases is that bureaucratic issues are often being created by default, rather than by design or intension. Newly created clusters or clusters with high participation of SMEs in their composition are characteristic examples of this situation. For example, in Portugal, bureaucratic procedures excessively impacted SMEs that participated mostly in system installations. Additionally, a lot of SMEs with tight margins found difficult to dedicate time and resources to fulfill administrative tasks and also to apply for funding. Finally, there are cases, like the Canadian one, where SMEs felt that the design of the cluster and the process itself was not created based on their needs, leaving hints for un-even competition and distortion of the market.

Innovation Policy

Science is a prominent key to success; sometimes, however, it is mistakenly sidelined by other relevant or irrelevant activities. "Innovation policy" ("smart growth") in a broad extend refers to the materialization of new ideas and their diffusion in the economic and social system. In other words, innovation policy attempts to influence and shape activities, often with the purpose of increasing economic growth. In an attempt to design Europe 2020 strategy, two important initiatives have been developed and adopted by the European Commission (EC): (i) the "Innovation Union" flagship initiative (https://ec.europa.eu/info/research-and-innovation/strategy/goals-research-and-innovation-policy/innovation-union_en), and (ii) the "Regional Policy contributing to smart growth in Europe 2020" (European Commission, 2010) that concerns smart specialization and growth. The main constituents of innovation policy are summarized in **Figure 3**, which depicts the sequence of actions that should be followed. Initially, a long-term, efficient and stable funding strategy will enhance for granted collaborative schemes and will benefit the creation of new jobs. This collaboration, in turn, implies the existence of certain places, such as online platforms, equipped with effective tools that are working toward both the facilitation of those initiatives and the interaction with the societal part.

Clusters that inherently support regional cooperation between diverse innovation actors, provide a favorable ground in which objectives set from the aforementioned consultations could be applied. Barriers and challenges also identified will help to detect the actions needed in order to develop a rational, cluster-based, innovative policy. In the medium term, clusters act as efficient platforms disseminating the good practices and maybe even later

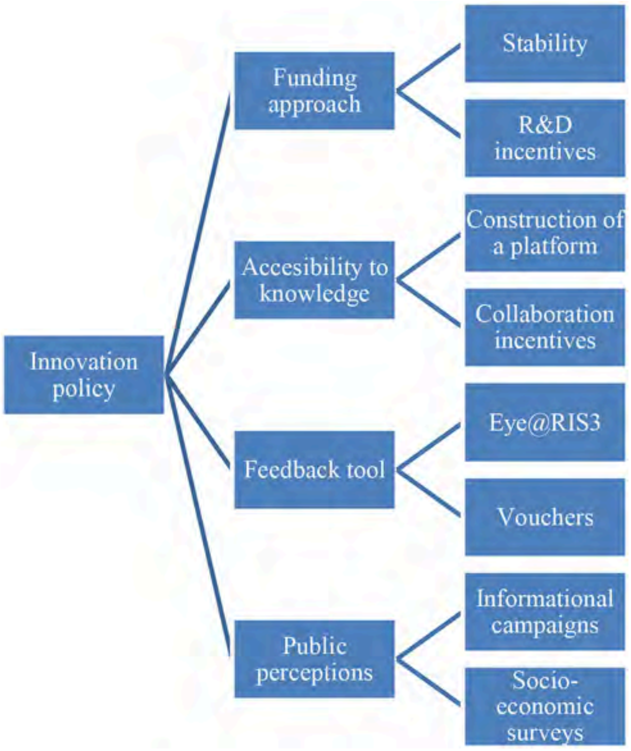

FIGURE 3 | Cluster policy: quadruple axis of innovation policy.

could be used as a guideline for the design of transnational innovation policy.

To start with, the concentration of key players with high experience in the BE sector shall be at the top of the agenda of this innovation system. In the Canadian case, the lack of experienced scientific staff was underlined, while in the German cluster a fear was expressed that mechanical engineering enterprises, suppliers and R&D institutions would move to places with higher perspectives in terms of salaries. The absence of a long-term funding plan, apart from the oncoming insecurity and instability to the concerned parties of a RES project (investors, scientists, institutions, SMEs, etc.), is the most eminent and recurrent issue that affects the development of RES clusters and subsequently, the whole process toward blue growth.

Another important issue that innovation policy has to deal with is that the existing practical knowledge and scientific findings are rarely concentrated in one database or platform, rendering it inaccessible to many stakeholders. A full exploitation of capabilities provided by universities and R&D institutions presupposes the collaboration between them and the stakeholders within the cluster. However, as stated by Jaegersberg and Ure (2017), the reality is hardly ever that ideal. Instead of generating shared value, it was noticed that the connection between universities and SMEs formed barriers in key areas like the German case, where universities were perceived having dissimilar goals and operation procedures from SMEs.

Clearly, incentives and ways of working together should be cultivated as well as a transfer-knowledge platform must be created. This collaboration is in agreement with MSSD and the general European vision to build on strengths and comparative advantages originated from SMEs in relation to R&D SMEs. An aftereffect of the need for collaboration is the development of the Strategic Research and Innovation for Smart Specialization (RIS3), which is a requirement in order to receive funding from the European Regional Development Fund (ERDF) (https://ec.europa.eu/jrc/en/research-topic/smart-specialization). In Sörvik et al. (2016) it was shown that some EU member states changed their attitude regarding collaboration on R&I due to the new cohesion policy, with the majority (67%) having increased cooperation the past two years.

Directly intertwined with the necessity of an online platform is the construction of a business tool that allows timely feedback to those developing and applying policies. The Eye@RIS3 for example (http://s3platform.jrc.ec.europa.eu/eye-ris3), as a part of the Smart Specialization Strategy Platform (S3P), has been developed as a strategic tool aiming to highlight and distribute knowledge among users. By updating the database with regional/national priorities, a high-quality feedback is obtained in topics related to European Innovation Partnerships, projects (H2020, Interreg MED), thematic workshops, etc., enabling others to find their niche in the market and search for potential partners to develop collaborative schemes on certain topics. Eye@RIS3 can be used also as a benchmarking tool allowing comparisons between RIS3 and R&I specializations in order to understand the innovation strategies of other countries or regions and identify competing niches.

A successful innovation strategy should look after for the settlement of more qualitative targets clearly expressed in the Europe 2020 strategy structured to create new job offers and to deliver a sense of direction to the society. Job offers seem to be achieved through voucher initiatives, recently gaining space in many countries, with the following two-fold impact: (i) permitting SMEs to share their problems related to innovation with knowledge providers, and; (ii) providing incentives to public knowledge provider to collaborate with SMEs. Finally, the innovation policy should necessarily deal with the problem of social acceptance. Again with the contribution of governance support, innovation must ensure the supply of high educated citizens. Informational campaigns and training platforms must be designed in an attempt to raise environmental awareness of the local communities. A certain feedback through socio-economic surveys, during the design phase of MRE projects, along with public consultation procedures should also be adopted.

Financial Policy and MREs Financing

Financial policy

Most of cluster's efforts have instinctively focused on finding effective financing tools to ensure the diversification and health of their economic activities. During the last decade, many researchers have tried to spot the hindrances encountered by RES projects in getting and appropriately managing funding. These barriers have their roots in "systemic" and "non-systemic" problems. "Systemic" problems will unavoidably appear and are related with politic/policy decisions and issues. "Non-systemic" problems refer to the barriers that stem from the insufficient awareness that characterize stakeholders regarding the existing financial institutions and funding instruments along with the risks and opportunities associated with them. Another side of "non-systemic" problems is the technological one. Specifically, a great mix of problems takes place such as lack of experience in terms of scientific research, new types of sponsors and business models, rendering private investors reluctant to fund innovative projects.

The organization of a financial policy around clusters is a challenging task. It aims to elucidate topics related to funding instruments and regulate governmental resolutions regarding public-private partnerships, Foreign Direct Investment attraction plans, tax rebates plans, favorable bank loans, etc. In this way clusters would become an organizing principle to integrate different economic policies, overcoming the obstacles that characterize each national economic policy. These issues have been also discussed in the financing strategy of MSSD 2016–2025, where the allocation of funds and the mutual involvement of shareholders is underlined as the most beneficial action toward the implementation of the financing strategy directions. These actions may embrace the construction of projects' portfolios or even the organization of fundraising activities during capacity building seminars and workshops. The Strategy also highlights the significance of the engagement between private and public sector. It also visualizes the creation of an independent investment facility that simplifies the economic framework by embodying many international institutions in an attempt to boost MRE investments.

A steady economic environment favors investments and facilitates projects of greater scale and incentives. A transparent political scene committed to a long-standing relationship with RES, which leaves little space to uneven competition, is a prerequisite. Market has detected the absence of a reliable mechanism able to reduce regulatory risks and cost of capital and hence, bring back confidence to its actors. Therefore, tax rebates plans and the issuance of power purchase agreements, for countries where no FiT system exists, are measures of critical importance. Perceived risks of investors are necessary to be abridged. Ideally these proclamations will be used as inputs in tools like Eye@RIS3, giving a general guideline to the innovation policy. Finally, clarity, simplification, transparency and equal access to information is a challenging task taking into consideration the extended coordination required in a multi-institution level. To qualify a financial policy as stable, a plan, full compliant with legislative policy, is imperative. Tremendous assistance in this effort provides the EC simplification handbook (http://ec.europa.eu/regional_policy/sources/docgener/factsheet/new_cp/simplification_handbook_en.pdf).

MRE financing

EU provides a big variety of public or private financing instruments targeting the RES field particularly through the European banks IEB and EBRD and the European fund organizations (ERDF, CF). The type of MRE, as well as the stage of development of the technology, will determine the choice of the most suitable financing instrument. In **Figure 4**, the financing instruments that are available and can activate and accelerate the development of MRE are presented, namely: (1) SME instrument; (2) Energy market; (3) Traditional financing tools (R&D Grants, venture capital, etc.); (4) Debt financing. Special reference is made to the SME instrument and the financing directly from the energy market. SME instrument is the dominant financial incentive provided by EU for SMEs. With around 4,000 SMEs being selected to receive funding the last three years of its implementation, it can be considered the dominant financial instrument for SMEs.

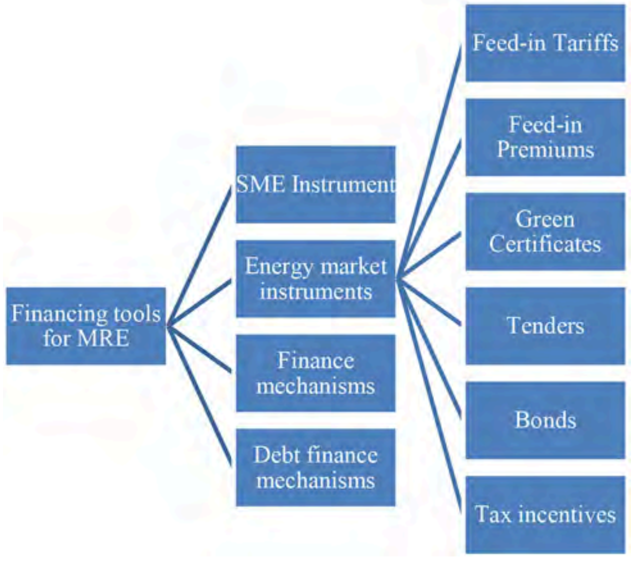

FIGURE 4 | The financing tools for MRE.

SME instrument. It was launched on 2017 as part of the Horizon 2020 (H2020) work programme (http://ec.europa.eu/research/eic/index.cfm). SMEs, either based in EU or established in a country related to H2020, have the potential to get funding for their innovation projects. The instrument has already provided a huge incentive to SMEs, by supporting the most impactful and groundbreaking ideas with the amount of €1.6 billion over the period 2018–2020 (https://ec.europa.eu/programmes/horizon2020/en/h2020-section/sme-instrument). Its aim is to give an innovation boost to the existing market and disseminate the projects' outcome in an international level. Specifically, the SME instrument is fulfilled in two or three phases. Phase 1 (feasibility assessment phase) is optional and provides the assessment of the technical feasibility and the commerciality of the project. A lump sum of €50,000 per project is granted and the duration of this phase may typically be around six months. In Phase 2 (Innovation Project), the indicative range of funding fluctuates between €500,000–€2.5 million or more, covering several activities like prototyping, design, testing, etc. This phase is also the most time consuming and it may vary between 1 and 2 years. In the framework of Phase 3 (Business acceleration), SME instrument proposes business acceleration services like linking with private investors. Finally, coaching service is being offered to SMEs by experienced business coaches, selected through the Enterprise Europe Network during phases 1 and 2 in order to ensure the sustainability of their projects in terms of strategy and innovation. Coaching and mentoring services are in progress, in an attempt to prepare SME for a pitching with investors to access potential funding. These initiatives are placed under the umbrella of finance mechanisms, some of which are described in the rest of this section. For other financial instruments, see (http://www.eib.org/en/products/blending/innovfin/products/index.htm) for InnovFin loans, (https://ec.europa.eu/growth/access-to-finance/cosme-financial-instruments_en) for COSME and (http://ec.europa.eu/regional_policy/en/funding/financial-instruments) for European Structural and Investment Funds.

Energy market instruments. FiTs were the first implemented mechanisms of public support. Incessant retail prices are being secured for RES plant operators for a certain period while from policy perspective, FiTs constitute the most stable and predictable instrument (see also Held et al., 2014; Ren21, 2014). As presented in Hogg and O'regan (2010), FiTs can be financed through tax revenues; alternatively, market participants (e.g., electricity suppliers, network operators, etc.) can adjust FiT costs among corresponding consumers. A fact worth mentioning is that countries that have adopted tariff systems have proven records of lower cost of capital in comparison with the ones that implement different instruments and involve higher risks in MRE projects. Despite the aforementioned advantages of FiTs, the price-driven nature of this instrument does not match with the policy of many countries. Recently some countries have decided to move to auctions bidding process (FiP) as a way to distribute renewable energy capacity. A recent overview of the FiTs in the European Union can be found in Cointe and Nadaï (2018) and (http://www.res-legal.eu/).

FiP systems are used as the main support instruments in Denmark and the Netherlands, while in Spain premiums and tariff system co-exist. The level of premiums is based on future expectations regarding the cost of electricity and the average market revenues, thus embodying risk of inducing additional costs for society and windfall profits for producers when production costs are over-estimated. In most cases, reduced tariffs have been achieved with this bidding process in comparison with previous incentives (Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and Bloomberg New Energy Finance, 2018). In the guidance of the renewable energy support framework adopted by EU (European Commission, 2013), it was suggested that FiPs, along with other support mechanisms, should take the place of fixed FiTs since the former are more rational, adaptable and able to support schemes that can lead to lower production costs. The pros and cons of fixed FiTs and FiPs are discussed in Bigerna et al. (2015) and De Jager et al. (2011).

Quotas obligations and tender schemes are currently based on fixed quantity instead of a fixed market price for electricity. According to Schaeffer et al. (1999), green certificates (GCs), the most well-known form of quotas obligations, are created by the producers of electricity, having a two-fold purpose: (i) to verify the implementation of obligations, acting as an accounting system, and; (ii) to facilitate electricity market from RES, leading to the establishment of a GC system for renewable electricity apart from the market of traditionally produced electricity. The GCs, bought from the producers of RES electricity, become valuable for the corresponding consumers since penalties are set to them if they do not fulfill the energy targets within specific period of time. Due to this increase of GCs supply and the competition between the producers it is foreseen that there will be a fall as regards the price of RES electricity. For this reason, GC are characterized as an efficient way to satisfy RES target.

Government tenders, the second scheme of fixed quantity, refer to the process where bids are invited from a variety of stakeholders for large projects that must be submitted within a deadline. Bidder with the lowest price "wins" contract and has the exclusive right for renewable electricity generation. Bids can take various forms (total investment appraisal, cost per unit of electricity). Though tenders seem to be a high-degree supportive scheme as it presents the highest cost efficiency, in practice it will be easily recognized that often tenders are accompanied with numerous problems. Intense price competition favors "large players," something that opposes with the idea of clusterization and the general European direction regarding SMEs. Moreover, it should be underlined that the lowest bid is usually aligned with the cheapest technology, a situation that must be avoided especially for MRE projects.

The fifth relevant category are bonds. Particular attention should be paid in the green bonds. As a conventional bond, a green bond (conceives also the blue growth concept) is a debt contracted for projects with an extended life-time, which are obliged to meet certain environmental qualities. What differentiates them is that in order to access the market of green bonds, time consuming compliance activities and some extra costs, mostly related with reporting activities, are required. By holding such asset institutional investors demonstrate their adherence to their own sustainability targets, reducing at the same time their exposure to MRE projects financial risks. The green bond market in Europe is yet a fraction of the international debt market. Total issuance of green bonds reached $120 billion in 2017 while global green bond issuance amounted of around $21 trillion. Compared, however, with the total amount allocated for climate-aligned universe ($696 billion) the amount of $120 billion corresponds to 17%; (Climate Bonds Initiative, 2017). Giant European energy companies have the monopoly of energy issuance. The Danish energy company Ørsted has passed to renewables (mainly offshore wind) from fossil fuels while many others are in a transitional stage, with funding provided stably by green bonds (Climate Bonds Initiative, 2018). Green bonds are typically for those who have an already tested experience in the market and are willing to pay over the odds. In case of MRE projects, if demand continues to increase ahead of supply, which is already a fact, it will inevitably lead to a pricing advantage for bond issuers. Benefits arising from the issuance of green bonds, not always tangible such as good reputation, can be identified through a careful examination of BE value chain.

Lastly, tax incentives and other RES incentive schemes may act complementarily. Some countries, like Greece and Spain,

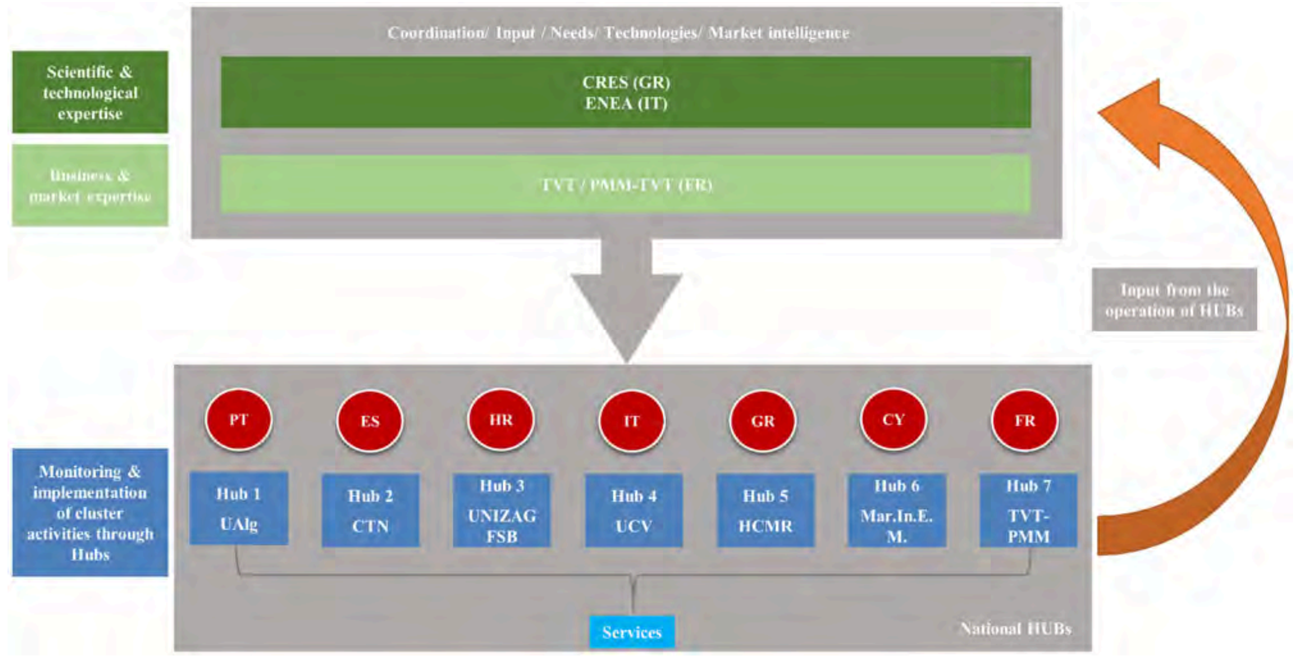

FIGURE 5 | Roles of the PELAGOS partners.

provide tax incentives (tax deductions, accelerated depreciation) in order to encourage specific renewable energy technologies and stimulate investments related to RES projects.

An in depth analysis including comparisons between these instruments and a meticulous evaluation of them using further criteria, like long-term competitiveness, governance and stability, can be found in De Jager et al. (2011).

THE PELAGOS PROJECT AND THE MEDITERRANEAN CLUSTER OF BLUE ENERGY

PELAGOS is co-funded under the Interreg MED programs by 85% from the ERDF and 15% from national resources (https://pelagos.interreg-med.eu) with a total budget of €2,396,104. The PELAGOS partnership is the following: (1) Centre for Renewable Sources and Energy Saving (CRES) (Lead Partner), (2) Hellenic Centre for Marine Research (HCMR)—Greece, (3) Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), (4) Association of Chambers of Commerce of Veneto Region (UCV)—Italy, (5) University of Algarve (UAlg)—Portugal, (6) CTN Marine Technology Centre (CTN)—Spain, (7) Maritime Institute of Eastern Mediterranean (Mar.In.E.M)—Cyprus, (8) Toulon Van Technologies (TVT/PMM-TVT)—France, and (9) University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture (UNIZAG FSB)—Croatia.

Structure and Roles

PELAGOS brings all the necessary structural blocks of designing and running a cluster that offers services to beneficiaries along the Mediterranean BE value chain in a robust way. The PELAGOS BE cluster aims to identify common opportunities in the business, technological and socioeconomic fields and is integrated under the framework of the Transnational Cooperation Scheme. The cluster is composed of seven national clusters (HUBs), where each HUB consists by national key actors dedicated to R&D, innovation and policy including mainly SMEs, technology providers, researchers, start-ups and spin-offs, entrepreneurs, policy makers, large firms, regulatory authorities and NGOs. The services of the cluster in a national level are offered by the HUBs while the cluster orchestrates the national and transnational activities. PELAGOS partners are exchanging in a coordinated manner and define common objectives and plans of action. CRES, ENEA & TVT-PMM act as technical and scientific organizations that provide methodological, scientific and technical background during pilot activities, while UAlg, CTN, UCV, HCMR, UNIZAG FSB & Mar.In.E.M., TVT-PMM act as operational institutions through pilot implementation and provision of support services to all key actors in their national HUBs; see **Figure 5**.

HUB Services

PELAGOS is preparing a suitable environment for cooperation and internationalization of the Mediterranean cluster and its members through the implementation of pilot activities at regional and transnational level. Certain services are provided from national HUBs in an attempt to stimulate MRE development in key market sectors by means of open innovation, strategic co-operations, MRE technology transfer activities and sharing of knowledge and experience. These services are summarized in **Figure 6**.

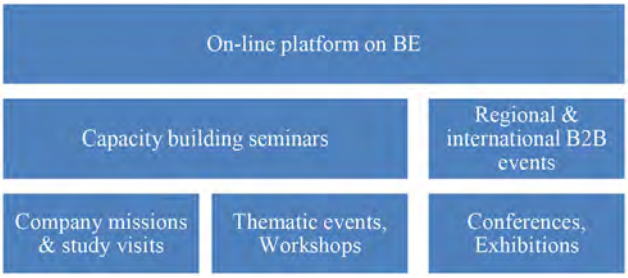

FIGURE 6 | Services provided by each national HUB to its members.

Through these series of services, several opportunities may emerge in terms of intelligence, innovation, networking and business growth such as: capitalizing on and fine-tuning previous experience and knowledge of BE sector, coordination of pilot activities, development of skills and competences and identification of new business opportunities, provision of mentoring and coaching services, assessment of environmental impacts and preparation of social acceptance, construction of evaluating processes, techniques, models, tools, methods and services. As regards particularly SMEs, a path of successive actions, shown in **Figure 7**, with associated outputs is planned in order to promote innovation and extroversion. Among several duties, cluster coordinators have the responsibility for ensuring, over the long term, that the cluster will continue to be effective and contribute to the creation of additional value.

The Case of the Greek Hub for Blue Energy

The Greek HUB for Blue Energy (GH4BE) is coordinated by HCMR and is composed so far by 54 members representing all the actors of the Quadruple Helix model of Blue Growth. 36 HUB members are enterprises mainly SMEs as the basic beneficiaries of the PELAGOS project, 8 are research centers and RTOs, 5 are public sector bodies, and 5 are civil society organizations (including NGOs and other clusters); see also **Figure 8**. The GH4BE ranks second in members among the national HUBs.

In a detailed elaboration and assessment of the innovation profiles of the SMEs members of the GH4BE, their innovation potential related to MRE systems exhibits a big variation from high to moderate levels but it is limited compared to services and software development. Lack of financing sources, limited extroversion and limited participation in EU co-financing projects are the main obstacles that have been identified throughout the existence of PELAGOS project.

The majority of Greek SMEs offer consulting and software (applications) development services and only few of them design, operate and install equipment and systems related to BE. The innovation profiles of SMEs clearly depict the lack of actors involved in designing, manufacturing/constructing and installation of MRE systems, as only two actors have been identified from the interviews. Services such as consultation, software development and GIS consist the main occupation of the SMEs, presenting high innovation potential and Technology Readiness Level (TRL) 5-9. Regarding the Demand Readiness Level (DRL), this varies between 2 and 9, depending on the technology/services demands of each SME. The six SMEs that exhibit the most promising status based on quantitative (TRL, DRL) and qualitative criteria (tendency and willingness for collaboration, etc.) received coaching and mentoring services, which led to the elaboration of their BE Market Driven Innovation Plans.

The main services that the GH4BE provided, through HCMR, to its members are the following:

Focused Capacity Building events:

1. Entrepreneurship and Technology Transfer: The philosophy for BE has been presented to the interested stakeholders. The fundamental role of research institutions was discussed and problems such as lack of funding and transferability of technological knowledge to SMEs were analyzed. The necessity for the establishment of European clusters experienced in BE and Blue Growth through success stories of viable start-ups was also endorsed.
2. Markets and MRE Technology Applications: The specifications and characteristics of MRE technologies and their application for the MS were presented and discussed.
3. Innovation soft-skills development: The positive results from the adoption of soft skills in successful businesses environments were discussed and justified through paradigms. Behavioral flexibility, adaptability negotiations, creativity, and eagerness to learn should formulate the actions for the sustainability of BE value chain.

Other focused services:

1. Company Missions to End Users in Maritime Industries: HCMR scheduled six appointments with large entities in Greece, where SMEs had the chance to present their products/ideas, extend their business cycle, and receive recommendations.
2. Investor Ready Business Plans Through Mentoring and Pitching Services With Investors: A wide agenda of topics (economic principles, financial funding schemes, funding opportunities, etc.) were examined. Additionally, an investment plan is being suitably prepared for a Greek SME in order to answer the concerns of an investor demonstrating that the business is ready to implement the idea and the business goals and objectives.

Scientific workshops:

1. Spatial planning, Coastal Zone Management, and Social Acceptance of MRE: These three important issues for the development of MREs in the MS were presented and analytically discussed.
2. Environmental Impact of MRE in MED Coastal Insular and Marine Areas: The positive effects and the impacts that MRE installations may have on the marine environment along with legal environmental issues have been presented.

Furthermore, aiming at increasing the social acceptance of MRE and attracting industry's and investors' interest, HCMR has been involved in scientific, managerial and promoting activities. The GH4BE in an attempt to promote cross-cluster communication, fostered linkages with the Norwegian Blue

FIGURE 7 | Services provided particularly to the SMEs of each national HUB.

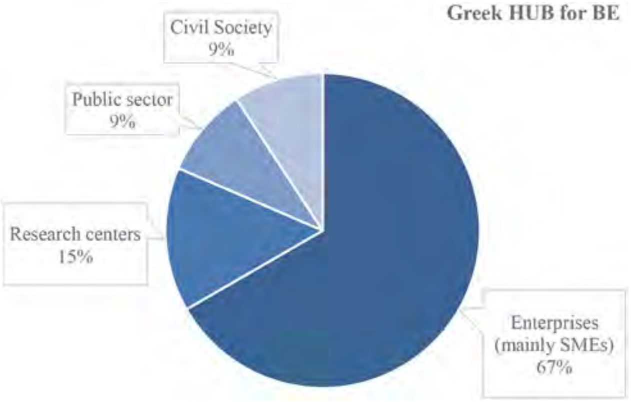

FIGURE 8 | Synthesis of the GH4BE.

Maritime cluster. HCMR also participated in the one of the biggest global maritime exhibitions (POSIDONIA 2018) looking for synergies with the maritime sector. GH4BE has created a close relationship with the Municipality of Piraeus, which currently is devoting remarkable efforts in launching a maritime cluster and is involved in Blue Growth. Moreover, HCMR promoted MRE research in the scientific community by coordinating the panel on BE during the 12th Panhellenic Symposium of Oceanography and Fisheries.

CONCLUDING REMARKS

The availability of natural resources in the MS that can be capitalized by the BE sector is more than sufficient to constitute a real impulse for the use of MRE technologies. However, if Mediterranean EU member states want to fully exploit the available potential, they should primarily commit to one specific and mature MRE sector. Specialization plays a substantial role in the successful exploitation of MRE while it explicitly contributes to the enhancement of value-added activities and smart strategies within the BE value chain, another crucial aspect for MRE development in the area. On these grounds, exploitation of offshore wind energy and the promotion of floating structures are considered the most rational choices.

The most important problem in the area is the polymorphic landscape of the basin dealing with economic, social and geomorphologic aspects. Common issues that hinder the development of Blue Growth are vague competencies between national and local level, bureaucratic issues, inconsistencies between the involved ministries, and financing difficulties. In addition, complicated legislative frameworks prevent many investments. Unnecessary barriers related to permitting and approval mechanisms and processes, tax rebate, complicating governmental tender terms should give their place to a simple, clear and holistic process. Elaboration of new banking tools suitable for deployment of MRE at various stages should constitute a key role in the political agenda. Furthermore, allowance of public-based input and community buy-in to renewable energy projects is a contemporary bet that can be won. Therefore, the nature and key role of clusters within an economy should be comprehended and identified so that potential financial incompetence and hindrances to competitiveness and growth are diagnosed promptly and prioritized accordingly.

In this work some tested tools and proven solutions are provided to cope with the aforementioned problems. A rational pathway is suggested for designing an efficient policy for the newly formed Mediterranean BE cluster. The proposed cluster policy is capable to further develop, enlarge and sustain the regional BE value chain based on legislative, innovation and financial policies. The Mediterranean BE cluster should focus on the unique sector-specific challenges, and institutional and coordinative issues, in order to be benefited from positive spillovers. Special emphasis is also put on the strategic position of SMEs in the cluster by promoting transnational/regional cooperation, share of knowledge and experience, and matchmaking activities leading to open innovation. PELAGOS cluster is being challenged to serve the aforementioned role, mobilize the involved stakeholders and form a solid BE value chain; on the other hand, national HUBs will also contribute (on their level) toward this aim. The overall anticipated impacts of the BE cluster are highly relevant to the innovation performance funded by supportive schemes and stable collaborations among the key actors that can bring new business ideas and products.

AUTHOR CONTRIBUTIONS

TS conceived the work. TS, CA, FK, and AP wrote the manuscript with support from LS. All authors designed the work and contributed to the final manuscript.

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Lifecycle Environmental Impact Assessment of an Overtopping Wave Energy Converter Embedded in Breakwater Systems

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Overtopping breakwater systems are among the most promising technologies for exploiting wave energy to generate electricity. They consist in water reservoirs, embedded in piers, placed on top of ramps, higher than sea-level. Pushed by wave energy, seawater fills up the reservoirs and produces electricity by flowing back down through low headhydro turbines. Different overtopping breakwater systems have been tested worldwide in recent years. This study focuses on the Overtopping BReakwater for Energy Conversion (OBREC) system that has been implemented and tested in the harbor of Naples (Italy). The Life Cycle Assessment of a single replicable module of OBREC has been performed for analyzing potential environmental impacts, in terms of Greenhouse Gas Emissions, considering construction, installation, maintenance, and the operational phases. The Carbon Footprint (i.e., mass of CO_2eq) to build wave energy converters integrated in breakwater systems has been estimated, more specifically the "environmental investment" (i.e., the share of Carbon Footprint due to the integration of wave energy converter) needed to generate renewable electricity has been assessed. The Carbon Intensity of Electricity (i.e., the ratio between the CO_2eq emitted and the electricity produced) has been then assessed in order to demonstrate the profitability and the opportunity to foster innovation in the field of blue energy. Considering the impact for implementing an operational OBREC module (Carbon Footprint = 1.08 t CO_2eq; Environmental Investment = 0.48 t CO_2eq) and the electricity production (12.6 MWh/year per module), environmental benefits (avoided emissions) would compensate environmental costs (i.e., Carbon Footprint; Environmental Investment) those provided within a range of 25 and 13 months respectively.

Keywords: blue energy, Life Cycle Assessment, Carbon Footprint, Carbon Intensity of Electricity, environmental investment

INTRODUCTION

The International Energy Agency (IEA) estimates that in 2017 global energy demand increased by 2.1% compared to previous years and the 72% of that increase has been met by deploying fossil fuels (International Energy Agency, 2018a). The electricity demand has grown by 3.1%, considerably higher compared to the overall increase in the energy demand. This increased demand resulted in an intensification of the global energy-related CO_2 emissions by 1.4% in 2017, reaching a historic peak value of 32.5 gigatonnes (Gt), a detour from the three past years in which global emissions remained flat (International Energy Agency, 2018a). However, renewable energies have met a quarter of the global energy demand growth (International Energy Agency, 2018a).

In order to accomplish the Paris Agreement (United Nations Framework Convention on Climate Change, 2015), the IEA flagship publication, World Energy Outlook 2017, foresees a "Sustainable Development Scenario" (among 240 energy mix scenarios in 2100) according to which a mixture of technologies is considered a prerequisite to meet climate objectives (International Energy Agency, 2017). In this line, the BP Energy Outlook 2018 foresees, in 2040, an extremely diversified world energy mix with a significant increase of renewable energy (BP energy Outlook, 2018). Moreover, International Renewable Energy Agency (2018) remarked that renewable energy combined with improved energy efficiency are the cornerstone of climate solution and, by 2050 the share of renewable energy in the European Union could grow from about 17% to over 70%.

According to the Intergovernmental Panel on Climate Change (2011), the use of renewable energy sources is the solution to avoid greenhouse gas emissions and it can help to increase energy security, allow energy independency of communities and decrease air, water and soil pollution (Ellabban et al., 2014; Magagna and Uihlein, 2015; Melikoglu, 2018; Şener et al., 2018).

Among renewable energy sources, ocean energy represents the most promising because of the impressive energy potential stored in oceans (International Renewable Energy Agency, 2014; Khan et al., 2017). Oceans represent the 70% of Earth surface (Ressurreiçao et al., 2011) and, capturing the sun's thermal energy, they can be considered as the largest solar collectors (Khan et al., 2017), besides tides driven by the gravitational pull of the moon and waves generated by the wind. Major advantages of ocean energies, compared to other renewables, comprise predictability (Yaakob et al., 2016), availability and abundance (Homma, 1985) as well as high load factor (Benbouzid et al., 2017). The theoretical energy potential from oceans has been estimated to be more than sufficient to cope present and projected global electricity request (International Renewable Energy Agency, 2014; Hussain et al., 2017). Estimation of this potential ranges from 20,000 to 800,000 TWh electricity a year (International Renewable Energy Agency, 2014) or between 4 and 18 million tons of oil equivalent (toe) (de Andres et al., 2017a,b).

Supporting the deployment of ocean technologies would result in the accomplishment of recommendations and directives of the European Union regarding the promotion of renewable energies (European Commission, 2009; Sannino and Cavicchioli, 2013) and referring to the target set for climate and energy policies for 2030 and 2050 (European Commission, 2013; Sannino and Cavicchioli, 2013) and the objectives of the marine spatial planning and integrated coastal management directive (European Commission, 2014).

Ocean energy concerns the energy sector included in the definition of Blue Economy (Union for Mediterranean, 2017). As recognized by the United Nations Environmental Programme (UNEP): "a worldwide transition to a low-carbon, resource-efficient Green Economy will not be possible unless the seas and oceans are a key part of these urgently needed transformations" (UNEP, 2012). Moreover, the sustainable development of ocean energy will contribute to pursue the Sustainable Development Goals (SDGs) (United Nations, 2015) and the Mediterranean Strategy for Sustainable Development (MSSD) (United Nation Environmental Programme/Mediterranean Action plan, 2016). In particular, the deployment of ocean energy would contribute to accomplish the target 7.2 of the SDG 7, requiring a substantial increase of the share of renewable energy in the energy mix, and the objectives 4 and 5 of the MSDD, aimed at fostering the transition toward green and blue economy. The United Nations have declared the Decade of Ocean Science for Sustainable Development (2021–2030) in order to enhance sustainable use of oceans and marine resources and support the development of ocean economy (United Nations Educational, 2018).

Ocean energy sources include salinity gradient, onshore and offshore wave energy, tidal and marine currents, ocean thermal energy, marine biomass, and offshore wind (both floating and stable) (Lewis et al., 2012; Borthwick, 2016; Hussain et al., 2017; Melikoglu, 2018). Ocean energy converters exploit these renewable sources to generate useful energy—commonly electricity (International Renewable Energy Agency, 2014). To date, wave and tidal energy converters are at the most advanced stage (Lewis et al., 2012; International Renewable Energy Agency, 2014; Uihlein and Magagna, 2016). Wave energy technology development started on 1940 in Japan through the work of Yoshio Masuada (Falcão, 2010) with a serious academic attention gained around early 1970s (International Renewable Energy Agency, 2014). However, the technology development and proliferation of full-scale prototypes occurred in the last decades (Cruz, 2007). According to Magagna and Uihlein (2016), due to their availability and affluence of resources, wave and tidal energy are likely to mark the most significant contribution to the electricity production mix in EU in the near future. It has also been recognized that, wave energy has the potential to compete with the current use of fossil fuels thanks to its availability and predictability (Alamian et al., 2017; Mustapa et al., 2017).

Wave Energy Converters (WEC) concern different technologies, the 82% of which refers to five types: point absorber, wave overtopping reservoir, attenuator, oscillating water column, and oscillating surge (or inverted pendulum) (International Renewable Energy Agency, 2014; Magagna and Uihlein, 2015). In most of the cases, wave energy is converted into electricity by means of two steps: wave energy is firstly converted into a simplified form of mechanical energy (purely potential or kinetic energy) and then, through a proper power take-off system (hydro turbine, hydraulic piston, etc.), into electrical energy (Kim et al., 2017). According to Lewis et al. (2012) more than 50 types of WEC have been conceived and are under development. However, due to the high cost only few technologies are ready for the commercial stage (Contestabile et al., 2017a). However, WECs look to be the most cost-effective systems among blue energy converters (Contestabile et al., 2017b).

As recognized by International Energy Agency (2018b), Environmental Impact Assessments (EIA) of ocean energy converters are necessary to inform regulators on potential impacts due to ocean energy deployment. It has also been highlighted the necessity of environmental monitoring plan before, during and after the installation in order to minimize risks (Copping et al., 2013; International Energy Agency, 2018b). Effects on benthic communities, species-specific response to habitat changes, entanglement of marine mammals, turtles, fish, and marine birds are examples of direct environmental impacts due to ocean energy technologies (Azzellino et al., 2011; Frid et al., 2012). Moreover, impacts due to building, operating, maintenance, decommissioning and disposal of ocean energy converters should be also considered (Sannino and Cavicchioli, 2013; Uihlein and Magagna, 2016). Life Cycle Assessment (LCA) is widely recognized as useful tool to evaluate environmental burdens of energy produced from different renewable and non-renewable sources (Sannino and Cavicchioli, 2013; Amponsah et al., 2014). To date, only a small number of LCA on ocean energy converters have been carried out (e.g., Sørensen et al., 2006; Parker et al., 2007; Rule et al., 2009; Walker and Howell, 2011; Banerjee et al., 2013; Douziech et al., 2016; Uihlein, 2016; Elginoz and Bas, 2017; López-Ruiz et al., 2018; Thomson et al., 2019) tackling different aspects, from eco-design to end-of life of plants and evaluating different potential impacts.

The Interreg Med MAESTRALE is a cooperation project, co-financed by the European Regional Development Fund, involving 11 partners from 8 European countries. It aims to investigate strengths, weaknesses, opportunities and threats of blue energy technologies in order to inform and support their deployment in the Mediterranean area. A survey of the most promising solutions developed in Europe is available in the MAESTRALE webgis (http://maestrale-webgis.unisi.it). Among available WEC technologies, OBREC (Overtopping BReakwater for Energy Conversion), installed in the harbor of Naples (Italy), is a full-scale WEC prototype integrated into an existing breakwater. It has been designed to capture overtopping waves and produce electricity in poor and mild wave climate (Contestabile et al., 2016, 2017a).

This paper presents results of an LCA applied to OBREC, in order to evaluate environmental impacts and benefits in terms of Carbon Footprint. The LCA has been carried out to provide a measure of environmental impacts of OBREC implementation in terms of greenhouse gas emission in a real environment: the harbor of Naples (Italy). Since OBREC is integrated in an already functioning harbor, we identify and calculate the environmental investment (in terms of CO_2eq) of renewable electricity production to capture the contribution of the additional inputs required by that technology to obtain electricity from an unexploited energy (wave energy in this case). Besides impacts, this study also focuses on environmental benefits given by renewable energy production (i.e., variation of the Carbon Intensity of Electricity of the Italian electricity mix). The electricity production can be estimated in terms of avoided emissions. Moreover, assuming that one OBREC module can replace 3–4 rows of two layers of antifers from the breakwater, the environmental cost-benefit balance concerns the environmental investment required to implement OBREC in place of antifers.

MATERIALS AND METHODS

Overtopping BReakwater for Energy Conversion (OBREC)

The Overtopping BReakwater for Energy Conversion, namely OBREC, is a system completely embedded in a rubble mound breakwater designed to exploit wave energy potentials. It converts the wave overtopping process into potential energy by collecting seawater, pushed through a frontal ramp, in upper reservoirs to feed a set of mini hydro-turbines. Electricity is produced by means of a generator linked to the turbines converting potential energy of water stored in reservoirs (Contestabile et al., 2017a). **Figure 1** reports the cross-section of OBREC highlighting geometrical parameters as showed in Contestabile et al. (2016).

The prototype implemented and tested in the harbor of Naples consists in a single module (5 m seafront length) that can be easily

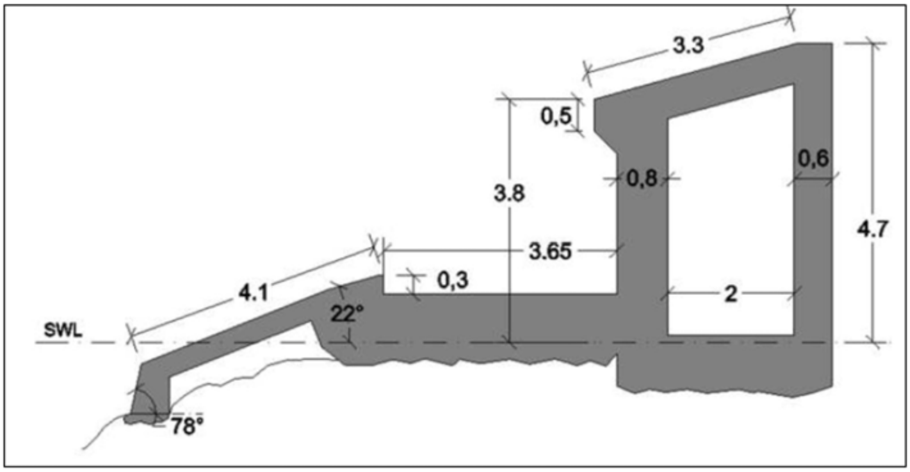

FIGURE 1 | OBREC cross-section (from Contestabile et al., 2016).

installed by assembling prefabricated elements, replicated and combined in rows along one side of a pier. The OBREC modules offer different solutions for the construction or refurbishment of breakwater systems and can potentially be used to partially or fully replace typical antifers, such as big stones or concrete tripods. The structure of one OBREC module, made of reinforced concrete (110 t concrete and 7 t iron), can likely replace 30–36 of 12-ton "antifers," a kind of cyclopean grooved concrete cubes with hole (each side is 2 m long) or 13–16 42-ton "tetrapods," (3.8 m high).

The module tested in the harbor of Naples embeds a set of pico hydro-turbine. The nominal power installed is about 3 kW. Based on ongoing monitoring campaign and numerical simulation by using a specifically-designed numerical model (OBRECsim, see Contestabile and Vicinanza, 2018), a 250 m pier in Naples is expected to generate more than 630 MWh/yr, corresponding to a wave-to-wire efficiency of 13.9%. The scenario simulated, take into account a new set of low head turbines, able to work with a wide spectrum of different incident wave conditions and water levels. Consistently, in this study, we assume an average electricity production of 12.6 MWh/yr for an OBREC single module 5 m long, in order to provide more reproducible results and considerations for other poor and mild wave climate.

Life Cycle Assessment (LCA) of the OBREC Module

The LCA has been applied in compliance with the International Standard Organization 14040 (2006a) and International Standard Organization 14044 (2006b). The life cycle of OBREC module has divided in three main phases of the production chain: (1) construction: production of structural elements and components; (2) building: assembly and on-site installation, including the transportation of the components to the building site; (3) maintenance: interventions for periodical check and maintenance (**Figure 2**). The end of life phase has not been included in this assessment, even if lifetime of structures and different components has been taken into account. Being OBREC able to replace, in mass terms, 3–4 rows of two layers of antifers from the breakwater and, considering that the main aim of this paper is the evaluation of the environmental investment required to implement OBREC, we assumed that decommission phase can be considered out of the system boundaries, as it would be equal both for OBREC and antifers.

The functional unit (FU) selected is represented by one single module (5 m seafront length) embedding the WEC (namely one module of OBREC). The system boundary includes the main lifecycle processes from *cradle to gate*, i.e., from cradle to a fully operating OBREC module.

Specific data regarding materials and energy needed to produce structural components (Phase 1) have been estimated based on metric computations (Contestabile et al., 2016) and considering main components: foundations, ramps and reservoirs made in reinforced concrete and pipes in PVC. The power take-off (PTO) system has been accounted as steel and PVC that are main materials of the pico hydro-turbine. Materials for electric connection (generator, stator, box and electrical cable) have been accounted as steel, PVC, copper, rubber, NdFeB (i.e., Neodimio-Ferro-Boro) alloy. A length of 1 km has been assumed for electric cable. Electricity losses have not been accounted.

The on-site installation (Phase 2) concerns energy use (electricity and diesel) for machineries (e.g., excavator) and materials (e.g., wood for the molds). A time span of 1 year (202 actual days considering work stoppage) for the whole building phase has been assumed. The average distance from the production site to the building site was assumed as 40 km for each component.

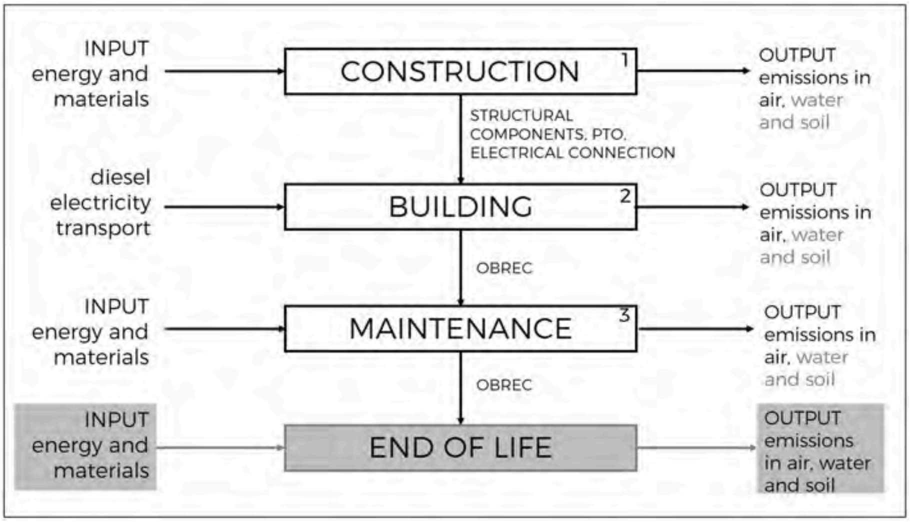

FIGURE 2 | Flow chart with phases of the production chain. Phase 1: production of components; Phase 2: on site installation including transport; Phase 3: maintenance during operation. Gray boxes represent flows and phases outside the system boundaries.

Maintenance (Phase 3) has been envisioned as 12 trips per year to the plant (average 30 km each) because there is no need of heavy interventions for ordinary maintenance. Nevertheless, the estimated time span for different components (e.g., 60 years for the concrete structure; 10 years for the turbine; 20 years for PVC pipes; 50 years for terrestrial cables and 25 years for marine ones), compared to the lifetime of the OBREC device (estimated 60 years), allowed to account for the replacement of components through maintenance.

The Life Cycle Inventory is modeled, and Life Cycle Impact Assessment performed by means of the LCA software tool SimaPro 8.4.0 (PRé Consultants, 2014). The Ecoinvent v3.1 (Wernet et al., 2016) database has been used for modeling the Life Cycle Inventory as source of secondary data. **Table 1** reports input flows considered in the Life Cycle Inventory of the OBREC module, including both primary and secondary data sources.

The characterization method used in this study is the Global Warming Potential—GWP at the 100 year time horizon (Intergovernmental Panel on Climate Change, 2013), hereafter called also Carbon Footprint (CF).

In this analysis we focused the evaluation of the lifecycle processes and the production of electricity through OBREC limited to its contribution to climate change. A complete impact assessment, including other impact categories, will be the scope of further research.

RESULTS AND DISCUSSIONS

Table 2 reports the energy and material flows per functional unit, i.e., one OBREC module, including the electricity production referred to a breakwater installed in poor and mild water climate in Italy.

The total CF of the OBREC module is 1.08 t CO_2eq per FU is mainly due to construction elements (884.31 kg CO_2eq) and minor contribution by building operations (85.28 kg CO_2eq) and maintenance (113.57 kg CO_2eq). **Figure 3** shows the contribution of each single input to the total impacts, in terms of CO_2eq, deriving from the life cycle of the OBREC module.

Most of the impact throughout the production chain of OBREC is due to the use of materials for the construction of components (82%), including structural elements, i.e., ramp, reservoirs, foundations (56%), and the WEC system, especially electric cables for the connection to the grid (18%). Other impacts are due to operations for assembling and installing the OBREC system on site (8%) and its maintenance (10%). These results are in line with other LCA evaluations regarding ocean energy technologies (e.g., Dahlsten, 2009; Uihlein, 2016; Thomson et al., 2019) demonstrating that most of their impacts are related to materials even beyond the installation and maintenance of the devices. CF results are closely related to the mass flows (**Table 2**) in line with what outlined by Uihlein (2016) regarding the closed

TABLE 1 | Primary and secondary data sources used in the LCA of the OBREC system.

Description	Input	Utilization phase	Primary data	Secondary data
Ramp Reservoir	Reinforced concrete	Construction (1)	Our processing[a]	Ecoinvent database, 2014
Pipes	PVC	Construction (1)	Our processing[b]	Ecoinvent database, 2014
Foundations	Reinforced concrete	Construction (1)	Our processing[a]	Ecoinvent database, 2014
	Steel	Construction (1)	Our processing[a]	Ecoinvent database, 2014
PTO (hydraulic turbines)	Steel	Construction (1)	Our processing[a]	Ecoinvent database, 2014
	PVC	Construction (1)	Our processing[a]	Ecoinvent database, 2014
Generator	Steel	Construction (1)	Our processing[a]	Ecoinvent database, 2014
	NdFeB alloy	Construction (1)	Our processing[a]	Ecoinvent database, 2014
Stator	Glass fiber	Construction (1)	Our processing[a]	Ecoinvent database, 2014
	Copper	Construction (1)	Our processing[a]	Ecoinvent database, 2014
Box	Aluminum	Construction (1)	Our processing[a]	Ecoinvent database, 2014
Electrical cable	Copper	Construction (1)	Our processing[b]	Ecoinvent database, 2014
	Rubber	Construction (1)	Our processing[b]	Ecoinvent database, 2014
	Iron	Construction (1)	Our processing[b]	Ecoinvent database, 2014
	PVC	Construction (1)	Our processing[b]	Ecoinvent database, 2014
Energy	Diesel	Building (2)	Our processing[c]	Ecoinvent database, 2014
	Electricity	Building (2)	Our processing[c]	Ecoinvent database, 2014
Molds	Wood	Building (2)	Our processing[c]	Ecoinvent database, 2014
Transport	Lorry	Maintenance (3)	Our processing[d]	Ecoinvent database, 2014
Transport	Passenger car	Maintenance (3)	Our processing	Ecoinvent database, 2014

[a] *Our elaboration based on Contestabile et al. (2016).*

[b] *Our processing based on average cable composition.*

[c] *Our elaboration based on average data of machineries used in a building site.*

[d] *Our processing considering an average distance of 40 km to the building site.*

Numbers in brackets in the "utilization phase" column correspond to the steps of production (see ***Figure 2****).*

TABLE 2 | Life Cycle Inventory for the production of the functional unit (i.e., the OBREC module).

	Description			Material	Raw Data	Unit	LT (year)	Value (unit/year)
Input	**CONSTRUCTION**							
	Structural components	Ramp and reservoir		Concrete	103,969.22	kg	60	1,732.82
				Iron	5,497.44	kg	60	91.62
		Pipes		PVC	54.17	kg	20	2.71
		Foundations		Concrete	6,476.25	kg	60	107.94
				Iron	1,295.25	kg	60	21.59
	PTO components	Hydraulic turbines		Steel	60.00	kg	10	6.00
				PVC	15.00	kg	10	1.50
	Electric connection	Generator		Steel	39.50	kg	20	1.98
				Ndfeb Alloy	14.40	kg	20	0.72
		Stator		Glass Fiber	4.30	kg	20	0.22
				Copper	6.40	kg	20	0.32
		Box		Aluminum	15.40	kg	20	0.77
		Terrestrial electric cable		Copper	1,877.00	kg	50	37.54
				Rubber	74.00	kg	50	1.48
				Iron	2,297.00	kg	50	45.94
				PVC	79.00	kg	50	1.58
	BUILDING							
		Energy		Diesel	2048.00	kg	60	34.13
				Electricity	5374.72	kWh	60	89.58
		Molds		Wood	212.06	kg	60	0.10
	Transportation	Transport		Lorry	-	kgkm	-	82,297.04
	MAINTEINANCE							
	Transportation	Transport		Passenger Car	-	km	1	360
Output	Electricity				12.6	MWh	1	12.6

link between environmental impacts and material inputs. In particular the 56% of the total CF is due to concrete and iron needed for the foundations and construction of the ramp and reservoirs; these structural elements accounted for 95% of the total mass of the OBREC device. Input flows required during the building phase can be considered negligible (namely diesel and wood) except for the electricity that is responsible for the 5% of the total CF of the OBREC device. Finally, the use of a passenger car for the maintenance operations accounted for 11% of the total CF of the OBREC.

However, OBREC can be considered an upgrade of a traditional breakwater, thus we can consider the CF as a sort of "Environmental Investment" required for implementing a breakwater integrated with an OBREC module.

The Environmental Investment (EI) has been defined as the additional environmental impact produced to upgrade a system to a more integrated state, as stated by Patrizi et al. (2015) and Saladini et al. (2016). According to this definition, the environmental investment would specifically refer to the emissions provided to integrate the WEC system, made to produce renewable energy as additional function, in the breakwater, built to protect the port basin as primary function. Accordingly, processes included in the evaluation of the EI concerns the construction of WEC elements (generator, stator, box, and electric connection), their on-site assembling and maintenance, while we can assume that structural materials properly belong to the breakwater system (the OBREC module replaces 30–36 antifers likewise made of concrete with almost the same mass) and must not be taken into account.

Based on this observation the EI required for upgrading a breakwater with an OBREC module is represented by the portion of CF of the OBREC module assessed above (i.e., 1.08 t CO_2eq) considering only the emission due to the implementation of the WEC system. In this way, the EI of OBREC is 0.48 t CO_2eq, i.e., 44% of total CF (**Table 3**).

The EI evaluation highlighted that the majority of CO_2eq emissions are still due to construction elements being responsible for 59% of the total EI (i.e., 0.28 t CO_2eq) of one module of OBREC. While the building and maintenance phases are responsible for the 18 and 23%, respectively of the total EI (i.e., 85.28 kg CO_2eq and 113.57 kg CO_2eq). In particular, 51% of the emissions are due to the electrical connection, more specifically to the terrestrial cable because of the copper and iron components. Therefore, a possible implementation to decrease emissions of OBREC can be represented by the use of electrical connection with higher environmental performances.

OBREC is expected to produce electricity with higher environmental performances then electricity produced from conventional resources. Results from the LCA allow for evaluating the Carbon Intensity of Electricity (CIE) of OBREC

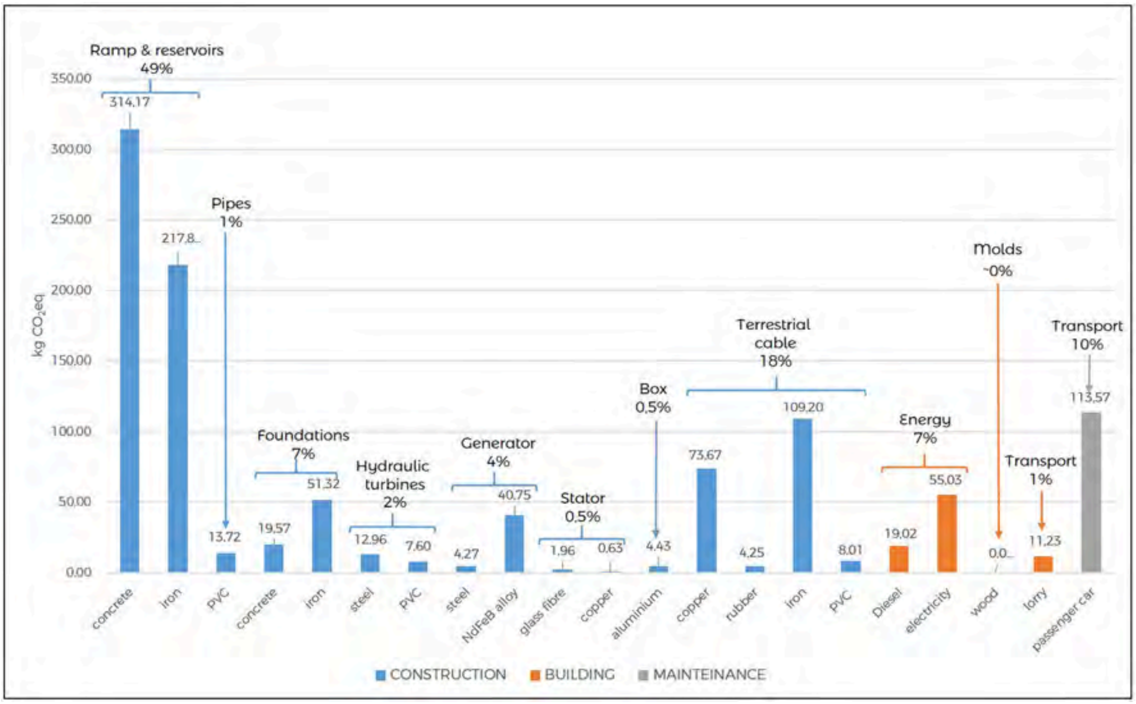

FIGURE 3 | Breakdown of the CF of the OBREC module by single input flows (bottom). The percentage contribution of each construction element is reported in detail (up). Colors represent three Life Cycle Phases (Legend: blue=construction; orange=building; gray=maintenance).

as the ratio between CO_2eq emitted (CF) and the produced electricity (Moro and Lonza, 2018). This ratio can be included in the list of performance indicators: the lower its value, the better the performance (Ang and Su, 2016).

The annual productivity of electricity is highly dependent on the marine characteristic of the site in which OBREC is implemented. In this paper data on annual productivity has been taken from a study carried out for the extension of the Duca D'Aosta pier in Naples, considering an electricity production equal to 12.6 MWh/yr for one OBREC module (5 m length). Obviously, a detailed wave resource assessment would be necessary.

The CIE calculated as the amount of emissions divided by the electricity production of one OBREC module on a yearly basis reported a value of 0.086 t CO_2eq/MWh when the total CF is considered. However, the estimation of the EI allowed for evaluating the CIE of OBREC in a more representative way. CIE calculated as the amount of invested emissions (EI) divided by the electricity production of one OBREC module on a yearly basis showed a value of 0.037 t CO_2eq/MWh. Compared to CIE values of other renewable energies, we can see that the CIE of OBREC is quite similar to that of hydroelectric reservoir being CIE 0.01 t CO_2eq/MWh (Sovacool, 2008). Both these values are much lower than the Italian electricity grid mix, i.e., 0.578 t CO_2eq/MWh of electricity produced (Ecoinvent, 2014).

In order to assess environmental benefits, we considered avoided emissions due to the implementation of OBREC based on CIE, that corresponds to 0.49 t CO_2eq/MWh (based on CF) and 0.54 t CO_2eq/MWh (based on EI) per renewable electricity produced. The avoided emissions in producing 12.6 MWh per year therefore range from 6.20 to 6.81 t CO_2eq/yr per OBREC module. Also, the carbon payback time for one module of OBREC (namely the time period of operation that is necessary to compensates emissions of total CF) was estimated to be 25 months. Focusing on the real EI the carbon payback time has been assessed to be 13 months.

TABLE 3 | Carbon Footprint compared to the "environmental investment" in terms of t CO_2eq: "CF" refers to the comprehensive impact of the OBREC module; "investment" specifically concerns emissions for integrating the WEC system in the breakwater system instead of using traditional antifers.

	CF (t CO_2eq)	Investment (t CO_2eq)
Construction	0.86	0.28
Building	0.09	0.09
Maintenance	0.11	0.11
Total	1.06	0.48

This paper presents results of LCA of an innovative plant to produce renewable electricity by deploying wave energy obtained through an upgrading of a breakwater. Even if results of environmental benefits are very site specific (i.e., Naples, Italy), we can maintain that CF and more properly EI assessment are a prerequisite to foster the blue energy deployment. According to Pisacane et al. (2018) preliminary assessment on potential impacts are necessary to inform policy makers before any blue energy implementation (International Energy Agency, 2018b). Results of EI of OBREC, in fact, represented a first step for future research, these values will not be subject to variability on the contrary of wave potentials. While wave potential is linked to the localization, emissions necessary to upgrade a breakwater are not.

The crucial point in this evaluation is that a planned investment would allow for the conversion of energy embedded in waves into renewable electricity. We can interpret WEC systems integrated in harbors as a concretization of Herman Daly's quasi sustainability principle (Daly, 1990). According to Daly, quasi sustainability is a transition process during which the investment of non-renewable resources (such as structural components of the OBREC module) is a necessary condition to foster the production of a renewable resource, e.g., electricity (Bastianoni et al., 2009).

Finally, deploying untapped potential energy of waves can be viewed as a proper solution to prevent the so-called "tragedy of the commons" (Hardin, 1968). As affirmed by Lloyd (2007): "anthropogenic global warming and oil depletion can be seen as the traditional common grazing of the Hardin's paper" on the "tragedy of the commons."

CONCLUSIONS

This paper presents an LCA of a Wave Energy Converter (WEC), namely OBREC (OBREC module installed and tested in the harbor of Naples) focusing on the Greenhouse Gases emission assessment, in order to evaluate environmental impacts and benefits of this blue energy technology. The implementation of a single module of OBREC provides 1.08 kg CO_2eq/yr, considering the production and transport of constructive elements, their on-site assembling and maintenance. Most of the impact is due to structural parts, made of reinforced concrete; nevertheless, an OBREC module can replace several traditional antifers (i.e., artificial rocks for the breakwater armor layer).

This observation allowed for making assumptions for evaluating the Carbon Intensity of Electricity (CIE). The Environmental Investment can be defined as the emission provided to install a fully operating WEC system into the breakwater in place of traditional antifers and therefore add the function of producing renewable energy to that of protecting the port basin. Based on this assumption, the impact of the WEC is 0.48 t CO_2eq/yr, i.e., 44% of the total CF, and the CIE is 0.037 t CO_2eq/kWh. This value is much lower (i.e., 94%) than the CIE of current Italian electricity mix. The potential reduced CO_2 emission due to the deployment of marine renewable energy for the electricity production have been considered as an "opportunity" for the blue energy technology development within a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis regarding the deployment of Marine Energy in the Mediterranean Area carried out by Goffetti et al. (2018). Threats have been highlighted in economic and legal aspects that slow down the implementation of blue energy technologies coupled with lack of economic incentives (Goffetti et al., 2018).

This study demonstrates that breakwater integrated WECs, such as OBREC, are profitable solutions for exploiting renewable sources in the marine environment. Despite these are at the early stage, the environmental performance of existing devices and prototypes, based on a lifecycle approach, looks promising and supports the opportunity to further develop and test innovative blue energy technologies.

AUTHOR CONTRIBUTIONS

NP, SB, and RMP conceived the paper. EN, NP, and VN elaborated and discussed data. DV, PC, and SB supervised the paper. All authors discussed the feedbak of the reviewers and contributed to the final manuscript.

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Combined Exploitation of Offshore Wind and Wave Energy in the Italian Seas: A Spatial Planning Approach

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The opportunity to co-locate wind and wave energy exploitation is analyzed in the Italian seas grounding on the rationale that benefits are greater when un-correlated resources are combined. The study shows that, although waves and winds are generally strongly correlated, in some conditions their correlation is lower and the combined energy harvesting more interesting. As spatial conflicts of sea use and demand for maritime space are increasing, the development of the marine renewable energy sector needs to be evaluated in the perspective of the cumulative pressures deriving from present activities or expected from future developments. The evaluation of areas of potential conflicts among human activities, environmental vulnerabilities and marine renewable developments may facilitate the early development of mitigation actions and negotiations between stakeholders. In this study the opportunity of co-locating offshore wind turbines and wave energy converters is analyzed through a spatial planning approach. Both the potential for combining different renewable technologies, and the impact associated to such development was considered in the context of the existing pressures (e.g., naval traffic; mariculture activities; submarine cables routes; dredge spoils dumping; offshore activities; windfarms and ocean energy projects) and vulnerabilities (Marine Protected Areas, Key habitat presence) through quantitative indicators. The portion of Tyrrhenian coast south of Elba island, the northern-western Sardinian coast, and the southern Adriatic and Ionian coastal waters appear to be the most suitable sites. Moreover, the study presents a spatial quantitative methodology to identify sites of potential interest for the development of the marine renewable energy sector in the perspective of cost-effectiveness and environmental impact minimization.

Keywords: Marine Spatial Planning, wind energy, wave energy, Mediterranean sea, environmental impact, renewable energy

INTRODUCTION

The marine environment represents a vast source of renewable energy. Ocean renewable energy infrastructures could contribute significantly to the future energy power supply (Ocean Energy Systems, 2017). Among the different developed marine renewable technologies, marine wind energy is the most mature type as regards technological development, commercialization, policy frameworks, and installed capacity (Soukissian et al., 2017; Agora Energiewende and Sandbag, 2018). Actually, most of the interest is focused on the development of new offshore solutions, such as wind turbines with larger rotors, deep water sites and floating platform (e.g., Hywind Scotland project www.statoil.com) (Onea et al., 2017). Floating technology can be considered in fact, as a commercially viable solution in order to harness available wind resource also at greater depth (>50 m) where the conventional fixed offshore wind turbines are no more economically feasible (McMillan and Ault, 2010). In addition, also Wave Energy Converters (WECs) have been identified as a technology with the potential to offer a significant contribution in the medium to long term (Liu et al., 2017). Globally, in 2017 wave energy deployments have doubled its capacity respect to the previous year, up to 8 MW (Ocean Energy Systems, 2017).

In Europe, most of the fully operating projects have been developed by the northern countries where there is a high source availability. However, also the Mediterranean sea is considered an attractive hot-spot for future developments of both technologies (Vicinanza et al., 2011, 2013; Liberti et al., 2013; Iuppa et al., 2015a,b; Onea et al., 2015, 2016a,c; Onea and Rusu, 2016b). Up to now, no offshore wind installations are operating in the Mediterranean waters, however the first offshore wind farm in the Italian seas has been approved and is going to be built in the Ionian sea off Taranto. It consists of 10 fixed-turbines with a total installed capacity of 30 MW, to power ∼9,000 households (EIA Report iLStudio Engineering Consulting Studio, 2009). Regarding the wave energy, only two typologies of WECs have been considered suitable to be entirely embedded into traditional coastal defense structures: the Oscillating Water Column (OWC) (Torre-Enciso et al., 2009; Arena et al., 2013; Viviano et al., 2016) and the OverTopping Device (OTD). The latest example of the second group is denominated OBREC (Overtopping Breakwater for Energy Conversion) (Vicinanza et al., 2014; Contestabile et al., 2017).

The feasibility of combining a floating wind turbine and a wave energy converters has been already investigated by several authors (Fusco et al., 2010; Veigas and Iglesias, 2013, 2015; Veigas et al., 2014a,b; Gao et al., 2016; Karimirad and Koushan, 2016). wind-wave technology is a viable solution to reduce the intermittence of the wind and wave resources regardless of the time interval, increasing in this way the attractiveness of a site in terms of its overall marine energy potential (Fusco et al., 2010; Azzellino et al., 2013a; Perez-Collazo et al., 2013; Onea et al., 2017). Therefore, the diversification of the mixed renewable energy technologies, determines a reduction of the power's variability (Fusco et al., 2010; Stoutenburg et al., 2010) and the energy costs (Astariz and Iglesias, 2016, 2017; Astariz et al., 2016).

The alternatives to combine wind and wave energy technologies have been investigated for the Mediterranean region by (Pérez-Collazo et al., 2015). In particular, according to the ORECCA[1] project results, the Mediterranean suitable sites are mainly restricted to three possible areas: the Blue Coast (southern France coast), the strait of Sicily (between Sicily and Tunisia) and the Aegean Greek islands. In recent years, the potential marine environmental impacts of renewable energy devices have been reported in different studies (Margheritini et al., 2012; Bailey et al., 2014; Riefolo et al., 2016).

In the EEA assessment of the onshore and offshore wind energy potential of the European seas (EEA European Environment Agency, 2009), it is shown that the offshore wind energy potential, between 10 and 30 kilometers from the coast, is concentrated in the Baltic, the North Sea (including the English Channel) and the Mediterranean, respectively accounting for 29, 25, and 20% of the 2030 projected total offshore wind potential (7,100 TWh). However, some offshore areas at this distance class have sea depths >50 meters that are not so much suitable for wind energy development. The same report states that at 30–50 kilometers from the coast, the Baltic, the North Sea (including the English Channel) and the Mediterranean sea respectively account instead for 30, 30, and 20% of total wind potential, that is estimated as 3,300 TWh in 2030. As far as wave energy is concerned, the closed basins, such as the Mediterranean, the Black and the Baltic Sea, are characterized by low wave power density values (<5 kW/m), due to the short fetching that does not let long period waves to be created (Kalogeri et al., 2017). In the Mediterranean sea, there are regions where the both wind and wave energy present low, but not negligible average values. Favorable areas for combined exploitation are in fact located in the Gulf of Lions, in the Sicily Straits (Central Mediterranean), off the coasts of Sardinia, off the NE coasts of the Balearic Islands (NW Mediterranean) and in specific sites in the Aegean Sea. The same authors indicated the Gulf of Lions (NW Mediterranean) and the Aegean Sea (NE Mediterranean) as ideal areas for wind power exploitation having wind power potential comparable to the most energetic northern sea areas, included the Baltic Sea (mean wind power potential ∼500–800 W/m^2).

It is worthwhile to stress the fact that any ocean energy development is likely to result in further transformation of the selected sites, already affected by other pressures. The Mediterranean Sea is known to be one of the world's most impacted marine environments (Micheli et al., 2013; Stock and Micheli, 2016). In this perspective, both the possible combination of different renewable technologies, and their potential impact on the environment, should be considered in the context of the existing pressures through a Marine Spatial Planning (MSP) approach (Douvere and Ehler, 2008; Ehler and Douvere, 2009; Jay, 2010; Backer, 2011; Azzellino et al., 2013b).

Focal point of this planning process is the analysis of the spatial data of the different vulnerabilities, the assessment of levels of vulnerability occurring in the area of interest and the quantification of the cumulative impacts affecting the area (Douvere and Ehler, 2008; Ehler and Douvere, 2009). The combination of vulnerability and cumulative impact can be used as a decision support tool to identify areas where ecosystem vulnerability and cumulative impact levels meet the objective of maintaining healthy ecosystems or where they are mismatched. The early prediction of the areas of potential conflicts creates the ground for mitigation actions or early negotiations between stakeholders. The exchange between

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[1] ORECCA Website (2015). Available online at: https://cordis.europa.eu/project/rcn/94058_it.html (accessed on July 2018).

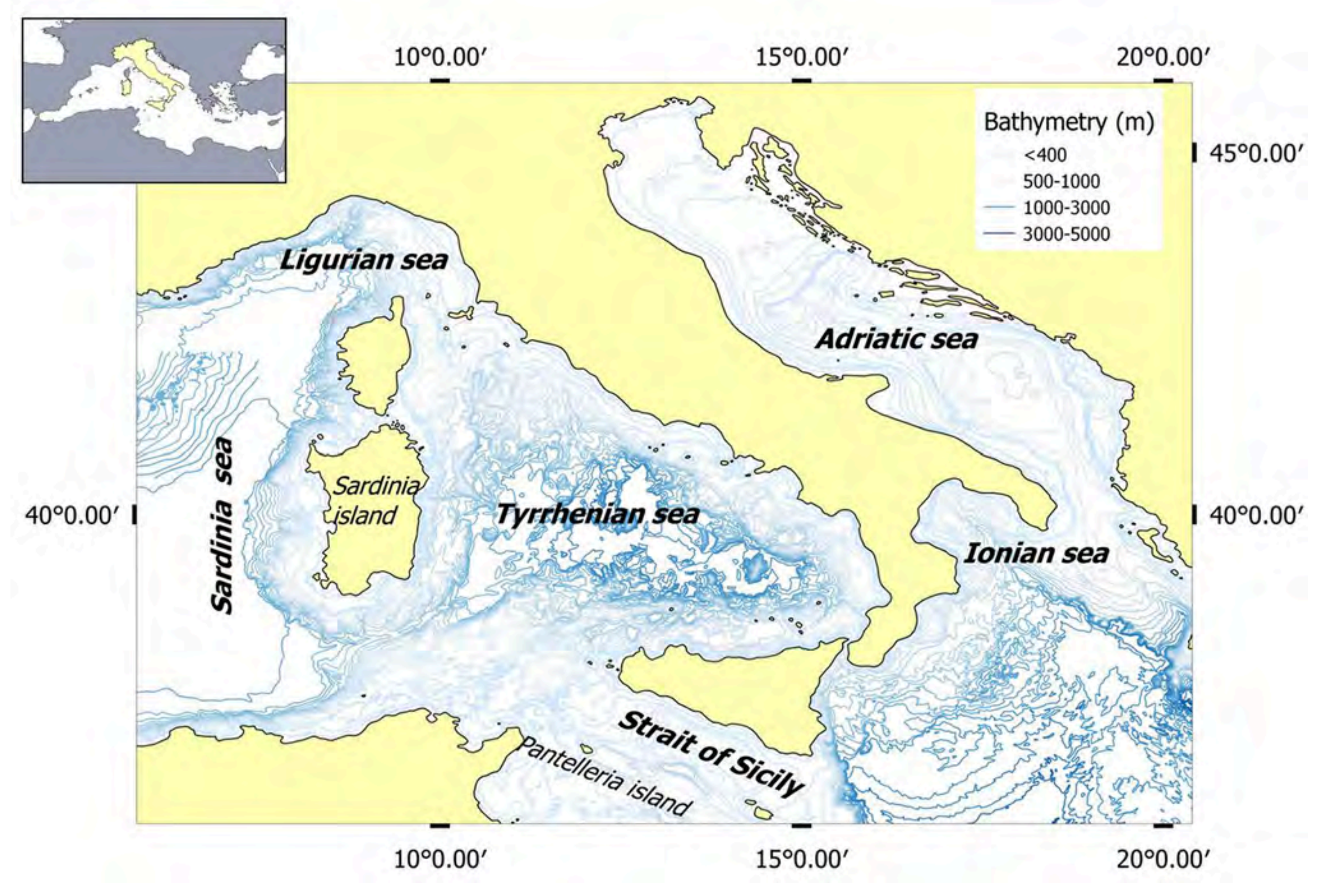

FIGURE 1 | Map of the study area.

decision makers, stakeholders, experts allow an integrated management of sea uses in the perspective of an optimized spatial decision support systems.

In this study the opportunity of co-locating offshore wind turbines and wave energy converters in the central Mediterranean area is analyzed and their environmental sustainability is evaluated through a quantitative Marine Spatial Planning approach.

MATERIALS AND METHODS

Study Area

The area considered in this study encompasses the waters around Italy in particular the Adriatic Sea, Ligurian Sea, Tyrrhenian Sea, and partially the Ionian, Sardinia Sea, as well as the northern part of the Strait of Sicily, from 36 to 46 degrees of Latitude and 6 to 20 degrees of Longitude (see **Figure 1**).

Data Gathering and Preparation

An analysis grid of 425 cells of 60 × 50 kilometers size was created (**Figure 2**) and data about wind and wave meteo climatic conditions, bathymetry and a set of vulnerability indicators and human pressures were gridded and used for the purpose of the spatial analysis. Bathymetry data were obtained through the GEBCO (General Bathymetric Chart of the Oceans)[2]. One minute Digital Atlas.

Wind and wave data have been extracted from the database ECMWF ERA-Interim Data Set (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim). Data, available for 164 stations (**Figure 2**) covering a 10-year time series from 2005 to 2014 were considered. Wind data were available every 3 h while wave data every 6 h, so the latter was assumed as reference unit for the study. Data used for this study were: horizontal and vertical components of wind speed at 10 m, mean wave direction, mean wave period, significant wave height.

The following set of vulnerabilities were used for the analysis:

- Marine Protected Areas presence;
- Posidonia beds;
- Cymodocea beds;
- Mediterranean coralligenous communities.

Marine Protected Areas (MPA) presence was considered based on the dataset available from the World Database on Protected Areas (WDPA, https://protectedplanet.net/) (UNEP-WCMC, 2016).

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[2] http://www.gebco.net/ (accessed on May 04, 2018).

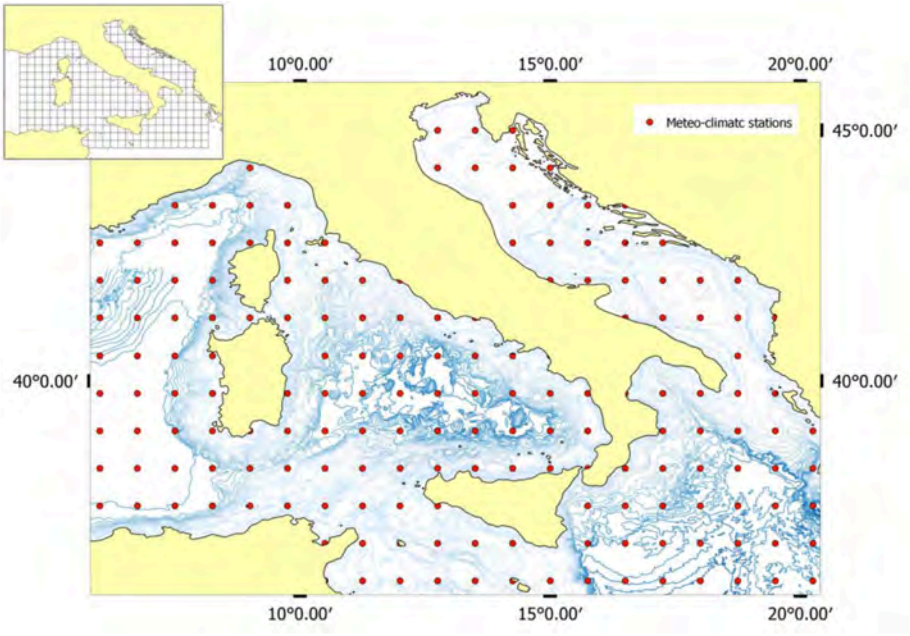

FIGURE 2 | Meteo-climatic stations (*n* = 164). The analysis grid is also shown.

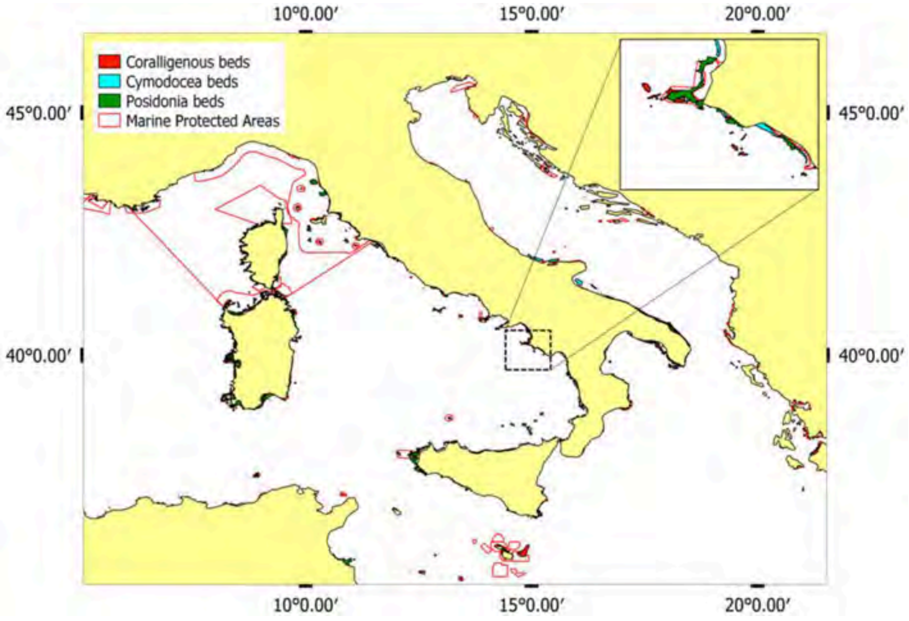

FIGURE 3 | Maps of MPA and Habitats.

Posidonia and Cymodocea beds as well as Mediterranean coralligenous communities have been considered among the vulnerable seabed habitats. These data, updated in September 2016, were extracted from the European Marine Observation Data Network (EMODnet) Seabed Habitats project[3] Seabed habitats have been derived from EUSeaMap which provides polygons based on individual survey habitat classified according to the EUropean Nature Information System (EUNIS).

As far as human pressure indicators were concerned, data on human activities at sea were extracted from the EMODnet data portal (http://www.emodnet.eu/ updated to 2017) which includes a substantial amount of regionally compiled and freely downloadable geo-referenced data related to different aspects of human impacts (http://www.emodnet.eu/human-activities).

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[3] http://www.emodnet-seabedhabitats.eu/access-data/download-data/

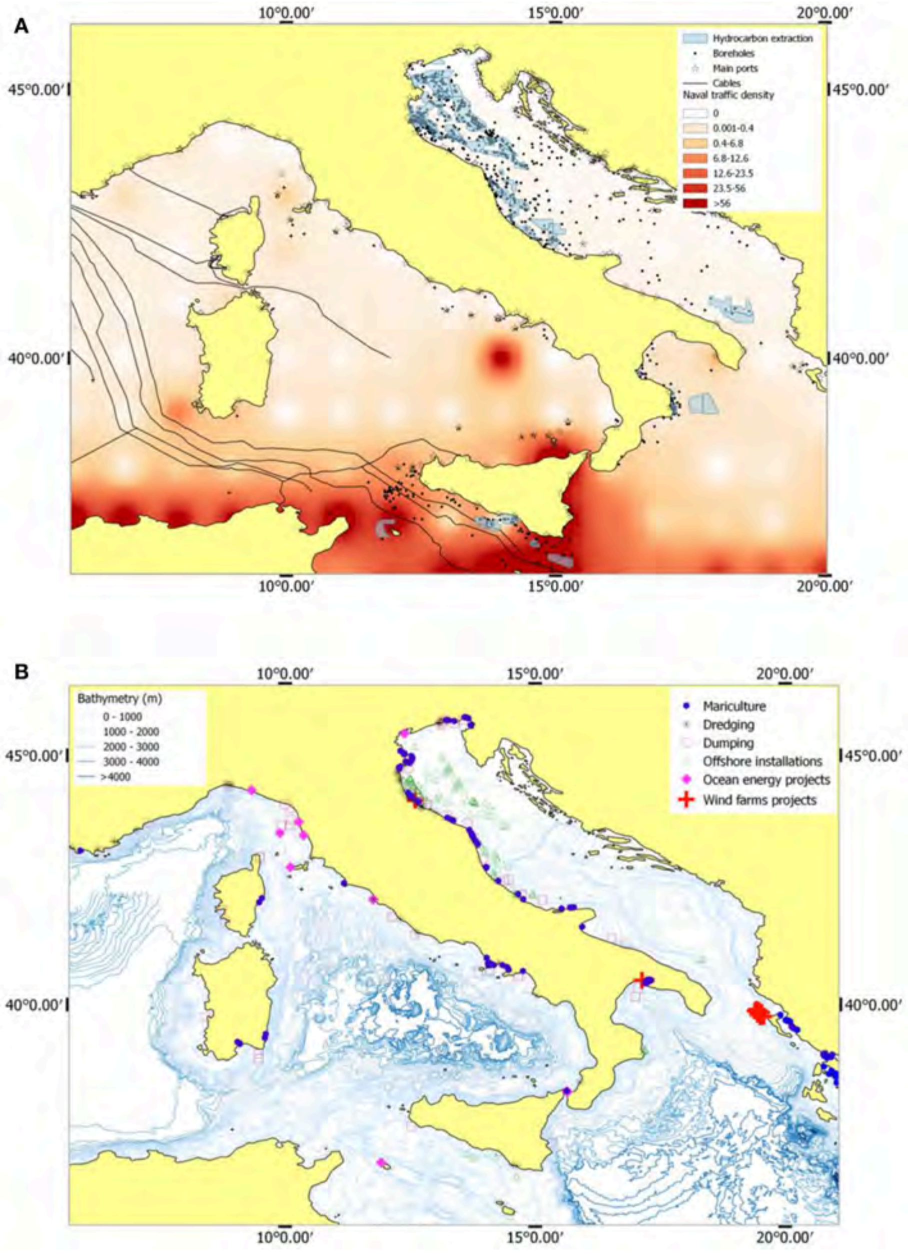

FIGURE 4 | Maps of the pressures: **(A)** hydrocarbon extraction and naval traffic; **(B)** mariculture, dredging and dumping and other activities.

Data in the following set of human activities was obtained from the EMODnet geoportal:

- Main ports;
- Mariculture activities (finfish and shellfish farms at sea);
- Submarine cables routes;
- Dredge spoils dumping;
- Dredging;
- Hydrocarbon extraction (Active Licenses);
- Boreholes Crude oil and Natural gas (Active);
- Oil and gas offshore installation (Operational and Closed down);
- Ocean Energy projects (wave, tidal, salinity gradient, wave/wind);
- Windfarms projects (Planned and Authorized).

In addition, data on naval traffic was derived from the results of PASTA-MARE project[4] which processed AIS (Automatic Identification of Ships) data and provide estimates of maritime traffic density.

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[4] Maritime traffic density-results of PASTA MARE project (2011). Available online at: https://webgate.ec.europa.eu/maritimeforum/content/1603

Figures 3, **4** show the maps of vulnerabilities (i.e., MPA and habitats) and pressures (i.e., human activities) used in this study.

Statistical Methods

The correlation between wind and wave parameters at the different locations was investigated by means of the Pearson's correlation coefficient:

$$r=\frac{1}{N}\sum_{k=1}^{N}\frac{\left[x\left(k\right)-\mu_x\right]\left[y\left(k\right)-\mu_y\right]}{\sigma_x\sigma_y} \tag{1}$$

where μ_x, μ_y, σ_x, σ_y are the mean and the standard deviation of the variables x and y, of k observations and N is the total sample size.

In order to reduce the dimensionality of the meteo-climatic dataset, Principal Component (PCA) and Factor (FA) and Cluster Analyses (CA) (Afifi and Clark, 1996) have been used. Particularly, PCA and FA were chosen to reduce the dimensionality of the wind and wave statistics. PCA extracted the eigenvalues and eigenvectors from the covariance matrix of the original variances. A Varimax rotation criterion allowing to reduce the contribution of the less significant parameters within each principal component, and rotating the axes defined by the preliminary PCA extraction. The Varimax rotation maintains the axes orthogonality condition. The number of factors to retain was chosen on the basis of the "eigenvalue higher than 1" criterion (i.e., all the factors that explained less than the variance of one of the original variables were discarded).

Cluster Analysis (CA), both hierarchical (HCA) and the not hierarchical K-means (Afifi and Clark, 1996), were used to analyse the similarities of meteo-climatic data groups. The Euclidean Distance was chosen as distance measure:

$$\mathbf{d_2(x_i,x_j)}=\sqrt[2]{\sum_{\mathbf{k=1}}^{\mathbf{q}}(\mathbf{x_{ik}}-\mathbf{x_{ik}})^2} \tag{2}$$

K-means was used when the data set was constituted by several thousands of records (i.e., time resolution year-month across the decade) whereas HCA was preferred when the data set accounted only some hundreds of records (i.e., time resolution: decade). When the hierarchical procedure was run, the Ward linkage method was selected as agglomeration criterion. K-means CA, on the other hand, was run three times: the final cluster centroids of the solution obtained after the second run were in fact used as initial centers in the third run. Only the third run results are showed in the present study.

TABLE 1 | Main statistics of the wind and wave parameters.

		v_W (m/s)	Wave direction (°)	T_Z (s)	H_S (m)
N	Valid	28,800	17,496	17,496	1,7496
Mean		4.0329	214.3284	4.8587	0.8696
Median		3.7351	221.8300	4.9004	0.8019
Std. Deviation		1.73520	50.92970	0.88049	0.41124
Minimum		0.74	2.65	2.30	0.15
Maximum		9.73	357.31	7.88	2.36
Percentiles	25	2.5534	181.8035	4.2962	0.5619
	50	3.7351	221.8300	4.9004	0.8019
	75	5.2447	251.3968	5.4599	1.1227

RESULTS AND DISCUSSION

Wind and Wave Conditions

The main descriptive statistics of wind speed v_w, mean wave direction, mean wave period T_z and significant wave height H_s

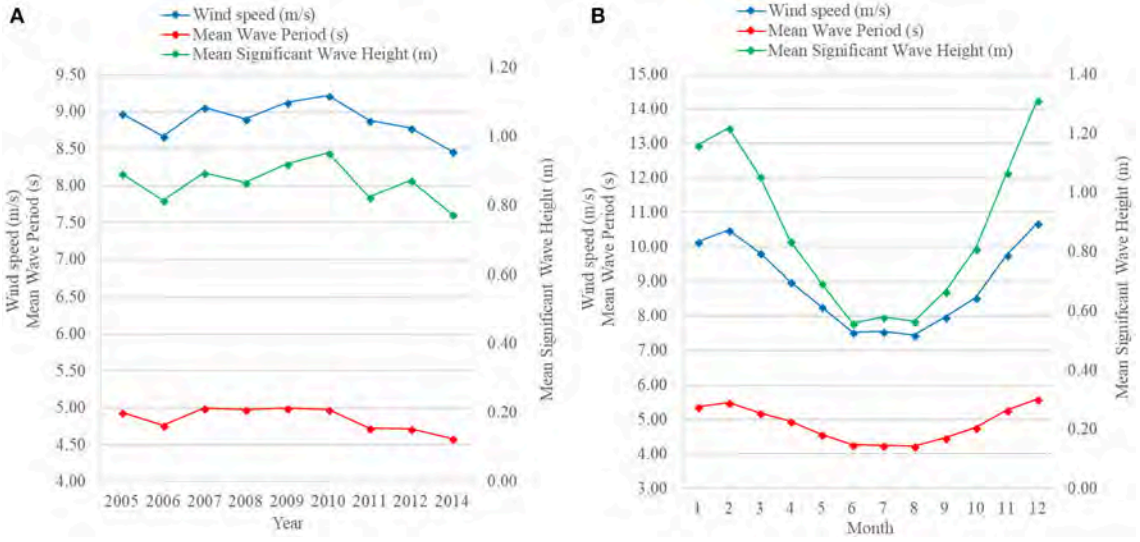

FIGURE 5 | (A) Inter-annual and **(B)** monthly variability in wind and wave patterns.

TABLE 2 | Correlations Matrix of wind speed (m/s), mean wave direction (°), wave period T_Z (s) and significant wave height, H_S (m), month and year.

		Wind speed	Wave direction	T_Z	H_S	month	year
Wind speed, v_W	Pearson Corr.	1					
	Sig. (2-tailed)						
	N	28,800					
Wave direction (°)	Pearson Corr.	0.138**	1				
	Sig. (2-tailed)	0.000					
	N	15552	17496				
Wave period, T_Z (s)	Pearson Corr.	**0.661****	0.243**	1			
	Sig. (2-tailed)	**0.000**	.000				
	N	15552	17496	17496			
H_S (m)	Pearson Corr.	**0.862****	0.218**	**0.889****	1		
	Sig. (2-tailed)	**0.000**	0.000	**0.000**			
	N	15,552	17,496	17,496	17,496		
Month	Pearson Corr.	−0.092**	−0.036**	−0.103**	−0.101**	1	
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		
	N	28,200	17,172	17,172	17,172	31,800	
Year	Pearson Corr.	0.001	0.068**	−0.102**	−0.038**	−0.051**	1
	Sig. (2-tailed)	0.813	0.000	0.000	0.000	0.000	
	N	28,800	17,496	17,496	17,496	31,800	32,400

Higher correlations are highlighted in bold.
***Correlation is significant at the 0.01 level (2-tailed).*

TABLE 3 | Factor loadings of the PCA solutions. Higher correlations are highlighted in bold.

	Component		
	1	2	3
Wind horizontal component at 10 m (U, m/s)	0.355	**0.855**	−0.038
Wind vertical component at 10 m (V, m/s)	−0.018	−0.123	**0.989**
Wind speed (v_W, m/s)	**0.905**	0.084	−0.098
Mean wave direction (°)	0.044	**0.940**	−0.131
Mean wave period (T_Z, s)	**0.881**	0.213	0.105
Mean significant wave height (H_S, m)	**0.966**	0.184	−0.042

Extraction Method: Principal Component Analysis.
Varimax rotation.

have been calculated (see **Table 1**) and their temporal variability has been also investigated. It can be observed in **Figure 4** that data in the study area are characterized by a certain degree of inter-annual (**Figure 5A**) and seasonal (**Figure 5B**) variability in terms of wind and wave patterns.

The correlations among parameters and their correlation with time (month and year) were investigated. As expected, mean wave period and significant wave height were found correlated to each other and both correlated with the wind speed (**Table 2**).

For the purpose of the combined exploitation of offshore wind and wave energy, the most favorable conditions occur when wind and wave temporal patterns are less correlated. Therefore, in order to identify cases where the variability of the produced wind and wave power would be reduced, the different meteo-climatic conditions were analyzed by using a PCA/FA and then classified by means of K-means CA and HCA.

Classification of the Meteo-Climatic Conditions

PCA/FA was applied to the horizontal (U) and vertical (V) wind components, v_w, wave direction, T_z and H_s. The resulting three components explains 89.9% of the original variance. The first component explain the 44.3% of the whole variance, while 28.6 and 17% of the variance is explained, respectively by the second and the third component. The factor loadings of the PCA/FA solution are shown in **Table 3**. The factor selection was evaluated on the basis of the scree plot (see **Figure 6**).

It can be observed that the first component accounts for the v_w, H_s and T_z and, consequently, it is the component that should be minimized to find wind and wave uncorrelated pattern. The second component accounts for wave direction and wind horizontal component and the third component accounts only for the wind vertical component.

A K-means CA was then applied to the factor scores obtained by the PCA/FA extraction at the time scale of year-month (e.g., 2008-1, 2009-4 etc.).

A five K-means clusters solution was chosen, where K-means cluster 1 and 2 show the most favorable meteo-climatic conditions for both wind and wave energy (see **Figure 7**):

- *K-means cluster 1*: shows v_w, T_z, H_s, wave direction and U wind component above the average and V wind component below the average;
- *K-means cluster 2:* shows all wind and wave characteristics highly above the average;

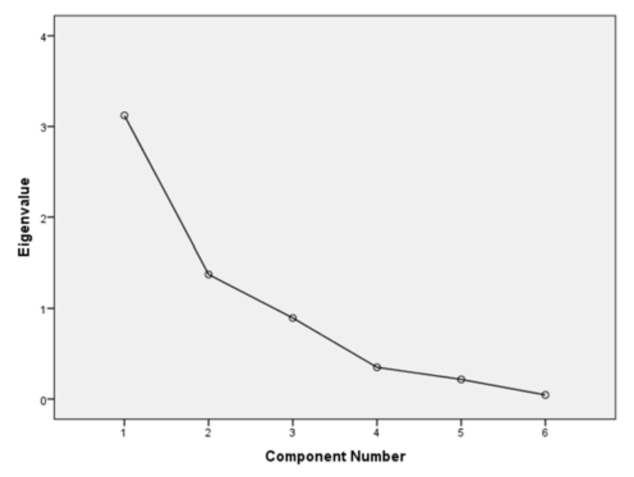

FIGURE 6 | Scree plot showing the extracted components and their corresponding eigenvalues. Three components present eigenvalue higher than 1. Only these were considered in the analysis.

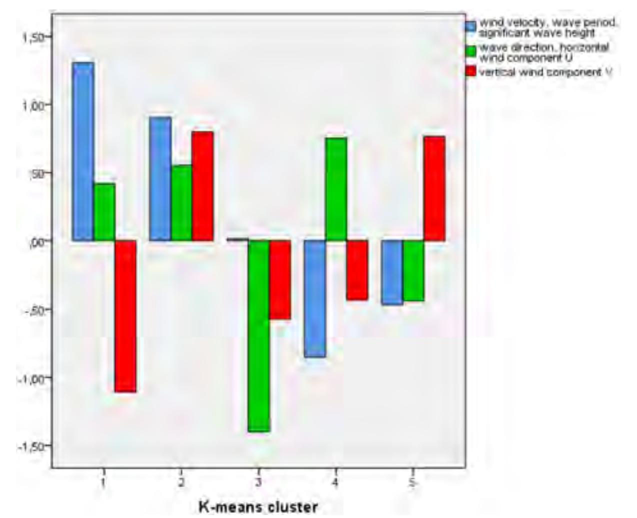

FIGURE 7 | Standardized characteristics of the five K-means clusters. K-means cluster 1 and 2 shows the most favorable meteo-climatic conditions for combined offshore wind and wave energy technologies.

TABLE 4 | Summary of the descriptive statistics of meteo-climatic parameters in the five selected clusters.

	Cluster number	v_W (m/s)	Wave direction (°)	T_Z (s)	H_S (m)
1	Mean	7.0189	244.1954	5.8513	1.4657
	Median	7.0236	245.9893	5.8261	1.4463
	Std. Deviation	0.97742	28.05989	0.53714	0.32199
	Minimum	3.53	151.28	4.13	0.48
	Maximum	9.72	327.53	7.82	2.36
	N	1,791	1,791	1,791	1,791
2	Mean	6.3096	236.0212	5.6843	1.2705
	Median	6.3126	236.5948	5.6279	1.2378
	Std. Deviation	1.14373	27.27497	0.47947	0.27122
	Minimum	2.35	113.86	4.39	0.49
	Maximum	9.19	323.53	7.88	2.13
	N	3,143	3,143	3,143	3,143
3	Mean	4.9634	151.2357	4.5885	0.7762
	Median	4.9505	152.7164	4.7436	0.7866
	Std. Deviation	1.14066	38.48107	0.80547	0.29004
	Minimum	1.20	2.65	2.30	0.16
	Maximum	9.73	245.43	7.11	2.03
	N	2,807	2,807	2,807	2,807
4	Mean	4.0967	256.2834	4.3092	0.5956
	Median	4.1109	255.7535	4.3721	0.5944
	Std. Deviation	0.86030	30.17478	0.62188	0.20302
	Minimum	1.23	147.67	2.59	0.15
	Maximum	6.71	357.31	6.38	1.35
	N	4,083	4,083	4,083	4,083
5	Mean	4.1508	188.4616	4.5601	0.6397
	Median	4.1976	191.6520	4.6464	0.6435
	Std. Deviation	1.13312	35.29018	0.69925	0.22378
	Minimum	1.21	23.50	2.46	0.15
	Maximum	8.09	311.69	7.08	1.88
	N	3,728	3,728	3,728	3,728
Total	Mean	5.0498	215.5785	4.8753	0.8754
	Median	4.9388	223.1816	4.9112	0.8060
	Std. Deviation	1.52051	50.82291	0.88329	0.41488
	Minimum	1.20	2.65	2.30	0.15
	Maximum	9.73	357.31	7.88	2.36
	N	15,552	15,552	15,552	15,552

- *K-means cluster 3:* shows wave direction, U and V components below the average and v_w, T_z and H_s slightly above the average;
- *K-means cluster 4:* shows v_w, T_z, H_s and V wind component well below the average while wave direction and U wind component are above the average;
- *K-means cluster 5:* shows v_w, T_z, H_s, wave direction and U wind component below the average but V wind component above the average.

In **Table 4** the different meteo-climatic characteristics of the five k-means clusters solution are summarized.

It is interesting to compare the correlations between the wind and wave parameters obtained pooling all the data set (reported in **Table 2**) with the ones (shown in **Table 5**) obtained after splitting the dataset into the described meteo-climatic clusters. The clusters showing the lowest correlation between wind speed, wave period and significant wave heights are the K-means cluster 4 and 5 that refer the meteo-climatic conditions that should be dominant to maximize the advantage to combine wind and wave.

To highlight the areas where the most favorable meteo-climatic conditions are dominant, a new cluster analysis was performed aggregating the derived K-means clusters values by station over the whole 10-year series. The aggregation allowed to reduce the dataset from several thousands of records to a hundred and to run a second

TABLE 5 | Correlation analysis between wind and wave.

	Cluster number of case	v_W (m/s)	Wave direction (°)	T_Z (s)	H_S (m)
1	Wind speed v_W (m/s)	1	0.137**	0.560**	0.793**
	Wave direction (°)	0.137**	1	0.307**	0.274**
	Wave period T_Z (s)	0.560**	0.307**	1	0.890**
	Significant wave height H_S (m)	0.793**	0.274**	0.890**	1
2	Wind speed v_W (m/s)	1	0-.144**	0.229**	0.718**
	Wave direction (°)	−0.144**	1	0.355**	0.132**
	Wave period T_Z (s)	0.229**	0.355**	1	0.747**
	Significant wave height H_S (m)	0.718**	0.132**	0.747**	1
3	Wind speed v_W (m/s)	1	0.196**	0.498**	0.704**
	Wave direction (°)	0.196**	1	0.425**	0.313**
	Wave period T_Z (s)	0.498**	0.425**	1	0.877**
	Significant wave height H_S (m)	0.704**	0.313**	0.877**	1
4	Wind speed v_W (m/s)	1	0.133**	0.376**	0.694**
	Wave direction (°)	0.133**	1	0.063**	0.130**
	Wave period T_Z (s)	0.376**	0.063**	1	0.842**
	Significant wave height H_S (m)	0.694**	0.130**	0.842**	1
5	Wind speed v_W (m/s)	1	0.037*	0.269**	0.644**
	Wave direction (°)	0.037*	1	0.215**	0.106**
	Wave period T_Z (s)	0.269**	0.215**	1	0.747**
	Significant wave height H_S (m)	0.644**	0.106**	0.747**	1

Data splitted into the five meteo-climatic clusters.

**Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).*

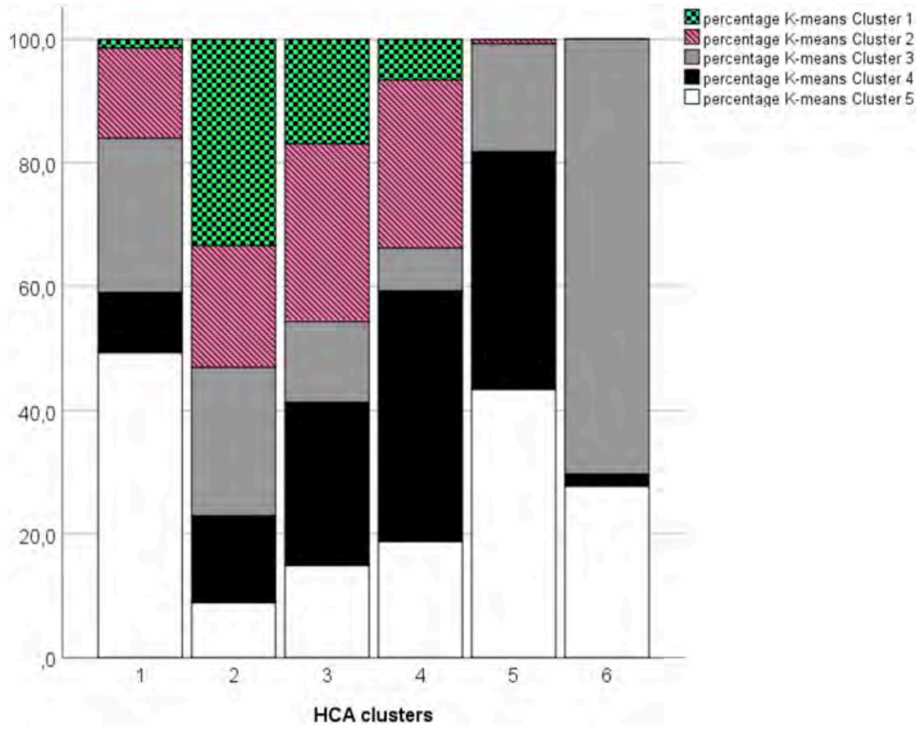

FIGURE 8 | HCA analysis aggregated by stations over the 10-year time series: each bar represents a cluster identified through HCA and colors represent the percentage of K-means Clusters present on each cluster. The HCA clusters of highest interest are 1, 4, and 5 which include the stations where the most favorable meteo-climatic conditions (i.e., K-means cluster 4 and 5) are dominant.

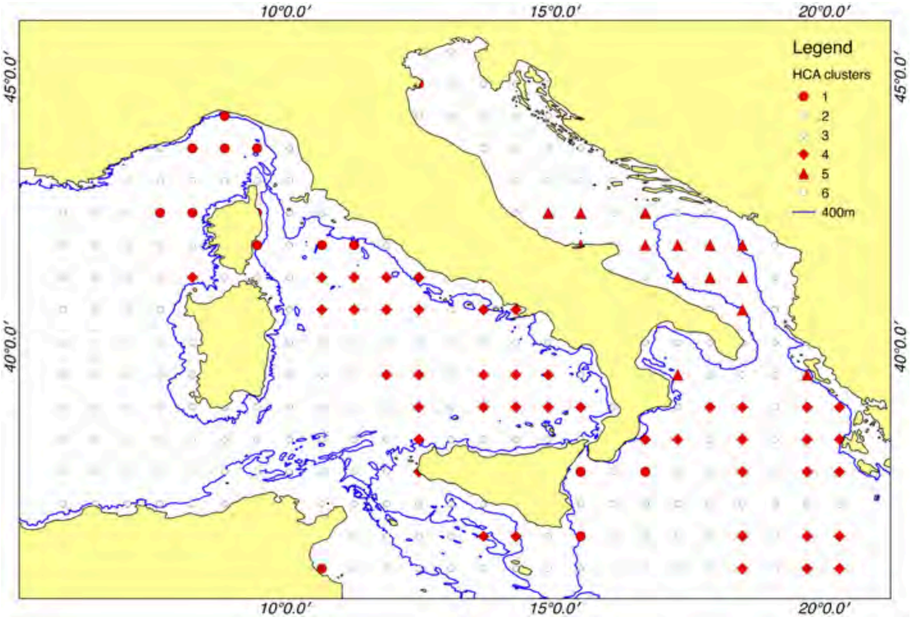

FIGURE 9 | Map of the HCA clusters. The 400 m bathymetry is also shown.

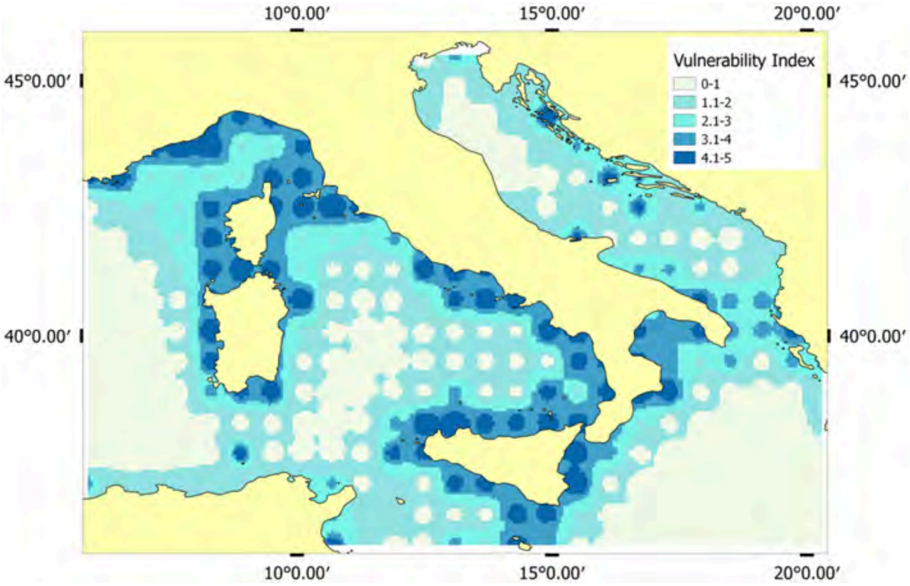

FIGURE 10 | Map of the Vulnerability Index (VI).

cluster analysis by using a hierarchical approach (HCA) with the Ward method to classify the station meteo-climatic dominant conditions.

Figure 8 shows the characteristics of this new six clusters solution: for the purpose of this study, the most interesting clusters are 1 and 4 and 5 which include the stations where the K-means cluster 4 and K-means cluster 5 (i.e., the ones showing the most favorable meteo-climatic conditions according to the K-means CA results over the time scale of the year-month) are dominant.

Finally, HCA clusters 1, 4, and 5 were mapped in order to identify stations showing the most favorable meteo-climatic conditions in terms of wind and wave energy availability (**Figure 9**).

Spatial Analysis of Vulnerabilities and Human Pressure

Due to the high complexity and the regional scale involved, the environmental background of the central Mediterranean Sea area, was considered through a set of multiple indicators, both of environmental vulnerability, and anthropic pressures. A matrix of 12 indicators of anthropogenic pressures and 4 indicators of environmental vulnerability was created for each of the 425 grid units.

For each indicator and every grid cell, two new variables have been calculated: the cell's presence/absence (1/0) and the frequency of occurrence (i.e., as the number of vulnerability elements or human activities per cell unit). Then, Vulnerability and Pressure Indexes were created of the kind presented by Azzellino et al. (2013b).

A Vulnerability Index (hereinafter VI) was defined for each grid cell by summing the presence of Marine Protected Areas, Posidonia and Cymodocea beds and the Mediterranean coralligenous communities. In this way, five classes of Vulnerability (from 1 to 5) were obtained and mapped (**Figure 10**).

Only 42% of the grid analysis cells had values higher than 1. The extension of the study area size and the existing data availability gaps both contribute to determine such condition. Grid cells falling in the lowest vulnerability classes (i.e., class 1 and 2) represent the 22 % of the total, reflecting the presence of MPA in offshore waters. The rest 19% of the grid cells are mostly concentrated in coastal areas and present the higher vulnerability classes (i.e., class > 2) due to the concurrent presence of protected areas, seagrass beds and coralligenous habitats (**Figure 11**).

So, in order to create a Cumulative Pressure Index (hereinafter CPI) avoiding any bias due to the variability in the unit of measurements, the frequency of the 12 different human pressures was normalized to 1 and the sum of the different anthropogenic activities within each cell unit was calculated and obtain a quantitative CPI (see **Figure 12**).

Finally, a cumulative impact index was drawn by multiplying the CPI by the VI. The obtained values of the Impact Index, specified on a logarithmic scale, were ranked into 4 classes of impact (≤0.04 low impact; 0.05–0.33 moderate impact; 0.34–0.61 high impact; > 0.62 very high impact) based on the distribution of the data. As expected, areas showing the higher score (high and very high impact classes) are in general coastal areas and mostly concerns the northern Tyrrhenian Sea, the waters surrounding Sicily and the northern Adriatic Sea. On the other hand, the analysis allowed to identify sites characterized by a low and moderate potential impact, where future wind-wave energy installation could be developed such as the central and southern Tyrrhenian sea, the southern Adriatic sea and the Ionian sea (see **Figure 13**).

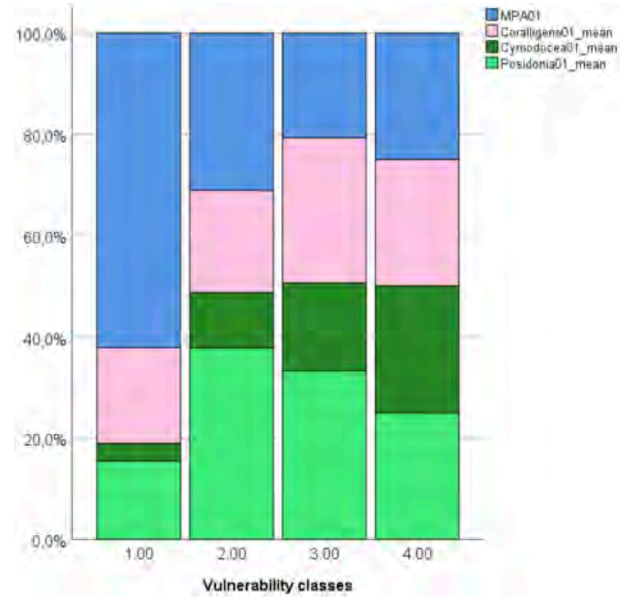

FIGURE 11 | Vulnerability classes description. Only the 4 classes with vulnerability higher than zero are shown.

Optimal Siting of Wind-Wave Energy Technology

The optimal locations for future wind-wave energy infrastructures can be identified by overlaying the areas showing the most favorable meteo-climatic conditions (i.e., stations classified as HCA Clusters 1, 4, and 5) with areas presenting medium and lower values of Impact Index (**Figure 13**). Based on this analysis (**Figure 14**) the optimal sites for future wind-wave energy installations can be identified for waters ranging between 50 and 350 m of depth (i.e., depth range suitable for floating offshore wind installations) and they appear mostly located along the Tyrrhenian coast south of Elba island, the northern-western Sardinian coast offshore Alghero, the southern Tyrrhenian off the Aeolian islands and along the southern Adriatic and Ionian coastal waters. Although the analysis been conducted at a coarse spatial scale, and is certainly affected by larger errors in those locations near the coast where hindcast models reveal their limits, still we believe it will be very useful as support for planning future wind-wave installations for the early minimization of potential impacts. Finer scale studies allowing a more accurate characterization of the local meteo-climatic conditions will be needed for the selection of the optimal wind turbine and wave energy converter combination that will leadto a less variable power output.

CONCLUSIONS

The present study highlights areas where a combined technology of wind and wave energy can be potentially developed in the perspective of energy availability and environmental impact minimization.

It is known that the diversification of wind and wave energies generates benefits in terms of produced power. The results of this study showed that despite the general strong correlation between wind and waves, local and temporary conditions of wind –wave weak correlation exist and may be exploited .. for effective combined production of marine renewable energy. The wind-wave meteo climatic analysis here presented showed that these conditions occur in the western and southern part of the study area, in both coastal and offshore deep waters.

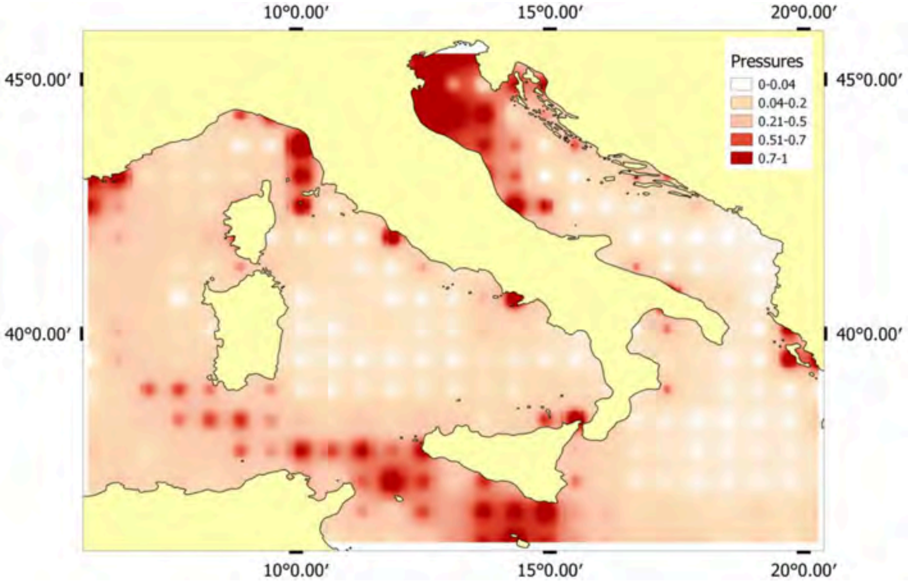

FIGURE 12 | Map of the Cumulative Pressure Index (CPI).

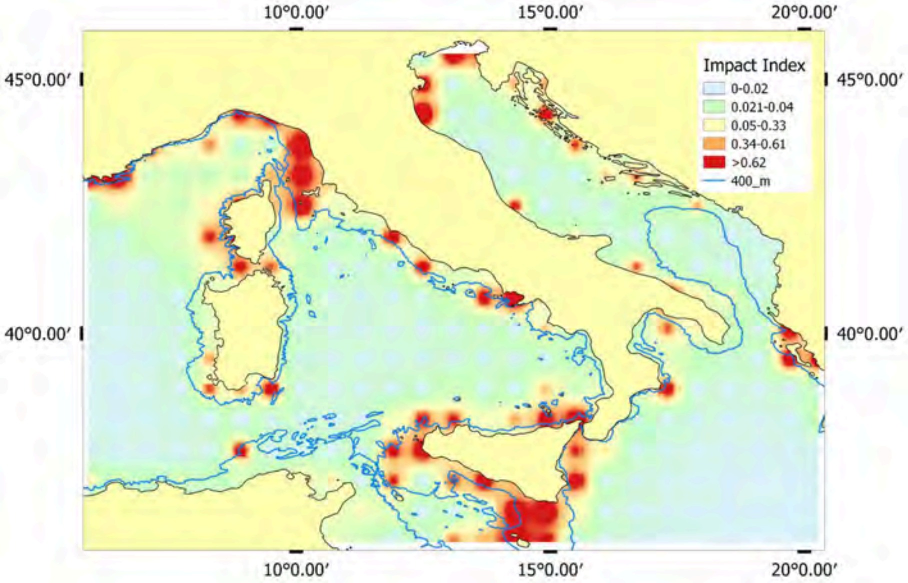

FIGURE 13 | Map showing the Impact Index, ranked into 4 classes of impact (≤ 0.04 low impact; 0.05–0.33 moderate impact; 0.34–0.61 high impact; >0.62 very high impact) based on the distribution of the data.

These results are in partial agreement with the ORECCA project outcomes that suggest only the Strait of Sicily and the French Blue Coast as potential development sites in the Mediterranean Sea area which corresponds to our study. However, their conclusions are mostly based on QuikSCAT[5] satellite offshore measurements of wind speed and direction (Furevik et al., 2010) which are known to have limitations. QuikSCAT data in fact make it possible to draw up homogeneous wind maps of large areas with 0.25° resolution, however measurements taken from satellites by means of scatterometers do have rather high uncertainties (up to 2 m/s) especially in closed basins such as the Mediterranean Sea and, even more, the Adriatic Sea or the Black Sea. So, the fact that our analysis, based on ECMWF data, outlines additional sites of potential developments, such as the Tyrrhenian coast south of Elba island, the southern Tyrrhenian off the Aeolian islands and the southern Adriatic and Ionian coastal waters complements and does not contradict ORECCA results.

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[5] http://manati.orbit.nesdis.noaa.gov/datasets/QuikSCATData.php/

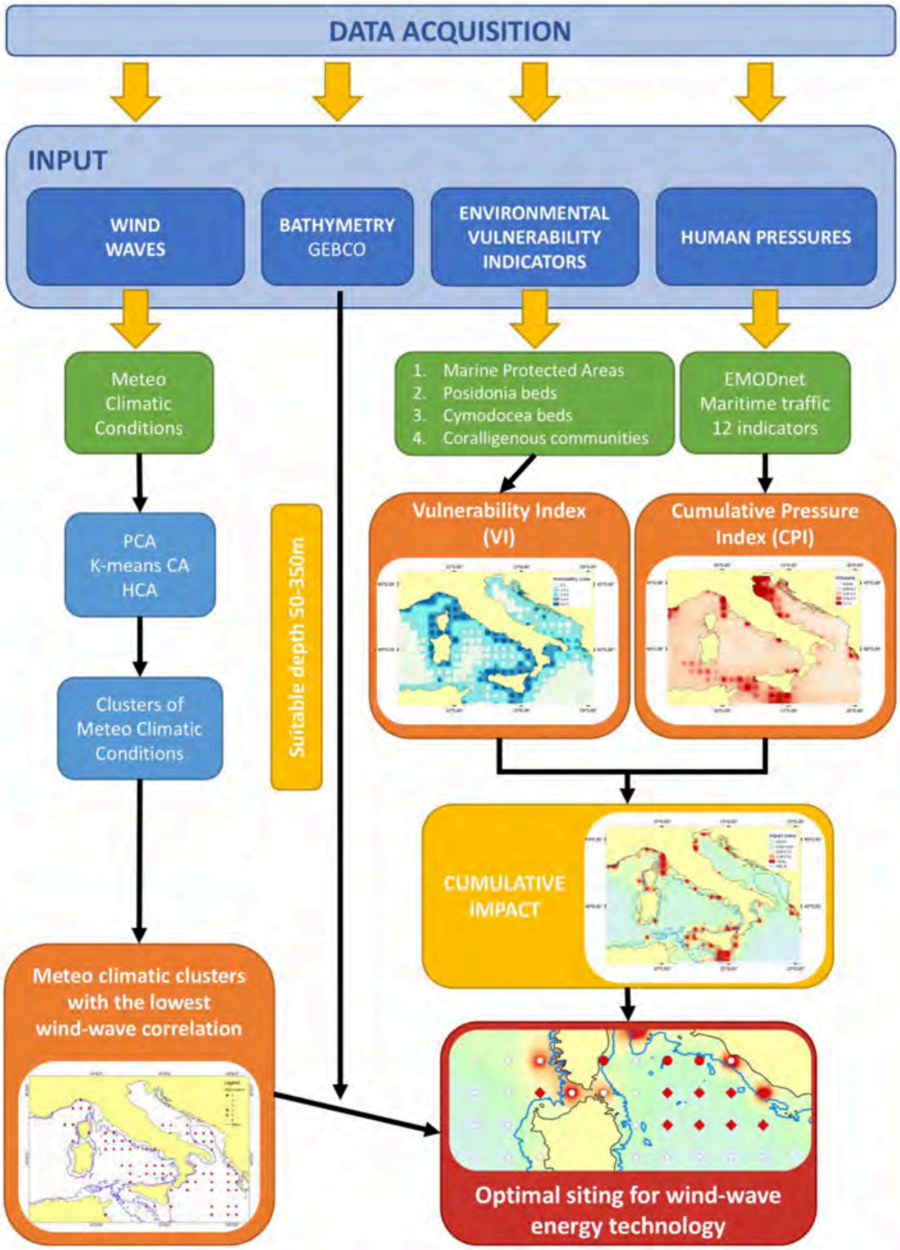

FIGURE 14 | Flow chart showing the optimal siting proposed methodology.

Optimal water depth for the development of wind turbines ranges from 50- to 350 meters, so, even though the favorable meteo-climatic conditions appear to be widely available, in some areas (e.g., waters off Corsica, and Ligurian Sea) these resources cannot be easily exploited due to the unfavorable conditions, the low feasibility, and the costs outweighing the benefits.

The study also demonstrates how quantitative elements of impact and vulnerability could be used to better coordinate the different uses of marine space, and to address the need for protecting the common interests from the unsustainable exploitation of finite spatial resources. Vulnerable coastal habitats (i.e., protected species presence as *Posidonia oceanica,* Delile, 1813) should be considered to estimate the ecosystem vulnerability within the suitable depth range for offshore wind farms installations. The used methodological approach allowed to restrict the optimal siting for combined wind wave energy offshore installations to some areas of potential development: along the Tyrrhenian coast south of Elba island, the northern-western Sardinian coast off the town of Alghero, the southern Tyrrhenian Sea off the Aeolian islands and along the southern Adriatic and Ionian coastal waters, all characterized by a good energy potential and a low Cumulative Impact Index.

The cumulative impact indexes developed in this study, although based on a smaller set of human pressures, appear to be coherent with the cumulative human impact assessment presented by Stock and Micheli (2016) and Micheli et al. (2013).

Environmental impact studies of this kind may feed quantitative spatial planning and support the selection of the sites of potential interest for co-locating wind and wave energy installations, providing support for the sustainable development of future wind-wave offshore parks.

AUTHOR CONTRIBUTIONS

AA and CL conceived the study, analyzed the data and wrote the paper. LR and VD contributed to data analysis and to the revised paper writing. PC and DV supervised the meteo climatic data assessment, revised the paper draft.

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Blue Energy Plants and Preservation of Local Natural and Cultural Resources

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Blue energy technology is one of the most promising and emergent RES sectors developed globally. Many of the pilot and/or fully functioning blue energy plants have been installed in northern European countries. Blue energy plants may have onshore and offshore constructions. Even if RES are highly acceptable by community members in a certain region, the construction of such a plant may rise conflicts. Citizens and local public authorities are usually skeptical about its consequences in local economies, environment, and cityscape. MAESTRALE project's main objective is to transfer available blue energy solutions in the Mediterranean basin by creating a quadruple helix model for their implementation, involving all the actors affected (citizens, scientists, policy makers, local authorities, entrepreneurs etc.). MED area is a region having a unique character and history. Its climate, culture, and landscapes make it a perfect tourist attraction in a global scale. Tourism, in other words, is one of the main pillars of the MED economy and it has to be as less affected as possible in the creation and operation of blue energy plants. This paper aims to seek how BE plants would be successfully incorporated in the existing Mediterranean cityscapes and/or landscapes, focusing mainly in Greek territory.

Keywords: blue energy, blue economy, landscape, RES public acceptance, history, community

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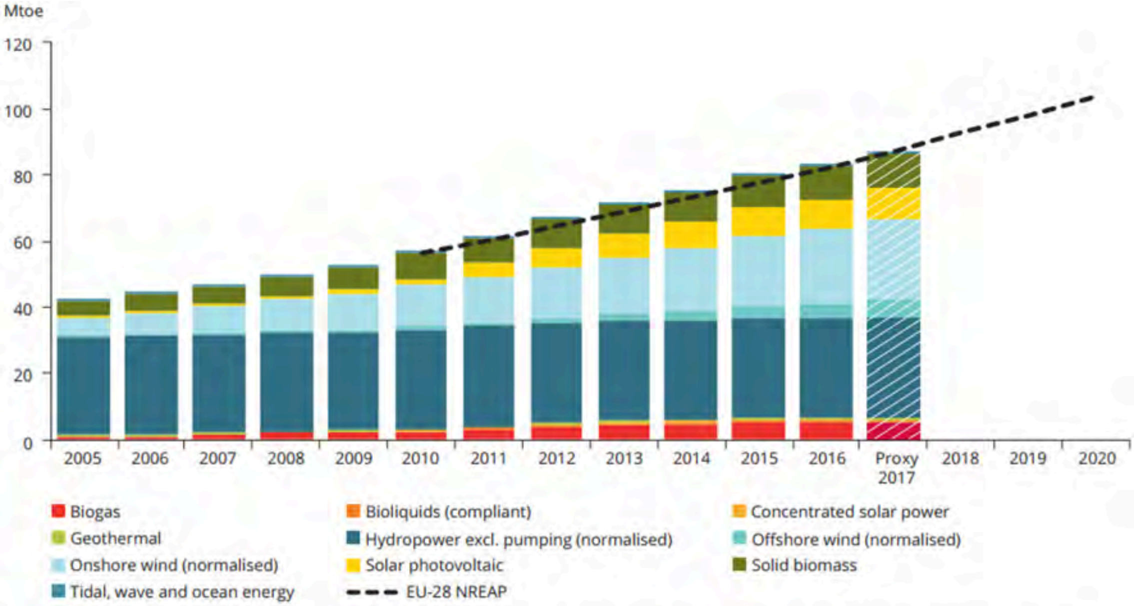
INTRODUCTION

The decarbonization of power generation is one of the most important environmental goals of many countries. The European Union along with national governments are reviewing the EU 20-20-20 strategy in order to ensure that at least 27% of all energy consumed in the EU will be from renewable energy sources (RES) by 2030 (EU Energy Climate Policy - Ocean Energy Europe., 2018). This will push the use of renewable energy in the power sector to at least 45% by 2030 (EU Energy Climate Policy - Ocean Energy Europe., 2018).

The most common forms of RES (excluding hydropower) used within the EU region are wind energy (onshore and offshore) and solar photovoltaic (**Figure 1**) (European Environment Agency, 2018). The variability of the deployment of certain types of RES in Europe depends on various factors e.g., different availability of low-cost renewable technologies, country-specific energy needs, and RES potential, different RES policies regarding spatial planning issues, administrative procedures etc. (European Environment Agency, 2018).

Blue/marine renewable energy (BE) installations (tidal current energy, salinity gradient, ocean thermal energy, offshore wind energy, marine biofuels) offer a variety of new type of RES to be exploited.



Notes: This figure shows the actual final RES-E consumption for 2005-2016, approximated estimates for 2017 and the expected realisations in the energy efficiency scenario of the NREAPs for 2018-2020. Wind power and hydropower are normalised. The consumption of RES accounts for only biofuels complying with the RED sustainability criteria.

Sources: EEA; Eurostat, 2018d; NREAP reports.

FIGURE 1 | RES consumption per category (European Environment Agency, 2018).

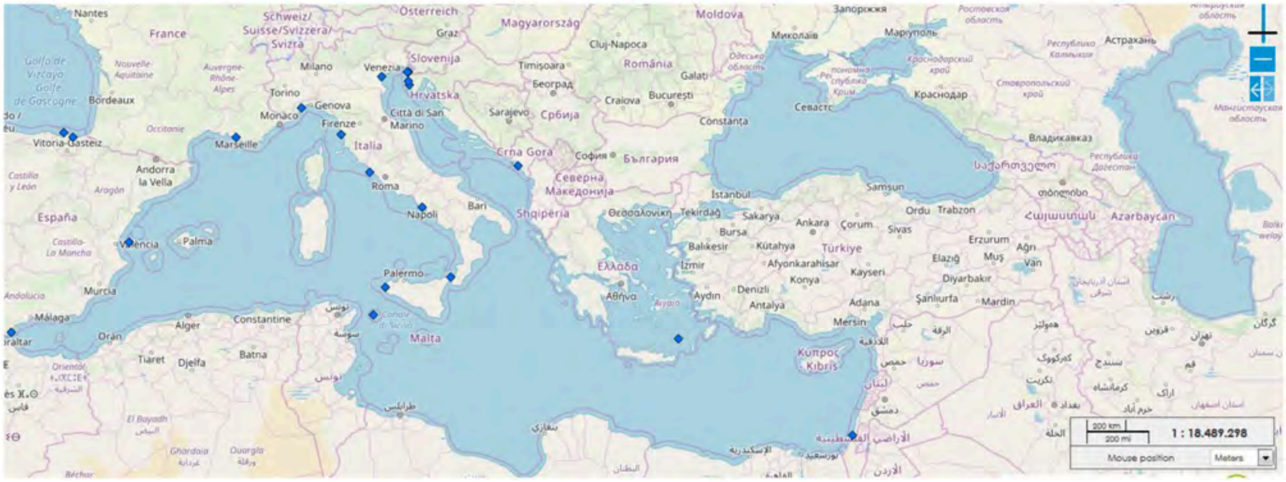


FIGURE 2 | Pilot projects in the MED area, (Maestrale WEBGIS, 2018).

Although just a few case studies regarding BE have been developed in the Mediterranean sea until now (**Figure 2**), the available data for its potential of wave energy, offshore wind, and marine currents prove to be exploitable. Toward this direction, the European Union has initiated the InnoBlueGrowth, a community of projects dealing with Blue Growth. More specifically it aims to establish growth initiatives and synergies in the sectors of aquaculture, coastal tourism, marine biotechnology, ocean energy, and seabed mining. Among them, MAESTRALE project that aim to set the foundations for a strategic deployment of BE in the Mediterranean area. Based on a survey of existing and innovative technologies worldwide, barriers and potentials in participating countries, MAESTRALE aims to broaden the sharing of knowledge among scientists, policy makers, entrepreneurs, and citizens (quadruple helix) and encourage effective measures and investments for the Blue

Growth. Its consortium consists of 10 partners from 8 countries. Project partners are cooperating to detect maritime renewable energy potentials in participating countries as regards their physical, legal, technological, economic, and social contexts. Such initiatives, in our opinion, create a more safe environment for future investments.

As Greek partners of MAESTRALE project, we would like to present our first results of our research on BE in Greek territory. Firstly, we will present the current context for implementing BE potential in Greece. Since we have not many BE installed capacity projects, we will then focus on research papers that investigate how to cope with externalities caused by specific BE technologies that are applicable also in the Greek territory. Lastly, we will try to propose how BE plants can be embedded successfully in Greek context.

BLUE ENERGY IN GREEK CONTEXT (ENERGY POTENTIAL, SOCIOECONOMIC FACTORS)

Greece is regarded to have a very interesting RES potential due to its climate and overall geomorphology (Mattmann et al., 2016; Soukissian et al., 2017). More specifically, unlike the Baltic and of the North Sea, the specific features of MED area, such as geomorphology and the bathymetry, density and intensity of traditional uses, the fact that the majority of states have not yet established Exclusive Economic Zones, the absence appropriate regulatory framework as well as the non-implementation of the Maritime Spatial Planning do not facilitate the businesses concerned are some of ingredients of puzzling Greek context (Andreadou et al., 2018; Blue Energy Potential in the MED Area., 2018).

Both in the coastal areas as well as offshore, Greek seas contain a great variety of uses and activities in great density, interconnected and categorized as follows:

- Protected areas such as Posidonia fields, natura 2000 marine areas, national (marine) parks, river deltas etc.)
- Marine Traffic
- Ports
- Fisheries and Aquaculture. There are several kinds of fishery and fishing fields according to EU law. Moreover, there is an ongoing procedure for designating Areas for Aquaculture Development.
- Tourism (Resorts and hotel, beaches, Marinas, Cruising, Yachting, Water sports)
- Cultural sites: shipwrecks in the sea basin from ancient times are areas strictly protected. On some of them are under ongoing research. Moreover, many onshore archeological sites are located in coastal areas (**Figure 3**).
- Submarine cables and pipelines
- Military activities

The integration of RES technologies is imperative in order to meet the country's 2020 goals. According to Law 3851/2010, Greece aims to increase the share of RES in gross total final consumption to 20% by 2020, which is 2% higher than that required by the EU Directive 2009/28/EC. Currently, the national plan for energy is currently under development and targets for 2030 and 2050 are not clearly defined (Greece State of the Environment Report/Summary, 2018). In the longer run, the Greek climate mitigation will depend upon appropriate investments for the grid transformation (Greece State of the Environment Report/Summary, 2018).

Regarding existing case studies in BE technologies in Greece, there are no BE plants fully implemented (**Figure 4**). In the past few years some offshore wind parks have been licensed to function but due to various factors they were not constructed (Coconet GIS, 2016). Eleven possible projects are located in Aegean area and two in Ionian area, with various capacities (EU 7th Framework Programme for Research and Technological Development), (CoCoNET).

The delay in terms relevant legislations regarding licensing for BE plants (and in this case offshore wind farms), one needs to consider the complexity behind the policy making in Greece in the field of BE. Public bodies that have jurisdiction to activities in Greek seas (Et.gr, 2001) are the following:

- Ministry of Foreign Affairs, holding the jurisdiction for the maritime international affairs
- Ministry of National Defense, head of the Hellenic Navy Hydrographic Service (HNHS).
- Ministry of Maritime Affairs and Insular Policy responsible for marine transportation, protection of the marine environment, ports, and marine investment as well as head of the Greek coastguard
- Ministry of Rural Development and Food, with jurisdiction in both fisheries and aquaculture
- Ministry of Infrastructure, Transport, and Networks (www.yme.gr), responsible for the country's port related constructions
- Ministry of Economy, Development, and Tourism (www.mindev.gov.gr; www.mnec.gr) responsible for spatial planning of touristic projects, as well as for the approval of the siting of marinas; for the licensing process of public and private works related to the coastal and marine space.

In the current context, MAESTRALE BE potential report aims to highlight possible technologies to be implemented in each partnering country by examining current data on various BE types in parallel with a Strengths—Opportunities—Weaknesses—Threats (SWOT) analysis (see **Annex**). The results of this report regarding the Greek area will be discussed below (Blue Energy Potential in the MED Area., 2018).

Regarding wind power, it seems that the wind potential of the Aegean Sea and, secondarily, of the Ionian Sea, is adequately exploitable at offshore locations (**Figure 5**) (Soukissian et al., 2017). More specifically, central Aegean sea has the highest wind power density (mean annual wind power density ∼885 W/m^2). During summer the overall highest value is observed reaching peak values around 1,172 W/m^2 over the south-eastern Aegean Sea, winter follows with highest value ∼1,090 W/m^2

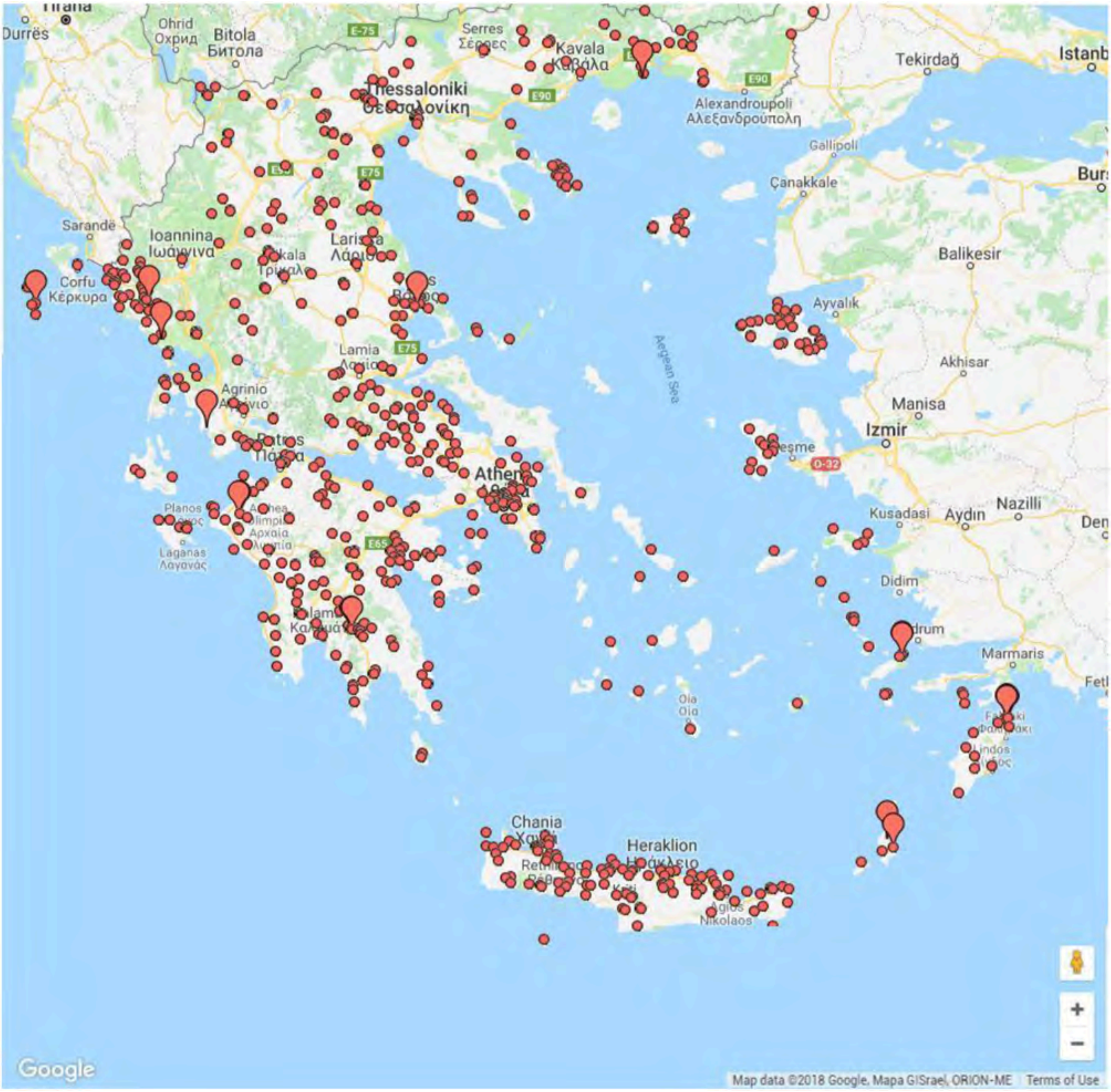


FIGURE 3 | Map of archaeological sites in Greece "Monuments In Greece". (Odysseus.Culture.Gr. http://odysseus.culture.gr/a/map/emap.jsp, 2012).

over the N. Aegean Sea, then autumn with peak value ~806 W/m^2 over the central part of the Aegean Sea, and finally, spring with peak value ~773 W/m^2 over the E. Aegean Sea. However, due to sea bathymetry as well as the extent of territorial sea, the potential to be exploited is limited. It is a well-known practice in Greek power market, there is an interest from investors to enter in a new market (e.g., offshore wind farms), creating new employment opportunities during construction and maintenance. Wind turbines, though, have a great visual impact on the surrounding landscape. For these reasons they may be in conflict with certain economic interests (tourism, marine traffic, fishing etc.).

Regarding wave energy (Stella, 2015) (**Figure 6**) Central Aegean Sea has the desirable range (5–10 kw/m) for power generation. More specifically, Ionian sea has the desirable range for the exploitation of this technology. Other possible areas of exploitation are around Skyros island, as well as around Andros and Tinos islands. Unfortunately, there are numerous protected areas in the aforementioned areas, while the existing bathymetry and limitations of territorial sea

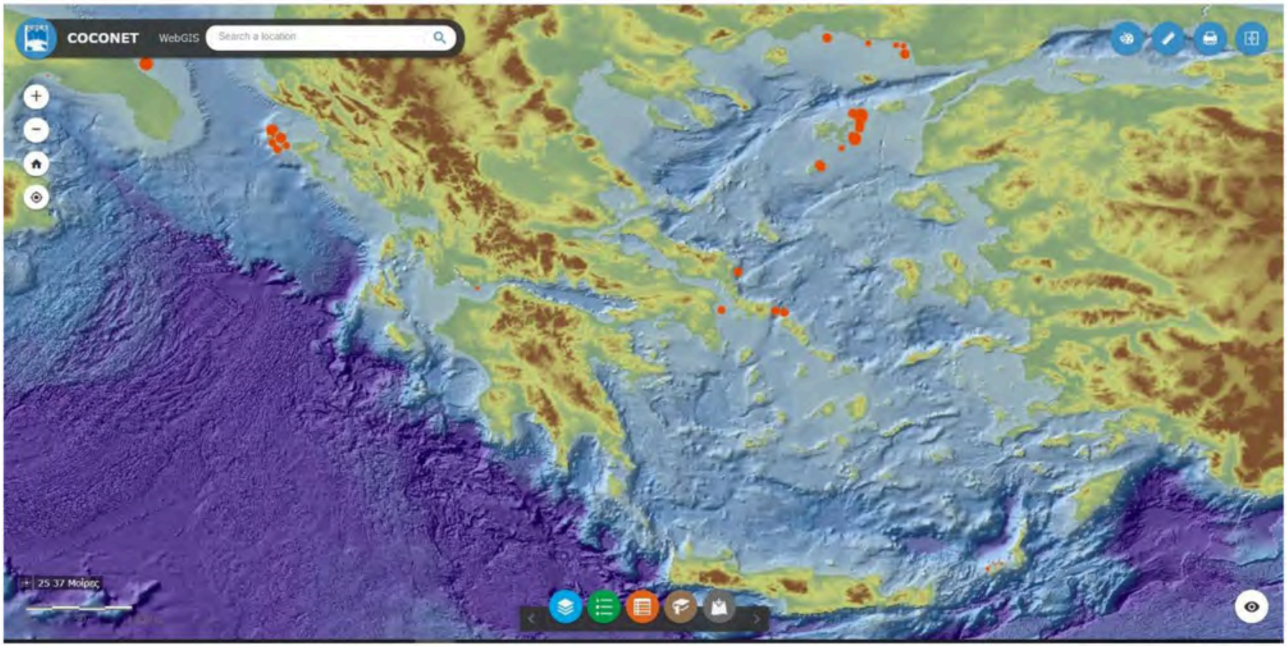


FIGURE 4 | BE plants not implemented (Greece) (http://gismarblack.bo.ismar.cnr.it:8080/mokaApp/apps/COCOV3H5/index.html?null).

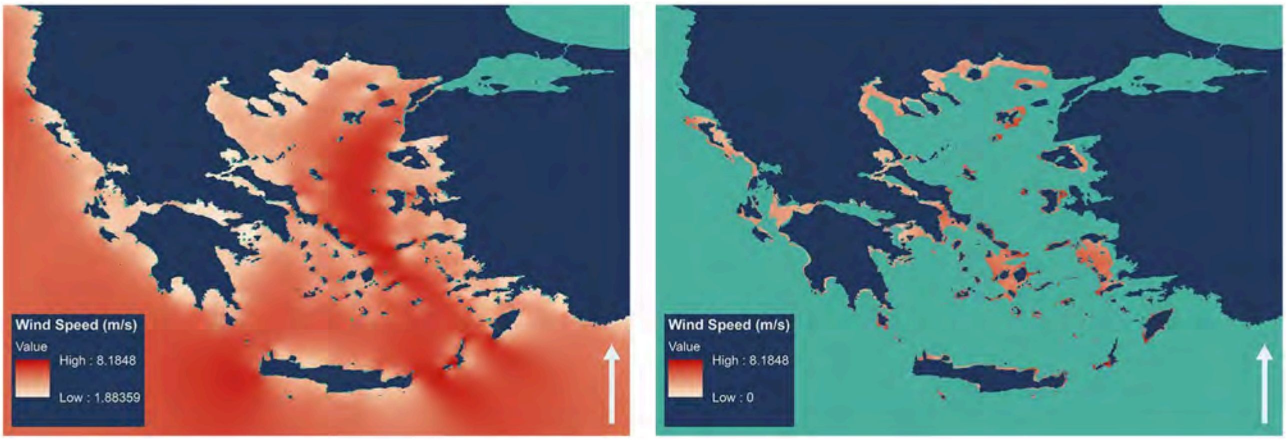


FIGURE 5 | Wind Energy potential in Greece. **(Left)** Potential in the whole Greek territory. **(Right)** Areas of exploitable potential focused on sites with proper bathymetry, out of nature protected areas and within greek territory sea (Maestrale WEBGIS, 2018). Further editing by overlapping the layers referred in open source vector software.

makes the available wave energy potential difficult to exploit. Regarding wave energy potential, there is a growing interest creating infrastructure for energy self-sufficiency in Greek not interconnected islands (NNI). Moreover, initiatives such as blue growth competitions etc. show an emerging interest on BE ventures, creating job opportunities as well as awareness about new types of RES. NIMBY attitude, though is common in Greek local societies concerning the adoption of new technologies. Time-consuming administrative procedures for licensing, construction and operation as well as the instability of tax system in Greece may hinder the implementation of BE plants. In addition, conflicting economic interests of existing power companies may threat the developments of such ventures. Also, due to the form of wave converters there might be a small visual impact of neighboring landscapes and this may affect negatively the local economies that are based on tourism.

Regarding marine current energy (**Figure 7**) the areas in Evia, in Kea, Kithnos, and Lesvos should be taken into consideration for exploitation (Stella, 2015; Maestrale Geo-Database, 2018). The velocity of currents is suitable for the exploitation of the energy produced using technologies similar to current energy, such as turbines or underwater kites. Tidal/marine current technologies can be implemented in certain regions in Greece as

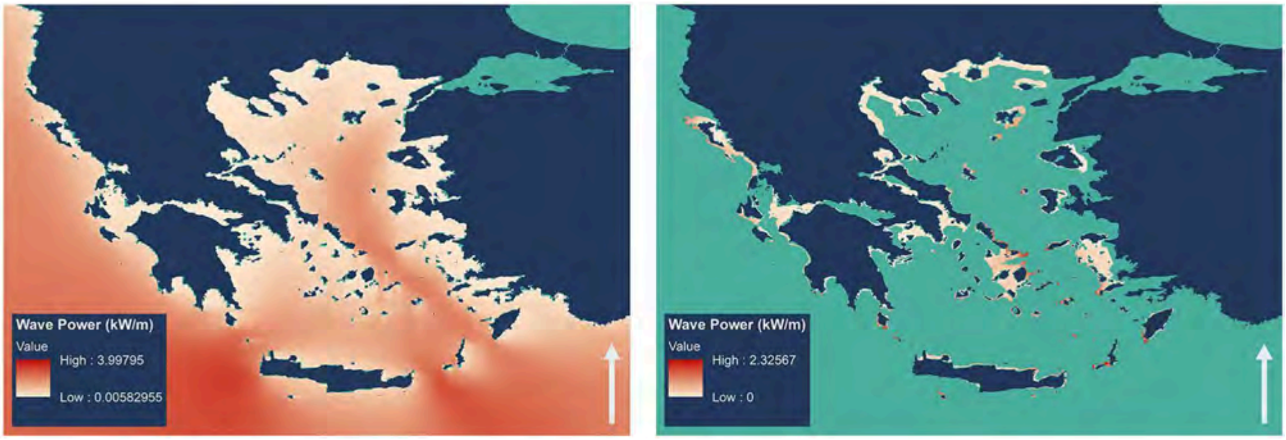


FIGURE 6 | Wave Energy potential in Greece. **(Left)** Potential in the whole Greek territory. **(Right)** Areas of exploitable potential focused on sites with proper bathymetry, out of nature protected areas and within greek territory sea (Maestrale WEBGIS, 2018). Further editing by overlapping the layers referred in open source vector software.

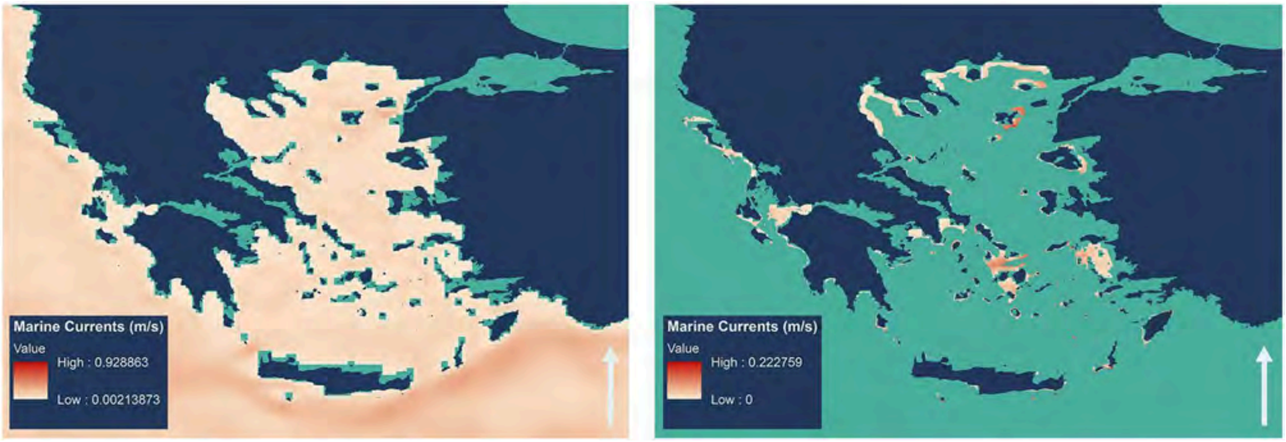


FIGURE 7 | Marine current Energy potential in Greece. **(Left)** Potential in the whole Greek territory. **(Right)** Areas of exploitable potential focused on sites with proper bathymetry, out of nature protected areas and within greek territory sea (Maestrale WEBGIS, 2018).

an alternative form of RES. It could be the most socially accepted type of technology since it is more likely to cause less conflicts due to the lack of visual impact. It may even make possible the establishment of synergies with already existing marine activities, due to the fact that the energy converters are submerged. Since, though, it is not a well-known type of BE technology, it may rise conflict among some social groups. Also, its lengthy construction period is a major investment disincentive.

Last but not least the possibility of sea algae cultivation needs to be taken into consideration. Though further research is needed, algae installations could serve as a supportive energy production system to other hybrid BE systems. Also, (micro)algae could be used as an alternative means of power generation in cities and rural areas. According to data retrieved from relevant databases, in Greece, sites with significant algae concentration are located in urban coastal areas (**Figure 8**) (Colella et al., 2016). The cultivation of algae could create job vacancies and protect marine areas form water pollution phenomena. It is, though, an unknown practice for Greek communities, which might lead to local resistance on its adoption. Its market acceptance as well, is not very well-known. For the time being though, alternative biofuel production technologies are more cost effective.

We could, in general divide the Greek territory in two parts regarding the blue energy potential exploitability:

- Islands for exploiting mainly wave and wind potential (and in some places also tidal energy potential)
- Urban coastal areas of the mainland, exploiting algae biomass

MAESTRALE project's main objective is to transfer available blue energy solutions in the Mediterranean basin by creating a quadruple helix model for their implementation, involving all the actors affected (citizens, scientists, policy makers, local authorities, entrepreneurs etc.). For our current research, we would like to focus on the social dimension of the helix, and more specifically the public acceptance of RES.

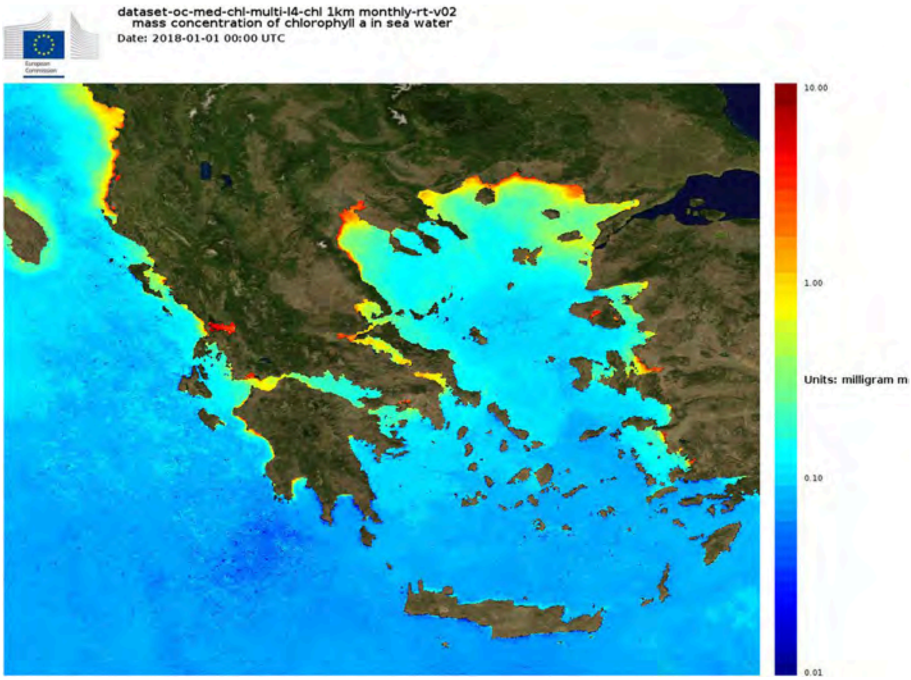


FIGURE 8 | Mass concentration of chlorophyll in sea water (www.waters-creative.co.uk, 2015).

FIGURE 9 | Traditional wind energy installations as an inspiration for scale, sizing, distances of offshore wind farms located in significant for Greek culture and tourism areas (Images accessed July 30 2018). **(Right)** Little Venice, Mykonos https://commons.wikimedia.org/wiki/File:Mykonos,_little_venice_02.JPG Attribution: I, Sailko Creative Commons Attribution 2.5 Generic license. **(Left)** Chiod islands retrieved from https://www.maxpixel.net/static/photo/1x/Sea-Marina-Chios-Greece-Windmill-Ruins-Holidays-1711777.jpg CC0. Public Domain.

LITERATURE ON PUBLIC ACCEPTANCE OF RES

From our point of view, social acceptance is one of the most crucial factors for the implementation of BE plants in the Mediterranean. Since wind power is one of the most promising in Greece, we focused our literature research mainly on wind energy plants (mainly onshore but also offshore).

According to Kaldelis et al., people tend to conceive the positive environmental externalities of RES in a global and/or national levels (Kaldellis et al., 2012). On the contrary, they realize their negative impact into their local environment and approximate surroundings. Contrary to the fact that BE technologies are far more costly to implement than traditional fossil fuel based ones, they are widely accepted also from people with low incomes (Welsch and Biermann, 2014).

Many researchers in the past few years tried to explain local citizen opposition on RES projects based on "Not In My Back Yard" (NIMBY) theoretical framework. In their paper though, Batel and Devine-Wright claim that there is a shift from NIMBY approach since many empirical studies failed to confirm its integrity (Batel and Devine-Wright, 2014). On the contrary, they propose to turn to approaches that "focus on everyday communication and thinking that hopes to link the human psychology and social and cultural trends" (Batel and Devine-Wright, 2014). VESPA framework serves as an alternative to NIMBY (Petrova, 2016), by organizing public concerns on RES into four major categories: Visual/landscape, Environmental, Socioeconomic, and Procedural Aspects.

Based on the literature review conducted so far, social wind energy externalities can be grouped to the following categories (Krekel and Zerrahn, 2017; Zerrahn, 2017):

- Visual/landscape aspect: It is mainly related to impacts on landscape aesthetics (visual disturbance). It is a main trigger of public opposition (Zerrahn, 2017). The conceived dimension of wind turbines, their visible height and the proximity to certain areas of interest (residences, touristic or not) are the most important aspects of this negative externality. It is closely related to the distance in which wind turbines are sited, and it influences a certain space stronger at considerable distances (Zerrahn, 2017). If it is beyond a predefined treatment radius, its visual impact diminishes (Krekel and Zerrahn, 2017). Also, the type of the landscape is important to public resistance and acceptance. If, for instance wind turbines are close to a scenic and/or culturally important landscape, it may raise more opposition. In industrial setting, the opposition is of lower intensity (Zerrahn, 2017). Finally it is highly dependent on the type of space wind farms are neighboring; in areas with low rise buildings, wind turbines are more visible.
- Environmental: This aspect discusses impacts on nature and biodiversity (Zerrahn, 2017). Although there are no researches proving long term impacts on species population, there are some showing both positive and negative impact on surrounding ecosystems. For example, collision of birds with wind turbines is recorded in the past (Marques et al., 2014) but redesigning wind turbines and wind power plants has decreased such incidents (May et al., 2015). Moreover, some studies proved that the foundations of wind turbines serve as artificial reefs (Langhamer et al., 2009; Wilson and Elliott, 2009). Moreover, noise pollution is recorded mainly on onshore wind farms
- Socioeconomic: It involves impacts on local economies. Regarding touristic economic activities, research has shown mixed evidence on how wind farms have affected local economies. They could harm marine activities associated with offshore or onshore spaces (maritime activities, shipping, tourism etc.). Moreover, RES installed technologies lead to decreased properties values (Friedl and Reichl, 2016). Oppositions to certain installed wind farms, may make potential buyers (potential residents—entrepreneurs) cautious about investing in certain spaces. This may affect property market, as well as investments on touristic stock.
- Procedural Aspects: Licensing a RES installation can be a lengthy procedure. This may affect investors' interest in certain regions.

Last but not least, we would like to point out another aspect that is safety concerns/reliability. Since wind energy is highly dependent on weather conditions (Zerrahn, 2017), grid systems based on availability of power may encounter problems in connectivity. On policy level, investments and technologies that promote energy storage should be promoted (Renewables 2017 Global Status Report, 2017), as well as improved grid connectivity (Eleftheriadis and Anagnostopoulou, 2015). In touristic locations, seasonal variations in energy demand must be also taken into account.

RESULTS/DISCUSSION ON HOW BE PLANTS COULD BE INCORPORATED SUCCESSFULLY IN THE LOCAL TERRITORIES

Mediterranean Area in general, has a complex identity. Since antiquity, it has been a very important cultural and economic hub. Nowadays, tourism is one of the main pillars of the MED economy and it has to be as less affected as possible in the creation and operation of blue energy plants.

Any new use/activity that has to be implemented should respect the coexistent uses to the possible extent, in order not to affect local economies. Especially when it has to be implemented in historical and cultural landscapes, spaces that are of great importance for local communities. Otherwise, strong public opposition might arise.

Public acceptance phenomenon, historically, has often been encountered with the adoption of new technologies but also with new architectural forms in public spaces (Petrova, 2016). Using RES and especially wind and hydropower, are well common practices for many centuries. Windmills and watermills were used for centuries and are part of many European Countries vernacular architecture (**Figure 9**). In most cases they are not only received positively, but they become tourist attractions themselves. It is the small scale, and the integration to the landscape and townscape that makes the difference.

Some guidelines retrieved from literature in order to reduce visual impacts on existing landscapes/cityscapes that could be also implemented in historical areas are the following

- According to literature, smaller wind turbine sizes are more preferable due to their lower impact on the landscape (van Rijnsoever et al., 2015). New BE installations should be downsized, by breaking the scale into more, small scale farms. Hybrid BE systems are preferred to farms installing only one type of BE technology and such types could also lead to downsizing of energy generators size (Castro-Santos et al., 2016).

- New BE installations, should be integrated to the local landscapes and townscapes, with the help of design professionals, that in cooperation with engineers dealing with matters like power production, noise, and various estimations, will deal with the aesthetic part of the plants, and their integration to the local natural and cultural environment.
- In urban areas there could be a potential for algae biomass exploitation. This is a type of BE that does not have visual impact, so wherever applicable, it could be used as a complimentary type of BE.
- Small pilot plants could test the viability of such projects as well as raise social awareness about these types of RES. Apart from wind and wave energy, other forms of BE technologies have not been fully tested in the MED area.

CONCLUSIONS

The integration of BE plants in a certain space is connected to its context, that is different in every case. Multidisciplinary approaches for their implementation are needed. Another matter to be taken into account the matter of scale as well as the specific context. Our conclusion is that in order for a new BE plant to be properly implemented in a local community there should be:

- A further linkage of legislation with up-to-date databases of protected areas, sea traffic, fisheries, and other maritime activities, underwater archeological sites, submarine cables and pipelines, military protected areas, could clearly define the areas where BE plants can be implemented. In other words, a detailed marine spatial planning similar to inland spatial planning. Particularly for the case of Greece, for the time being there is MSP regulatory framework is in its infancy.
- Involvement of local communities in the creation of the BE plant, in a participatory design manner
- Architects and design professionals should be included in the teams responsible to design BE plants especially on how they will be integrated to landscapes and townscapes. In BE facilities neighboring with culturally significance, the principles of vernacular RES technologies (e.g., windmills) that have to be considered is their smaller scale ad integration with the existing landscape. For example, complementing a promontory and/or surrounding a gulf in a linear way, might be some design solutions to consider. In other words, BE plants should not be scattered in any place, ignoring the surrounding environment. If the design of wind farms does not respect the surrounding historical landscape/cityscape local opposition to BE plants will surely arise. Unfortunately, full scale best practices of BE plants have not been found.
- Design professionals should also be involved in wind turbine design, so as to find ways to decrease its scale while retaining the capacity favored (e.g., creating hybrid systems in order to reduce visual impact, find alternative ways to design wind turbines in order to decrease their visual impact etc.).

Mediterranean is a new market for installing BE plants. Their form, size, scale, and arrangement are of critical importance for their social acceptance. A multidisciplinary team is needed to address such issues. In other words, Mediterranean is too beautiful to confront it or neglect it. We should rather follow the context of its unique character and let it drive us to widely accepted and desired results.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2019.00040/full#supplementary-material

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Blue Energy Potential Analysis in the Mediterranean

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This paper describes the status of the potential of blue energy (BE) in the Mediterranean region, with focus on the region around Cyprus. Previous studies are reviewed, the main findings of the blue energy potential analysis performed in the frame of the MAESTRALE project are presented, and the most promising blue energy sources for the Mediterranean are highlighted. The findings of this report suggest that there is a good exploitability potential of different forms of BE in the Mediterranean. The most highlighted BE form for the Mediterranean region is offshore wind energy. This is also true for Cyprus, where marine biomass follows as the second most promising blue energy form. Marine thermal energy can also be used for heating and cooling. The main physical barrier for the implementation of BE projects is the bathymetry around the island.

Keywords: renewable energy, offshore marine renewables, ocean energy, blue energy, Maestrale project

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INTRODUCTION

Energy demand increases year by year, while the current primary energy mix is made up from more than 80% of fossil fuels (IEA, 2015). As a result, the energy sector is responsible for a significant percentage of CO_2 emissions globally (IEA, 2015). The European Union (EU) Renewables Directive addresses two of the biggest challenges of our time; energy security, and climate change. In 2004, the European Renewable Energy Council (EREC) set a binding energy target of at least 20% renewable for the EU by 2020 (Zervos et al., 2011). The respective targets of the European commission for 2030 were set to at least 32% (European Commission, 2018). This target is crucial not only for securing the energy supply in the European continent, but also for the mitigation of the climate change consequences and the enhancement of the competitiveness of the economy.

Therefore, the energy sector must turn to new energy sources and more efficient technologies in order to fill the energy demand with clean energy, such as onshore renewable energy sources and ocean energy. While the onshore renewable energy forms, such as photovoltaics, solar thermal, geothermal, wind onshore, biogas, biomass, and other forms, are more developed today, the offshore ocean energy types are less exploited. The ocean is regarded as a vast source of renewable and clean energy that exceeds our present and projected future energy needs many times (Takahashi and Trenka, 1996) and is expected to play a crucial role in the future energy system (Magagna and Uihlein, 2015). It thus has the potential to help reduce CO_2 emissions and alleviate the global climate change threat. Nevertheless, it is also critically important that the development of new ocean energy technologies does not harm the marine environment (Pelc and Fujita, 2002).

Blue energy (BE) is not strictly defined in the literature. Initially, this term was used to describe only the energy produced by exploiting salinity differences between fresh and salty water (Ross and Krijgsman, 2004; Kuleszo et al., 2010). More generally, this term describes the energy coming

TABLE 1 | Projections for renewable electricity in 2020 from offshore wind energy (Zervos et al., 2011).

Country	National RES industry roadmap			National renewable energy action plan (NREAP)		
	MW installed	RES electricity generation (GWh)	% in electricity consumption	MW installed	RES electricity generation (GWh)	% in electricity consumption
Cyprus	0	0	0	0	0	0
Greece	0	0	0	300	672	1
Italy	500	1,800	0.5	680	2,000	0.5
Malta	95	283.3	9	95	216	6.9
Portugal	200	563	0.9	75	180	0.3
Slovenia	500	1,100	7	106	191	1.2
Spain	3,000	8,400	2.2	3000	7,753	2.1

TABLE 2 | Projections for renewable electricity in 2020 from tidal, wave, and ocean energy (Zervos et al., 2011).

Country	National RES industry roadmap			National renewable energy action plan (NREAP)		
	MW installed	RES electricity generation (GWh)	% in electricity consumption	MW installed	RES electricity generation (GWh)	% in electricity consumption
Cyprus	0	0	0	0	0	0
Greece	37	180	0.3	0	0	0
Italy	9	39	0	3	5	0
Malta	0	0	0	0	0	0
Portugal	300	750	1.2	250	437	0.7
Slovenia	0	0	0	0	0	0
Spain	1,000	2,500	0.7	100	220	0.1

from any form of offshore marine renewable source (Soma and Haggett, 2015; Lillebø et al., 2017). According to Ellabban et al. (2014), ocean energy is the energy coming from waves, tidal currents, ocean currents, salinity gradient, and ocean thermal energy conversion (or temperature gradient energy).

EU is currently at the forefront of blue energy development (Magagna and Uihlein, 2015) but this is still a nascent industry. Even though the highest potential for the development of ocean energy is in the Atlantic seaboard, it is accepted that there exists potential also in the Mediterranean and the Baltic basins. Magagna and Uihlein (2015) presented a critical review of the status of ocean energy technologies. They concluded that tidal and wave energy represent the two most advanced and promising types of ocean energy technologies in converting ocean energy into renewable low-carbon electricity and noted that tidal energy technologies are expected to become commercially viable before wave energy.

In this paper, the energy potential analysis conducted for the purposes of the Maestrale project is presented with emphasis on the region of Cyprus. The Maestrale project, is an Interreg MED 2014-2020 Programme co-financed by the European Regional Development Fund. The University of Siena, (UNISI) coordinates a consortium of 10 partners from Italy, Greece, Malta, Spain, Portugal, Croatia, Slovenia, and Cyprus (Oceanography Centre, University of Cyprus). This project intends to lay the foundation for a Maritime Energy Deployment Strategy in the Mediterranean. The three main objectives of the project are: (i) Knowledge transfer between the partners and professionals who already have experience in the sector outside the MED area; (ii) Creation of regional and transnational networks (Blue Energy Labs) of key stakeholders such as policy makers, public authorities, research institutions, entrepreneurs and citizens, in order to promote and establish BE projects; and (iii) Elaboration of two or more pilot projects in each regional area with the highest feasibility conditions for the region. More information about the MAESTRALE project can be found at https://maestrale.interreg-med.eu/.

ENERGY POTENTIAL IN THE MEDITERREANEAN

In the framework of the Maestrale project, Blue Energy is considered in a broader sense and includes: (i) wave energy (offshore and onshore), which can be embedded on manmade structures, such as ports and wave-breakers, or on floating buoys; (ii) offshore wind energy by means of floating or fixed-foundation turbines; (iii) marine biomass, which includes sea weed farms or micro-algae absorbing seawater nutrients and CO_2; (iv) salinity gradient energy, i.e., energy extracted by exploiting the difference of salt concentration between fresh and salty water; (v) ocean thermal energy, where the temperature difference between air and ocean or between different ocean layers is exploited for

TABLE 3 | Highlighted BE forms in the seven participating countries in the MED region.

BE form	Croatia	Cyprus	Greece	Italy	Malta	Slovenia	Spain
Offshore wind	High potential at Cres, Krk, and Senj	High potential at the South coast of the island	High potential at Steno Kafirea and Kasos	High potential in Oristano, Alghero and Messina Straits	Proposed the use of floating turbines due to steep bathymetry	Modest expectations for exploitability	Most promising BE form. Floating turbines for medium level
Marine thermal	Most promising BE form in the region (already in use)	Highlighted in 1st regional BEL (already used by a hotel)			Heating the buildings	Most promising BE form (already in use)	
Wave		Highest potential at the West coast	High potential at Skyros, Andros, Tinos, Karpathos and western Crete	High potential in Tyrrhenian Sea and S-W of Sardinia	High potential for offshore wave technologies		Hybrid technologies usage for greater exploitability
Marine current			High potential at Evoia, Kea, Samos, Kithnos and Mytilene	High potential at Messina Straits			
Marine biomass		Highlighted as promising in the in 1st regional BEL	High potential but further research is required				
Salinity gradient	High salinity gradient due to river inputs (not mature technology)						

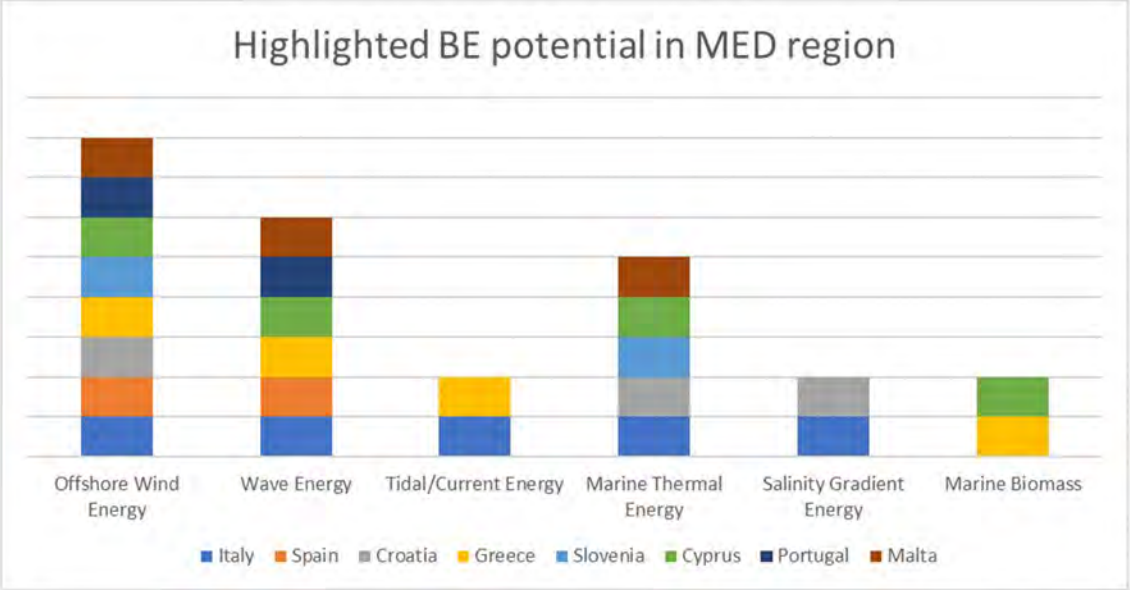

FIGURE 1 | Highlighted BE forms by each country of study. Marine thermal energy is used directly for heating and cooling rather than for electricity production.

cooling or heating buildings; and (vi) marine current energy, using floating, seabed moored, and kite-like turbines.

According to the national Renewable Energy Sources (RES) Industry Roadmaps developed in the framework of the REPAP2020 project (Zervos et al., 2011), ocean energy is planned to represent 0.15% of electricity consumption in 2020. Installed capacity is expected to rise from 245 MW in 2010 to 2,543 MW in 2020. The main markets in the Mediterranean in 2020 will be Portugal, France and Spain, while in the rest of Europe it will be Ireland and the United Kingdom. Wind energy is expected to produce 495 TWh and represent over 14% of the total electricity consumption in 2020. Wind power installations will grow from around 85 GW in 2010 to over 213 GW in 2020, with a compound annual growth rate of 9.7%. Offshore wind is expected to play a prominent role, having 43 GW of cumulative capacity in 2020. The projections for Renewable Electricity in 2020 from

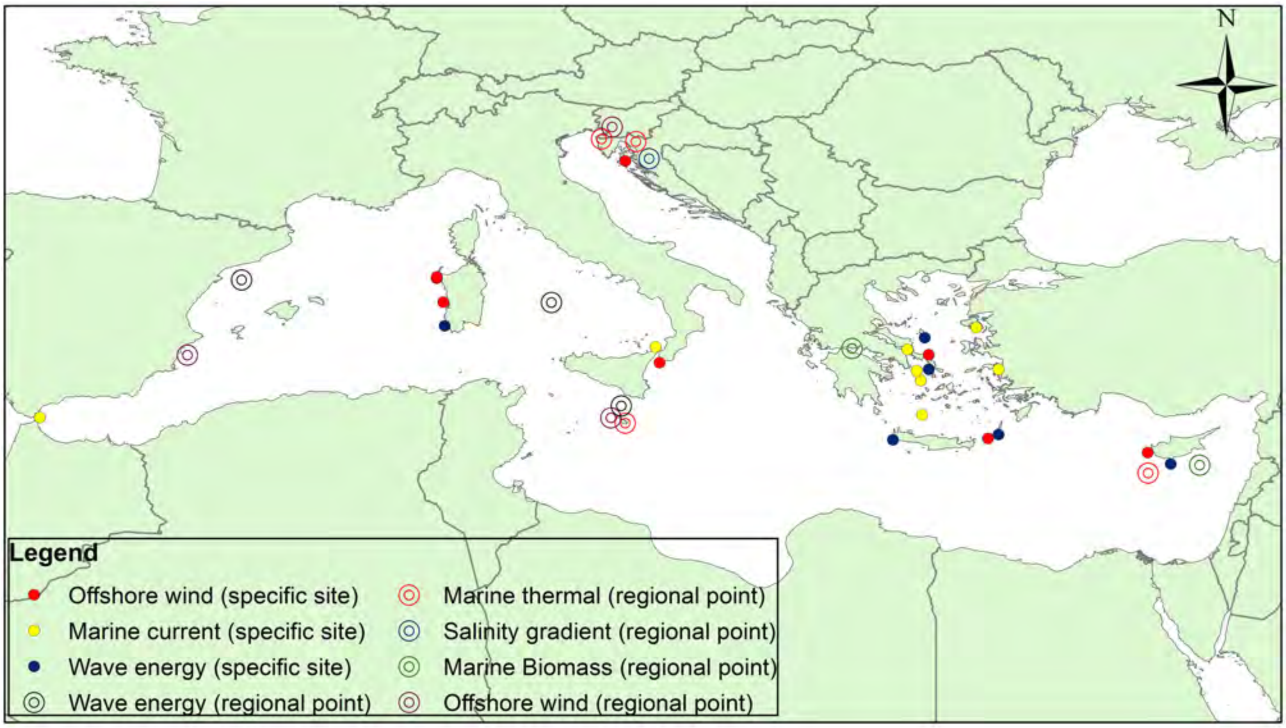

FIGURE 2 | Locations of highlighted BE forms as reported from the partners. Solid circles represent specific locations, while hollow circles represent general regions.

Wind Offshore Energy and Ocean Energy, taken from the data provided in the Zervos et al. (2011), are tabulated in **Tables 1** and **2**, respectively.

To analyse the potential of all BE forms, MAESTRALE partners reviewed and highlighted the most promising sources in their study areas, taking into account physical, legal, technological, economic, and social contexts. The findings of each partner for their region are summarized in **Table 3** and in **Figure 1**. **Figure 2** indicates the locations (solid circles) or regions (hollow circles) of the BE forms highligted by each partner.

Cyprus

Blue Energy Potential

Exploitation of BE energy resources in Cyprus is of critical importance in order to gradually replace the heavy dependence on fossil fuels with sustainable energy, as required by EU regulations and directives. However, the 20% target set by EU (Zervos et al., 2011) for 2020 proved to be too optimistic. Cyprus achieved only 9.3% by 2016 through the use of wind farms, photovoltaic (PV) systems, solar thermal plants, biomass and biogas utilization plants. Cyprus aims to have 13% of its energy consumption coming from renewables by 2020. The Cypriot National Renewable Energy Action Plan (NREAP) splits the overall 13% renewable energy target for 2020 into 16% renewable electricity, 23.5% renewable heating & cooling and 5% renewable transport (Zervos et al., 2011). However, according to a recent study by the International Renewables Agency (IRENA), Cyprus has the potential to produce 25–40% of its total electricity supply from renewables, mostly solar energy, by 2030; this can be further increased by implementing installations with storage capacity (Cyprus Country Report, 2018). In the Cyprus draft integrated national energy and climate plan for 2021–2030 (Partasides et al., 2019), the renewable energy share targets have been set between 15 and 25% for 2030.

The datasets used to produce mean annual wind speed were produced by SKIRON model of the University of Athens (Kallos et al., 1997). **Figure 3** indicates that the mean wind speed, based on data for the period 2010–2017, reaches up to 7 m/s, mainly in the Aegean region and the Karpathian Sea. However, the region around Cyprus does not exhibit such high mean wind values, with the mean wind speed reaching 5.5 m/s at the regions North and South of the island. At the areas East and South of the island the main wind speeds are lower, with mean wind speeds ranging between 3.5–4 m/s. It is visible that the area around Cyprus is not as energetic as the Aegean Sea, but according to Soukissian et al. (2017), an acceptable mean annual wind speed threshold of 4.5 m/s at 10 m height is required for an area to be suitable to accommodate a wind park. As a result, Cyprus is near the lower limit with mean annual wind speeds ranging between 4 and 6 m/s. These wind speeds may allow the creation of a sustainable offshore wind farm but far from the coast. The sustainability of such offshore wind parks might be increased with emerging technologies. Such technologies could be hybrid solutions, harvesting two different energy forms (e.g., wind and wave).

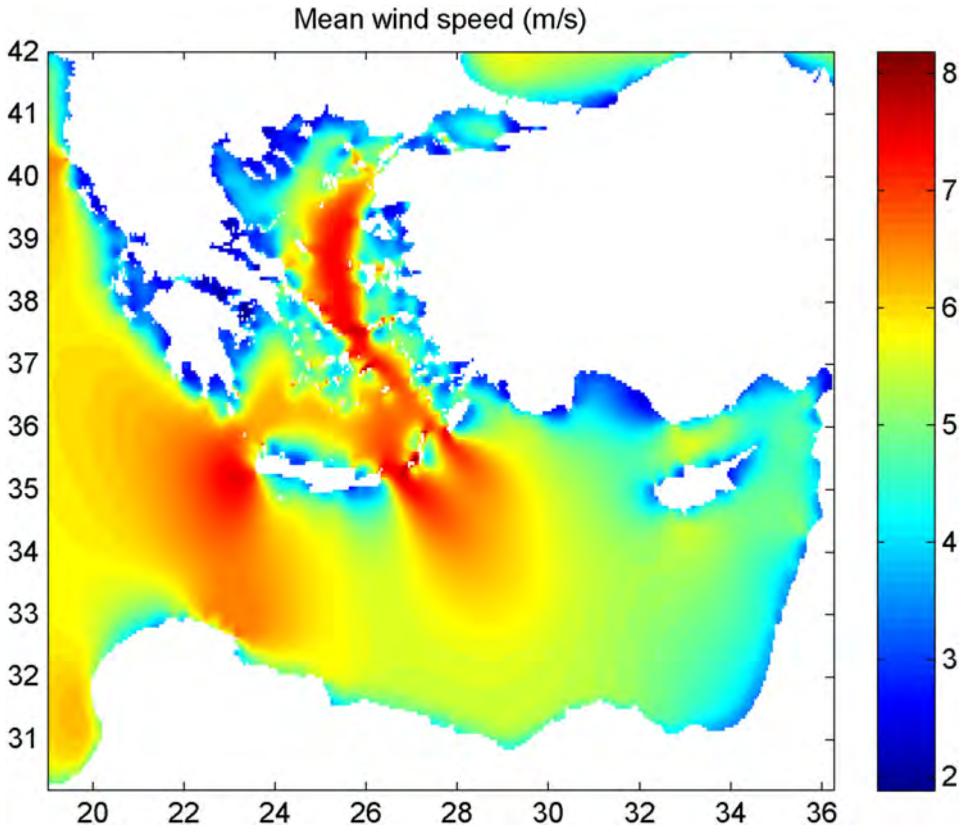

FIGURE 3 | Mean wind speed for the Eastern Mediterranean during 2010–2017.

Regarding the wave characteristics, a Cyprus Oceanography Center WAM version was used to produce an analysis for the period 2010–2017. The two main components that characterize wave energy are significant wave height and wave period. The mean significant wave height (SWH) reaches up to 1.2 meters in the EM region (**Figure 4**). The highest mean values are observed East and West of the island of Crete. The mean SWH around Cyprus reaches up to 0.8 meters at the West side of the island. More specifically, the highest values are observed at the coastline between Akamas peninsula and Akrotiri area. At Pomos region, north-west of the island, the mean SWH values are near 0.6–0.7 meters. At the rest of the coastline the mean SWH values drop significantly near 0.3 meters. As shown in **Figure 5**, higher wave period (WP) values are in the South part of EM near the African coasts. At those regions the WP values are just below 5 seconds. The highest WP values around Cyprus are observed at the northwest, west and southwest coastlines of the island. The values at these locations are near 4.5 s. At the remaining coastline the WP values are falling to 3 seconds. The combination of WP and SWH analyses shows that the areas with higher wave energy potential are located in the west side of the island. The results for WP and SWH are similar to those reported in the E-WAVE project for the significant wave height and wave period over a decadal period 2001–2010 (Zodiatis et al., 2014).

Using the Copernicus MEDSEA reanalysis data (Fratianni et al., 2015), the mean thermal gradients for the Eastern Mediterranean during 2006-2015 between depths 1.5–7.9 m and 1.5–24.1 m are plotted in **Figures 6** and **7**, respectively. Clearly, the west side of Cyprus has greater vertical temperature differences and thus the greatest potential at the Cyprus area. It should be noted that marine thermal energy is already used for heating and cooling in a hotel located in Limassol, at the south-west coast of Cyprus.

Using the same reanalysis dataset, the mean surface currents for the Eastern Mediterranean during 2006–2015 were plotted in **Figure 8**. In the region of EM the surface current speed is low. The peak values are near 0.4 m/s in EM. As a result, marine current energy potential, is considered as very low, since mean current velocities, around Cyprus, are near 0.1 m/s (**Figure 8**), while the threshold set by Soukissian et al. (2017) requires current speed from 1.5 to 2 m/s.

Finally, regarding marine biomass, in Med-algae, a recently completed research project, it has been shown that the use of micro-algae as a biofuel is a quite promising technology (Omirou et al., 2018). The results of the project indicated that marine biofuel production in the region is highly feasible using local marine algae blooms. The quantity and quality of biofuel produce depends on the aquatic environment and the species of micro algae used.

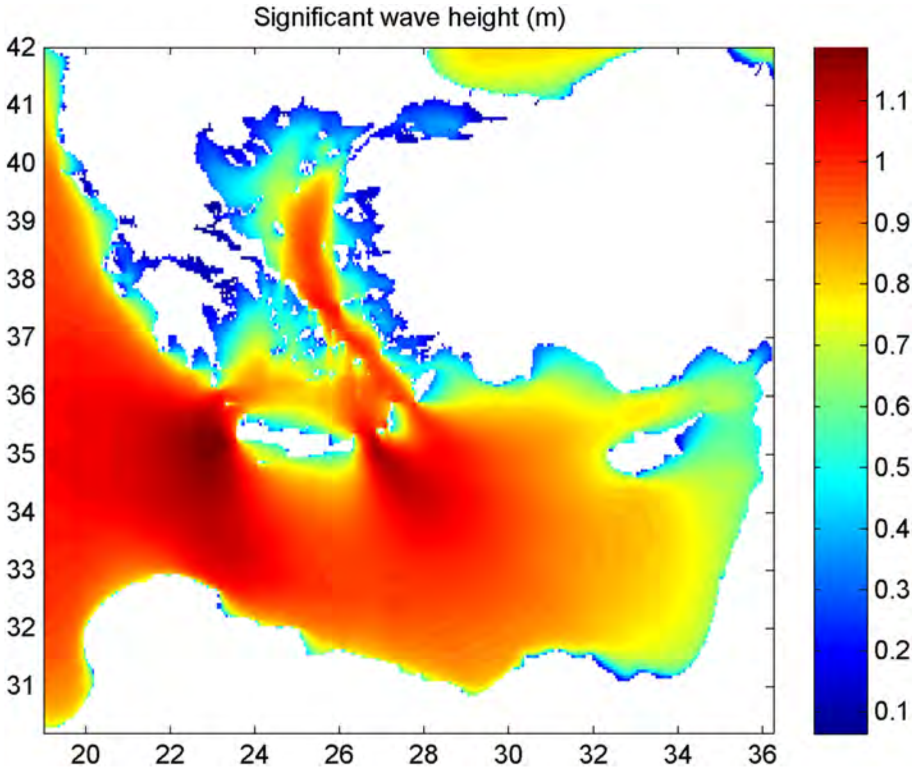

FIGURE 4 | Mean significant wave height for the Eastern Mediterranean during 2010–2017.

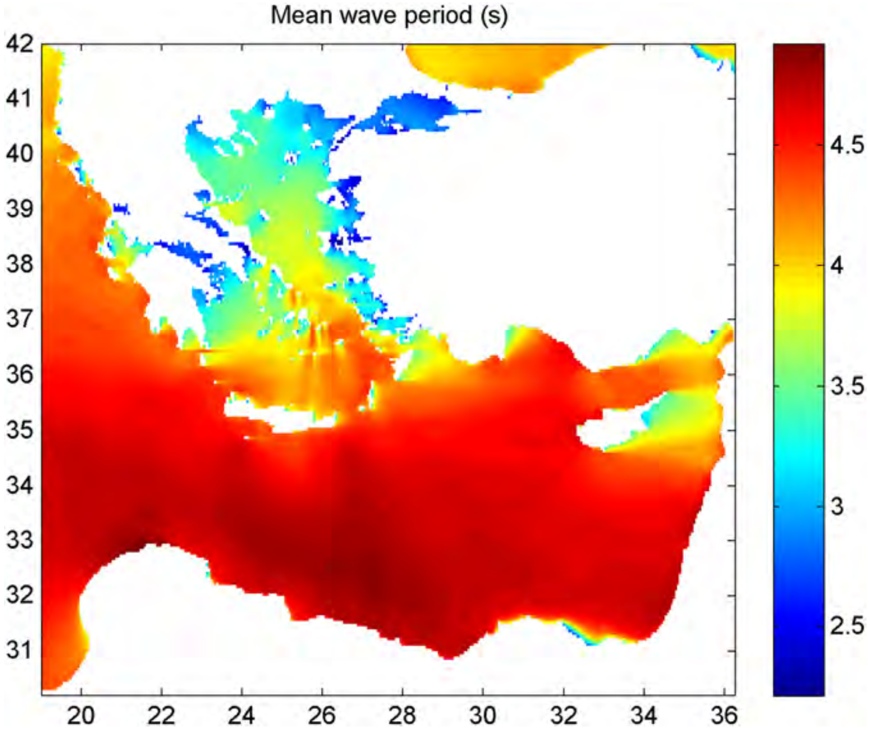

FIGURE 5 | Mean wave period for the Eastern Mediterranean during 2010–2017.

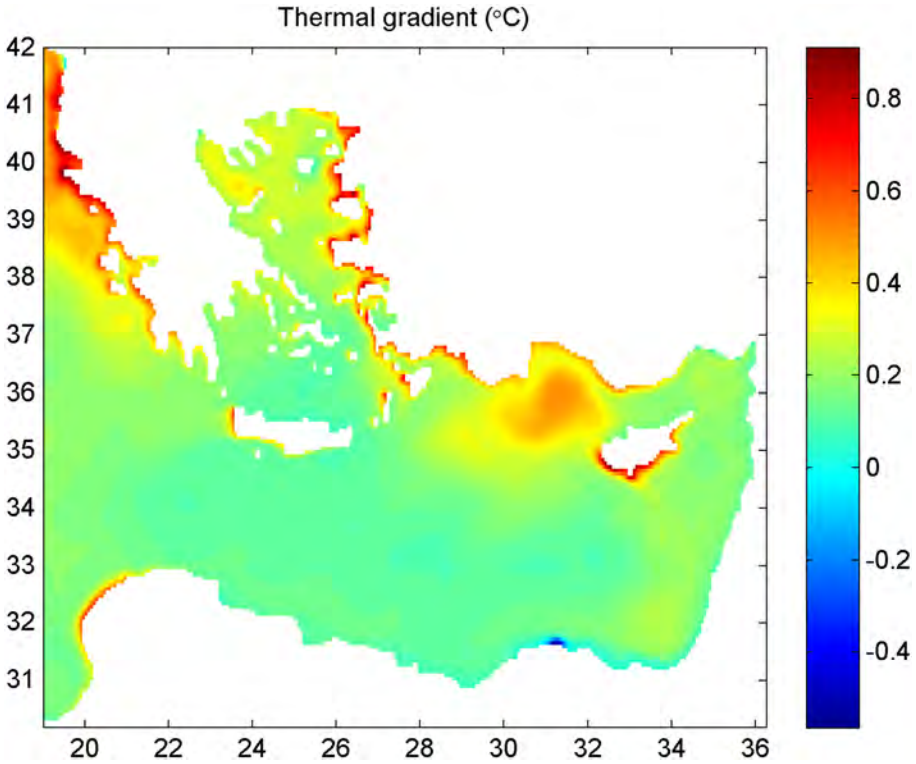

FIGURE 6 | Mean thermal gradient between 1.5 m and 7. 9 m depth for the Eastern Mediterranean during 2006-2015.

Geomorphology

A great problem in developing BE initiatives in the Mediterranean region is the deep and steep bathymetry, which characterizes the whole basin. This is visible in **Figure 9**, which shows that most of the seafloor around Cyprus is very deep. In addition to the deep bathymetry there are not many locations where the seafloor is flat (**Figure 10**). This fact further restricts the site selection for any offshore BE projects. A solution to the deep bathymetry of the region is the use of floating technologies, which can overcome the high costs of fixed foundation technologies.

Other Participating Countries

Two partners from Italy have submitted independent potential energy reports, the findings of which are merged here. The highlighted BE forms are offshore wind energy, wave energy and marine currents. For offshore wind energy, two high-potential locations were identified at Alghero and Oristano near Sardinia and in Messina Straits near Sicily with annual mean wind speeds of 4.9, 5.4, and 5.7 m/s, respectively (Soukissian et al., 2017). One important drawback in this case, is bathymetry, which can exceed a depth of 30 m in just a few hundred meters distance off the coast. However, this issue may be addressed with new emerging floating technologies. The mean wave energy identified for the region is 9.4 kW/m at the south-west coast of Sardinia and 4.75 kW/m near Sicily (Soukissian et al., 2017) and at the Tyrrhenian Sea (Luppa et al., 2015). In addition, marine current exploitation is feasible at very specific locations. In general, the marine current velocity is low, apart from Messina Straits where it ranges from 1.8 m/s to 3 m/s during spring tides (Soukissian et al., 2017).

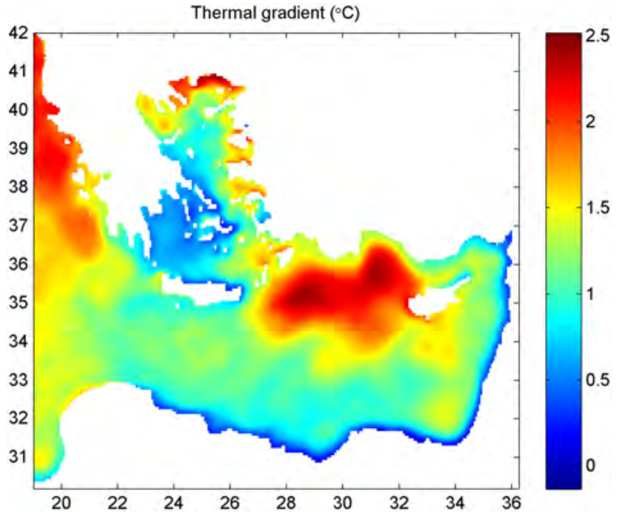

FIGURE 7 | Mean thermal gradient between 1.5 m and 24.1 m depth for the Eastern Mediterranean during 2006-2015.

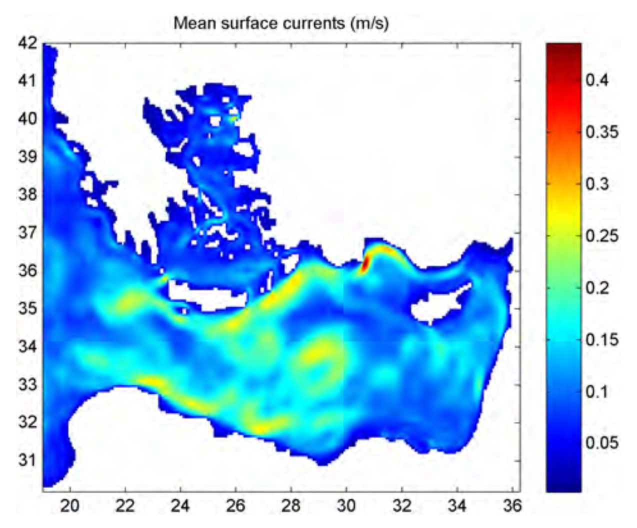

FIGURE 8 | Mean surface currents for the Eastern Mediterranean during 2006–2015.

The analysis of Istrian Regional Energy Agency (IRENA) for Croatia showed that the BE forms with the greatest potential are offshore wind, salinity gradient and thermal energy. The most promising areas for offshore wind energy are near Cres and Krk islands and near Senj. According to the feasibility scenarios of Hundleby and Freeman (2017), under certain assumptions, an offshore wind energy park is feasible if the mean wind speeds are 7.5–8 m/s. These scenarios and assumptions lower the feasibility potential of offshore wind energy in Croatia. It has been reported that salinity-gradient energy exploitation is favored by the high vertical differences in salinity observed due to river runoffs in North Adriatic Sea (Russo and Artegiani, 1996). The main drawback for this BE form is the technology, which is still developing and has not reached a commercialization level yet. The BE form with the most highlighted potential is thermal energy. This BE form is used directly for heating and cooling using marine heating pumps. Heat is extracted for heating the buildings and is stored during the cooling phase of buildings. The temperature differences between air temperature and seawater make this BE form the most promising and viable in the region.

In Greece, the BE potential analysis carried out by Aristotle University of Thessaloniki (AUTH) concluded that the most promising BE forms are offshore marine currents, wave energy, wind energy, and marine biomass. Marine current energy is generally low in the MED region. This potential is remarkably high and can be exploited only in certain areas. Such areas in Greece, are located near Evoia, Kea, Samos, Kithnos, and Mytilene (ORECCA Project, 2011), where the minimum spring tide marine current is near 1.75 m/s, a magnitude that allows the exploitation of marine current energy. Wave energy potential ranges between 5 and 10 kW/m near Skyros, Andros and Tinos in the central Aegean Sea, near Karpathos and western Crete, where wave energy harvesting may be feasible. Regarding offshore wind energy, the areas with the highest potential are found in the Aegean Sea at Steno Kafirea, with a mean annual wind speed of 7.5 m/s and with available wind potential energy of 546 W/m^2. Another favorable location is Kasos, in the Karpathian Sea, with a mean annual wind speed of 8 m/s and with available wind potential energy of 570 W/m^2. Finally, the potential of marine biomass is highlighted, but for its exploitation, further research advances and better understanding of its commercialization impacts are still required.

Two separate potential analyses have been carried out by the two partners (Cluster Maritimo-Marino de Andalucia and Business Innovation Centre of Valencia) in Spain. Offshore wind energy and wave energy are highlighted as the most promising BE forms. The two analyses suggest that the most promising BE form is offshore wind energy. It was also pointed out that the only viable solution for commercialization of offshore wind energy is floating wind turbines due to the deep bathymetry of the MED region. The W2Power floating wind turbine was proposed as a possible solution, since it can operate well at the wind speed ranges encountered in the MED region and has been tested extensively. For wave energy, a hybrid solution of wave extraction technology is suggested, in order to increase the feasibility of wave energy extraction projects due to relatively low wave energy potential at the region. Such technology is the Butterfly converter from Rotary Wave. Finally, tidal energy is also highlighted for the area near the Straits of Gibraltar, where current velocities reach up to 2 m/s. The issue with this BE form is that existing technologies cannot harvest energy at these current speeds and new technologies are not yet mature enough.

The coastline of Slovenia is only 46 km, which limits the possible site allocation of any potential offshore renewable technology. Nevertheless, according to the report of Goriška Local Energy Agency (GOLEA), the most important BE forms are offshore wind and marine thermal energy. The offshore wind energy does not allow very high expectations, since mean annual wind speeds can reach up to 5 m/s. An important feature is micro-siting which can favor higher wind speed at specific locations. The most promising BE form, however, is marine thermal energy. This energy form is not used to produce electricity but is rather used for energy efficiency. In fact, the existing capacity of the region is 1.4 MW with an annual heat extraction of 2,300 MWh. The mean annual sea temperature is 17.6°C ranging from 9 degrees in February to 26 degrees Celsius in July and August. These temperatures are much lower or higher compared to the air temperature, hence they are suitable for heating or cooling.

Lastly, according to the BE potential analysis report of Malta Intelligent Energy Management Agency (MIEMA), the most promising BE forms for Malta are wave energy, offshore wind energy and marine thermal energy. According to the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) the wave potential of the region reaches up to 7 kW/m at 25 km off the coast of Malta and becomes lower closer to the coast. In addition, offshore wind speed reaches 6 to 7 m/s in areas located 25 to 50 meters from the coastline (ORECCA Project, 2011). Once again, floating-turbine technologies are mentioned since the steep bathymetry of the region does not allow the use of fixed-foundation wind turbines.

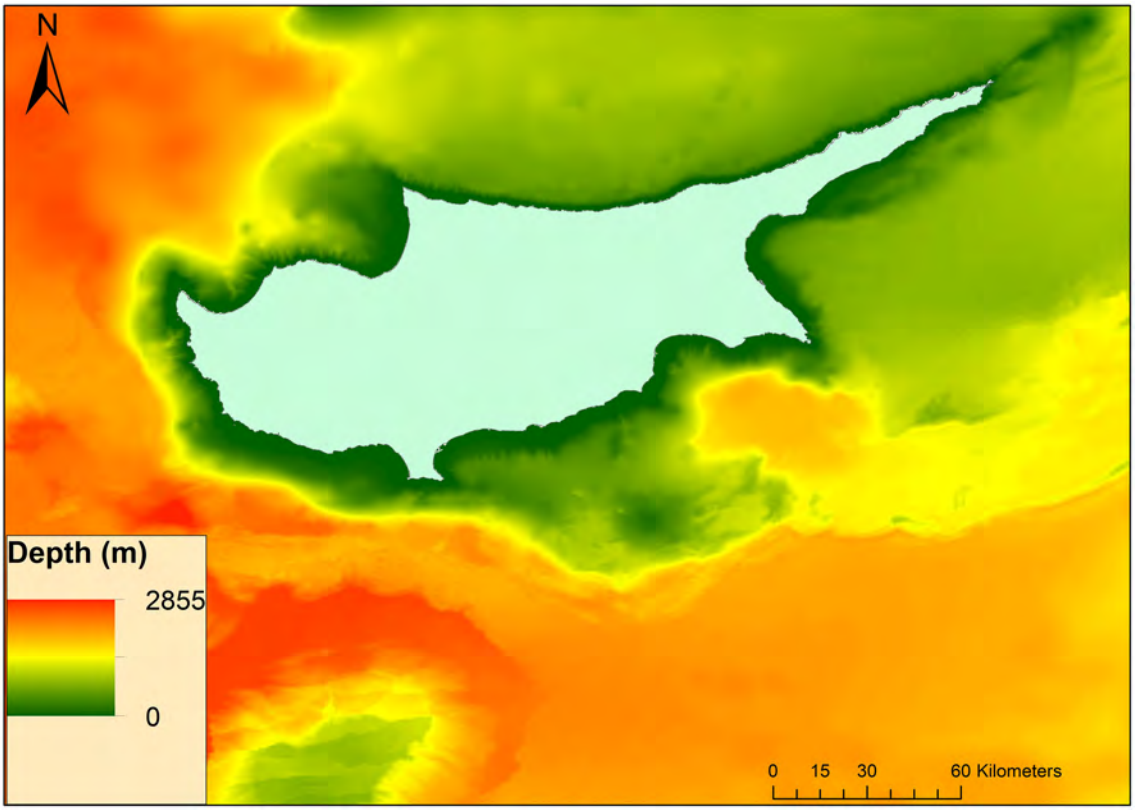

FIGURE 9 | Bathymetry around Cyprus.

Moreover, like Croatia and Slovenia, the marine thermal energy is proposed for use as energy storage and source when needed. This can be a feasible scenario for energy savings due to the sea/air temperature differences both in the summer and in the winter.

The detailed results of the Blue Energy Potential Analysis for all Mediterranean countries participating in the MAESTRALE project can be found on the MAESTRALE website (https://maestrale.interreg-med.eu/). In addition, a webgis portal (http://maestrale-webgis.unisi.it) has been created, which contains an updated database of Blue Energy potential, best practices projects, stakeholders, as well as physical and environmental constraints in the Mediterranean region.

DISCUSSION

As illustrated in **Figure 2**, all BE forms were highlighted as promising throughout the MED region. However, the most highlighted BE form in the study area is offshore wind energy, which has been selected by all 8 countries and by 9 out of 10 partners. It is worth noting that in some regions the potential of this BE is characterized as low, since the wind speed is not as high as in other regions outside the MED region. This impacts the feasibility of possible investments in such regions.

The second BE form which was highlighted by most partners is the wave energy. Wave energy has not been considered by countries in the Adriatic Sea. To increase exploitability of wave energy potential, partners made several suggestions. One suggestion is the use of hybrid technologies, which combine wave-energy extraction with photovoltaics technologies. Another suggestion is to use wave energy extraction technologies along with other constructions such as ports or wave breakers to have dual impact.

Marine thermal gradient is highlighted in all central Mediterranean countries and in Cyprus, but not for producing electricity. This BE form is mainly used for heating (winter) and cooling (summer) systems for the benefit of the local businesses and communities. These systems may not produce electricity, but they result in electricity consumption. Partners who highlighted this BE form indicated that it has the greatest feasibility compared to other BE forms. The fact that this BE form has been already tested and established in commercial projects increases its perspectives compared to other BE forms in the MED region.

Less highlighted BE forms are the tidal, the salinity gradient, and marine biofuel energy. Nevertheless, the expectations for tidal-current and salinity gradient energy in the MED region were not high. This is due to the fact that certain physical conditions must be met for those BE forms to have a high potential. On

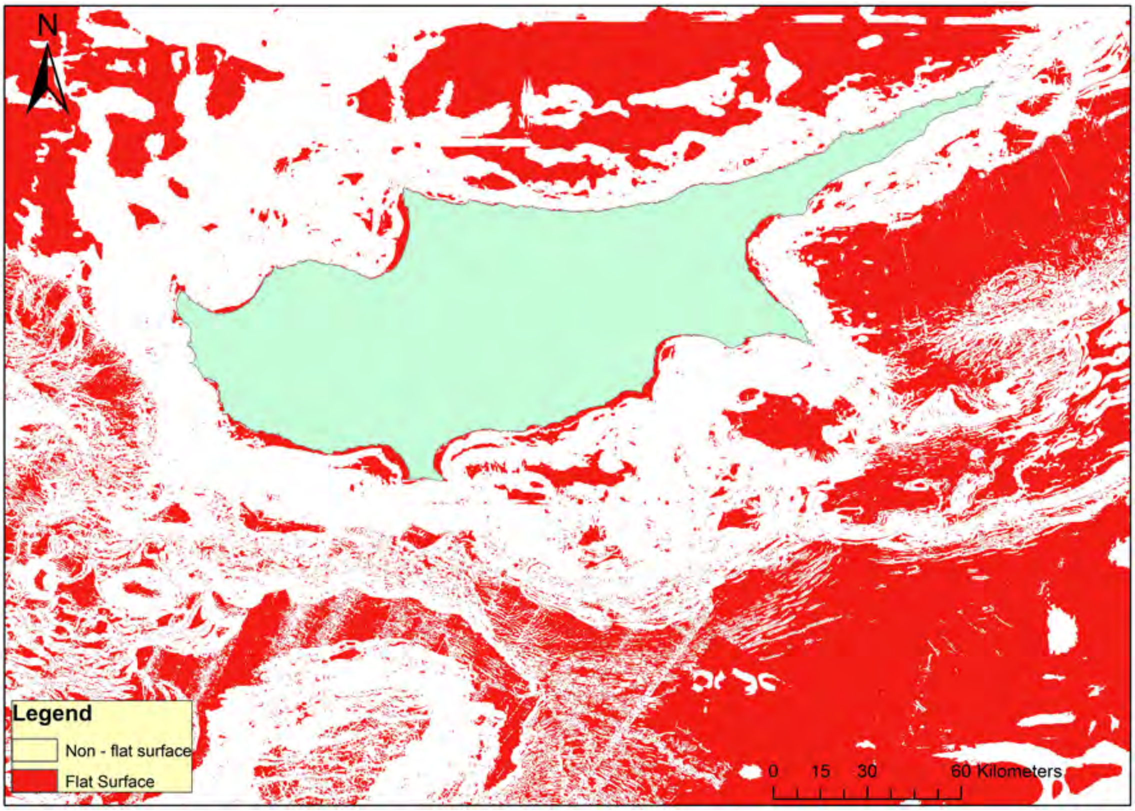

FIGURE 10 | Flat seafloor areas (in red) around Cyprus.

the one hand, the salinity gradient energy potential can be high, only if there is fresh water input on the top layer and high salinity water at the water layer below. The major drawback of salinity gradient energy is that the extraction technologies are still in an experimental phase. On the other hand, tidal-current energy potential is in general low at the MED region with the exception of some isolated regions, identified in Greece (Kea, Kithnos, Mytiline, Evoia) and Italy (Straits of Messina). The least highlighted BE form is marine biomass which has been considered only by Greece and Cyprus.

Other factors that may affect the BE potential in the region have been identified by the partners. A factor, indicated by many partners, is the steep bathymetry, which characterizes most of the MED region and constitutes a major economical barrier. To overlap this barrier, most of the partners recommend floating BE technologies rather than fixed-foundation ones. Floating structures also give the flexibility of avoiding some high interest areas and at the same time remaining at areas of high energy potential.

Additional factors that impact BE projects' development, include bureaucracy of getting the required licenses, lack or insufficient national legislation for offshore renewables-constructions, and public and local acceptance. Social acceptance is often a prerequisite in implementing offshore projects. In Italy for example, the lack of social acceptance for offshore constructions can result in project rejections or costly delays (Pisacane et al., 2018). Another study in Italy revealed that the local society was in favor of onshore renewables, such as photovoltaics and wind farms, but against offshore renewables (Goffetti et al., 2018). In Cyprus, social acceptance for implementing the Orites onshore wind Farm was encouraging but it may not be the same when it comes to offshore constructions near touristic infrastructure (Fokaides et al., 2014). The visual impact of offshore constructions and the lack of Marine Spatial Planning (MSP) is causing conflicts between different stakeholders, which can impact the social acceptance of the project (Soma and Haggett, 2015; Soukissian et al., 2017). However, certain case studies in the UK showed that social acceptance for offshore projects is greater when there is an intensive and early engagement of the public to shape those projects (Soma and Haggett, 2015).

A key component for the introduction of early-stage marine technologies is the rigorous assessment of their environmental effects and impacts. Such assessments must comply with the EU legal obligations and environmental and marine law (Martínez Perez, 2017). Using legislation tools such as the Environmental Impact Assessment and Marine Spatial Planning (MSP), the EU has guided member states toward the introduction of legislation regarding the Blue Energy sector (Martínez Perez, 2017). The Mediterranean countries that participate in the MAESTRALE project have reported that they have incorporated the EU directives referring to energy and renewable energy sources into national legislations. But since the Blue Energy sector in the Mediterranean region is new, there are still many gaps in the existing legislation. The effects of the BE installations have admittedly not been thoroughly identified by the European Commission, and therefore the regulatory framework that should accordingly be followed is still inadequate (Martínez Perez, 2017). This constitutes another constraint to the implementation of BE projects.

Some countries, such as Croatia, Spain and Slovenia, have specific laws that regulate renewable energy projects in the marine environment (MAESTRALE Project, 2018). Other countries have issues on permitting procedures and regulations regarding coastal zones and marine spatial planning (MAESTRALE Project, 2018). In Greece, the procedures are very complicated and time consuming due to the large number of public services having jurisdiction in the sea (MAESTRALE Project, 2018). Goffetti et al. (2018) have characterized the current permitting procedures and existing gaps in the Italian law as a weakness and threat. In addition, according to European Marine Spatial Planning (https://www.msp-platform.eu/), none of the Mediterranean countries that are involved in the MAESTRALE project have a legally binding MSP. Cyprus has only recently established an MSP for the district of Limassol. The deadline for establishing MSP has been set for 2021 (European Commission, 2015). A recently drafted new law along with its regulations aiming at improving the permitting procedures have been submitted to the parliament for approval.

CONCLUSIONS

Offshore wind energy is the most promising BE source in Cyprus and in the entire Mediterranean region. The proven economic viability in other parts of the Mediterranean Sea along with the fast-technological progression in this sector, the current wind energy market and the stable annual energy availability, make it the most promising candidate BE source for Cyprus. In contrast, wave and current/tidal energy are not firmly commercially established and depend on the prevailing atmospheric conditions. Moreover, they have limited potential to be considered for exploitation, at least with currently available technology.

Most BE forms can be applied throughout the MED region. The differences between countries are expected, given the different locations and geomorphological characteristics. It is evident that BE can be used in the MED region to produce electricity power or to reduce electricity consumption. A challenge in implementing BE projects is the steep and deep bathymetry in the MED region, which, however, may be tackled with floating technologies. In addition to the energy potential and bathymetry, any future BE endeavor in the MED region must also consider socio-economic factors, such as national legislation and impact on the local society, which may affect the feasibility of the project.

Overall, the Mediterranean region should play a prominent role with a clear long-term commitment to blue renewable energy. Although the task remains challenging today, it is the only true sustainable alternative to the current European energy system, in environmental, social and economic terms, as well as targets beyond 2020.

AUTHOR CONTRIBUTIONS

GN, AK, AN, and MN worked on the Blue Energy Potential Analysis and contributed to the literature review and the discussion of the results. AM obtained the results for the Cyprus region and contributed to the literature review and the discussion of the results. GG supervised the Blue Energy Potential Analysis and the results around Cyprus and contributed to the literature review and the discussion of the results.

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PERSPECTIVE
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Introduction of Blue Energy in the Mediterranean: The Conceptualization of the Sea as "Space" and Emerging Opportunities for Greece and Mediterranean Countries

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When we think of the term "space," we tend to imagine an onshore area with certain features, such as borders, governing laws and regulations, land uses, geomorphology, materials, and substance. Seldom, however, we will think of the sea as space, despite the fact that it has all the aforementioned characteristics: it covers a certain area, it has specific features and serves different operations. For Mediterranean countries like Greece, the sea has always been a core element of their identity in both geographical and cultural terms. Throughout history, the sea served as a means to boost their economies through trade and other maritime activities and their culture through interaction with other cultures and civilizations. Nowadays, the sea is set to play yet another important role in terms of renewable energy exploitation and energy self-sufficiency. One can therefore easily understand how important this space is. However, the sea's significance in these aspects has not been fully fathomed yet, nor is it considered as a space that needs to follow specific rules for its "healthy" development. This paper tries to identify how the introduction of Blue Energy can function as a driving force for the conceptualization of the Mediterranean Sea as space and, subsequently, for its regulation. Furthermore, it is presenting the opportunities that Blue Energy technologies can bring to Greece and to any Mediterranean country for a prosperous, environmentally friendly and sustainable future.

Keywords: Blue Energy, Blue Energy technologies, Blue Growth, Maritime Spatial Planning, maritime activities

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INTRODUCTION

The Mediterranean Sea covers an area of approximately 2.5 million km^2. Its 46,000 km long coastline is divided between 22 countries with a combined population of more than 460 million. One third of this population resides in coastal areas and has become increasingly urban over the last few decades (UNEP/MAP, 2012). The densely inhabited region has been the field of intense human activity for millennia and it remains so. The economies of the surrounding countries are heavily dependent on the sea. Fisheries and aquaculture in the Mediterranean generate a Gross Value Added (GVA) of more than 4 billion euros and almost 353,000 jobs; maritime transport has a

GVA of 27 billion euros, while 550,000 people are directly employed in the sector (Plan Bleu, 2014). Finally, with the Mediterranean being the world's leading tourist destination, attracting one third of International Tourist Arrivals worldwide and almost half of which in coastal zones, it's hardly surprising that coastal tourism is generating a GVA of 135 billion euros and offering employment to 3.2 million people (Plan Bleu, 2014). By being an extremely busy sea, the Mediterranean is inevitably subject to constant environmental and economic pressures, which are expected to intensify in the future. The population of Mediterranean countries is projected to rise to 529 million by 2025 (UNEP/MAP, 2012), while almost all maritime activities are expected to continue to develop resulting in increased conflict for space and resources (Randone, 2017).

Blue Energy, which includes the well-established offshore wind, as well as nascent technologies such as wave, tidal, current, ocean thermal, osmotic power, and biomass production from algae, is an emerging maritime activity, which the EU has set as an additional pathway to achieve its energy and climate change goals. Given the emphasis placed by the EU on renewable energy, it is safe to assume that Blue Energy will develop into an important industry and will therefore lay significant spatial claims into the sea in the near future. This will add to the pressures of already established maritime activities such as tourism, fisheries and aquaculture, maritime transport, etc., whose cumulative impacts are becoming increasingly hard to accommodate under the current regime of sectoral management. However, the highly spatial character of industries like Blue Energy facilitates the shift to more spatial approaches of regulation, like Maritime Spatial Planning (MSP). According to Stephen Jay, with some of the marine activities becoming site-specific, as they need fixed structures, "some marine areas are becoming more clearly defined for specific uses and are being more widely conquered for development—and therefore for planning also" (Jay, 2010a). In essence, Blue Energy can assist in the conceptualization of the Mediterranean as a space that needs a coherent vision for the future, by functioning as a driving force for the adoption of a spatial regulation approach. This in turn will allow Mediterranean countries to reap the multiple benefits from the sustainable development of Blue Energy.

BLUE ENERGY PROSPECTS IN THE EU

The EU has a strong track record of commitment to renewable energy. It has been almost a decade since Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 "on the promotion of the use of energy from renewable sources" (also known as the Renewable Energy Directive) entered into force, setting for the first time and for each member state a binding national target for the share of energy from renewable sources in gross final consumption of energy for 2020. Ranging from 10% for Malta to 49% for Sweden (Annex I), these national targets are consistent with a target of a 20% share of energy from renewable sources in the EU gross final consumption of energy in the same year. Furthermore, the Directive requires that the share of energy from renewable sources in all forms of transport in 2020 is at least 10% of the final consumption of energy in transport. In accordance with Article 4 of the Directive, each member state has compiled and adopted a national renewable energy action plan in order to achieve their respective national obligations.

The EU has taken further steps since then, toward combating climate change and transitioning to a low carbon economy. One of the ten priorities of the EU Commission under President Jean-Claude Juncker, who assumed office in 2014, is "a resilient energy union with a forward looking climate change policy." Indeed, in the 2015 United Nations Climate Change Conference that took place in Paris, EU committed to a binding target of an at least 40% domestic reduction in greenhouse gas emissions by 2030. Within the same context, a "Clean Energy for All Europeans" package consisting of 8 proposed legislative acts, was published by the European Commission on 30 November 2016 (European Commission, 2016). Political agreement has recently been achieved on four of them, including, the Regulation on the Governance of the Energy Union (European Commission, 2018d), the revision of the Energy Efficiency Directive with an energy efficiency target for the EU for 2030 of 32.5% with an upwards revision clause by 2023 (European Commission, 2018a) and the revision of the Renewable Energy Directive with a binding renewable energy target for the EU for 2030 of 32% with an upwards revision clause by 2023 (European Commission, 2018b).

Blue Energy can contribute in meeting the aforementioned targets, while generating economic growth and jobs. According to a recently published EU Commission study, approximately 3 billion euros were invested in ocean energy alone over the last decade and up to 9.4 billion euros more could be invested by 2030, which would lead to a total of 3.9 GW cumulative installed capacity (European Commission, 2018c). The Ocean Energy Strategic Roadmap, produced by the Ocean Energy Forum and submitted to the European Commission in November 2016, estimates that under favorable conditions the installed capacity could reach 100 GW by 2050, thus covering 10% of the EU's power demand (Ocean Energy Forum, 2016). In terms of jobs creation, the sector already accounts for 2,000 high-skilled jobs, primarily in research and development, and according to Ocean Energy Europe it could see up to 20,000 more by 2035 (European Ocean Energy Association, 2013). In short, Blue Energy technologies have the potential of gradually developing into a thriving new industry for the EU and, as such, into a driving force for the regulation of marine space.

BLUE ENERGY AND THE REGULATION OF MARINE SPACE

As a new type of use in the Mediterranean, Blue Energy has to overcome several barriers to realize its full potential. First and foremost, it has to find the space necessary to develop among existing and well-established activities like maritime transport and fisheries. This will surely lead to competition with other

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Abbreviations: EU, European Union; GVA, Gross Value Added; MSP, Maritime Spatial Planning; SEM, Southern and Eastern Mediterranean; SMEs, Small and Medium-sized Enterprises.

users of the marine environment, especially given the fact that Blue Energy installations are fixed structures, which inevitably gives them priority over other uses in the space allocated for their deployment. Furthermore, any Blue Energy installation will likely have to face the concern of stakeholders involved in coastal industries that could find themselves affected by it, like tourism. Finally, it has to deal with the uncertainty caused by the current *ad hoc* and sectoral management of maritime activities, which in turn might increase costs and risks of potential investors (Young, 2015). By introducing a coherent vision for the future, Maritime Spatial Planning (MSP) can create the space necessary for the development of Blue Energy in the Mediterranean. As Jay points out while discussing offshore wind, MSP opens up the possibility of well-established activities making space for wind energy—a development less likely to occur under sectoral regimes of regulations—and as a politically—determined process it allows for the prioritization of the latter over the former (Jay, 2010b). This observation can be extended to all types of Blue Energy. Furthermore, MSP will limit competition for space by creating synergies between Blue Energy and other uses, it will increase the level of certainty for investors and thereby, it will reduce costs (European Commission, 2015).

For all the above reasons, the need to develop Blue Energy is functioning as an important driver for the application of MSP (Douvere and Ehler, 2008; Young, 2015). Indeed, the importance of Blue Energy as a driving force for the planning and regulation of marine space is acknowledged in the preamble of Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for Maritime Spatial Planning: "The high and rapidly increasing demand for maritime space for different purposes, such as installations for the production of energy from renewable sources, (…) require an integrated planning and management approach." According to Article 5, member states shall aim through their maritime spatial plans "to contribute to the sustainable development of energy sectors at sea, of maritime transport, and of the fisheries and aquaculture sectors," while taking measures to protect and improve the environment and combat climate change.

The Directive indicates that all coastal member states had to designate the competent authority or authorities for the implementation of the Directive and transpose the latter into national legislation by 18 September 2016. MSP should be implemented and respective maritime spatial plans established as soon as possible and by 31 March 2021 at the latest. The majority of Mediterranean EU member states have indeed completed the transposition process, but have not yet developed legally binding plans. Therefore, maritime activities are still managed on a sectoral basis and, in the case of Blue Energy, sometimes even this is lacking. In Greece, for instance, there is no specific legislation or rules for Blue Energy. As is the case with most Mediterranean EU member states, there is legislation pertinent to renewable energy in general, but for the time being it doesn't include any provisions regarding Blue Energy. The adoption of the first maritime spatial plans by 2021 will hopefully open the way for Blue Energy ventures and allow Mediterranean EU member states to benefit from the opportunities that Blue Energy presents.

OPPORTUNITIES FROM BLUE ENERGY AND THE CORRESPONDING TECHNOLOGIES

The more methodical and meticulous maritime legislation and the various Blue Energy technologies that have been implemented more systematically in the northern countries of the EU, already provided evidence of their great benefits, both in terms of energy preservation and economic growth. Countries like Sweden, where national MSP has been in place since September 2014 (NorthSEE, 2018) together with a National Maritime Strategy and the corresponding environmental legislation, have succeeded in the correct and successful use of Blue Energy. Producing the energy by various Blue Energy plants which at the same time created new areas of expertise and research for their Small and Medium-sized Enterprises (SMEs), while leading the country to further economic prosperity, energy self-sufficiency and CO_2 emissions reduction.

The example of Sweden, describes in fact, the two basic opportunities or benefits that the use of Blue Energy technologies can offer to the Mediterranean and European countries in general. On one hand, it is all the advantages that the use of Renewable Energy Sources can address: environmentally friendly energy production, minimization of CO_2 emissions, energy self-sufficiency, boost of economy by eliminating expenses spent for the purchase of typical and gradually depleting sources of energy. On the other hand, it is the establishment of new job opportunities and fields for Research and Development in the Blue sector. To this adds, the new inventions and final products related to Blue Energy products that are created by Start-Ups, SMEs etc. and are introduced into the market. Given the fact that Blue Energy is still at an infant stage for the Mediterranean, the opportunities for development in various sectors related to Blue Energy are high. The possibilities of evolving Blue Energy production through viable economical implementations of all technologies become more and more realistic, even more so that all the Blue Energy technologies, beyond the already commercially and economically deployable technology of offshore wind (Union for the Mediterranean Secretariat, 2017), are developing rapidly in terms of commercialization.

However, in the case of Mediterranean and possibly in comparison to the North and Baltic Seas, the production of Blue Energy and the installations of the corresponding technologies, need to be performed in connection with, in respect to and in parallel with the rest of maritime activities, e.g., coastal tourism, as suggested in various points throughout the reports of DG MARE on the "Blue Growth potential in the Mediterranean and the Black Sea." A study for maritime economic activities conducted for the Mediterranean countries and in particular for Albania, Bosnia and Herzegovina, Croatia, Cyprus, France, Greece, Italy, Montenegro, Malta, Slovenia, Spain, and Turkey in 2010, has shown that the total GVA generated by all 12 countries exceeded the 63 billion EUR, which is more than three times the total GVA generated by all maritime economic activities in the Baltic Sea. Additionally, three of the aforementioned countries—Italy, Greece and Spain—represented the 81% of this activity" (European Commission- EUNETMAR, 2014a).

The high value figures obtained by the study, clearly state the importance of maritime activities to the economy of the said countries. At the same time they lead to the conclusion that any decision related to Blue Energy installations for the Mediterranean, needs to be taken under careful consideration considering that they might affect the rest of maritime activities. Especially in the case of the coastal areas of certain countries such as Italy, Spain, Turkey, Greece and France where most of the maritime activities take place (e.g., tourism), analysis has shown the large economic importance of the specific areas, by exhibiting a GVA of over EUR 150 billion (European Commission- EUNETMAR, 2014a). This demonstrates that the economy of these countries depends highly on their coastal activities and any choice of alteration or addition in the activities of the area, need to safeguard the existing operations or even further promote the economic growth.

Especially for Greece, having the second largest coastal zone in the EU (within a range of 10 km from the coast) covering 49.442 km^2 (13.3% of the EUs coastal area) and an extensive coastline of 15.021 km (representing 11% of the total EU-22), all the aforementioned seem to have a higher importance. Greece is characterized by a high degree of insularity, composed of an estimated number of more than 6,000 islands and islets (European Commission, 2014). Reports from EU and DG MARE in 2012 about the socio-economic features prove that the GVA of the coastal area is EUR 181.8 billion, in other words the 93.1% of country's total, while the people employed in coastal areas reach the 91.3% of country total. The same report mentions that "the large dependence on maritime activities of Greece is due to the fact that the main economic areas are coastal." The 7 largest marine and maritime activities as identified in this report for Greece are: Coastal tourism, Deep Sea and Short Sea Shipping, Fishing for human consumption, Passenger ferry services, Cruise tourism, Yachting and marinas (European Commission- EUNETMAR, 2014b). Therefore, any implementations of Blue Energy should be done with precaution. The positive however in this case is that for most of these activities, any installations of Blue Energy can work as a helping hand to the development and growth of the sector.

Being a popular touristic destination, Greece receives annually a large number of visitors especially during summer. In the case of some islands and in certain periods, this number can reach almost twice or triple as the number of the local inhabitants, multiplying the energy demands. This creates a periodical load or peak points on the grid that can cause instability of the power supply and can lead even to the failure of the energy operation system. Given the fact that the islands in their majority, if not all, have on site energy production of certain capacity, the environmental, economic and social impact in such periods of overload can be quite high. Blue Energy installations can address this problem and can provide the islands with an environmental solution, by procuring self-sufficiency for the islands in terms of energy throughout the whole year. By selecting a combination of 2 or 3 different types of Blue Energy technologies that could supplement each other during their operation, according to the local characteristics and energy potential of the sea, these installations could achieve the minimization of the CO_2 emissions while relieving the islands' economy and the satisfactory supply of energy to cover the demands. At the same time, these installations could go beyond their primary usage and become a touristic attraction to a certain public interest in ecotourism while combined with activities, such as diving. With a proper design of the Blue Energy installation e.g., in their foundations to facilitate the biodiversity and the fish inhabitation, like in an artificial reef, these technologies can introduce an innovative way, not only to succeed in the production of clean energy and to create places of interest for "new tourist flows" (European Commission, 2014), but as well to promote the continuous enrichment and development of aquatic life, since fishing boats are not allowed to approach the areas around the installations for safety reasons.

CONCLUSION

All the aforementioned applications of Blue Energy, its technologies and the possible corresponding areas of research, are not only applicable for Greece; they could be of use in any of the Mediterranean countries. Besides, the described combinations of Blue Energy installations with the maritime activities are not restricted to the ones described above. In general any maritime activity that demands energy can be directly connected with Blue Energy technologies. And all these manifest the big opportunities that those technologies can bring to Greece and to every Mediterranean country. What is, however, needed in all cases and before planning any viable scenario for Blue Energy implantation, is an in depth analysis of the country's seas energy potential, together with the various environmental parameters and the analysis of the local maritime activities. For the case of Greece, for example, in the search of appropriate areas for the implementation of such technologies, an analysis has to be performed while taking into consideration, beyond the energy potential of the seas: (a) the transport from the mainland to the islands and from island to island for touristic or trade purposes which form a complicated maritime traffic pattern, (b) all the environmentally protected areas, (c) the shipwrecks, (d) the sea bathymetry, (e) touristic destinations, (f) optical disturbance, etc. The result of such an analysis and for the case of Greece has shown that smaller in size installations but more in quantity could be the key for reaching the full capacity of the Greek Blue Energy Potential (MAESTRALE, 2018). However, it should not be overseen that an important factor for the realization of any Blue Energy scenario is the existence of a detailed and clear supporting legislation and MSP. Otherwise none of the intended implementations, no matter how promising, can come into feasible realization. Similar problems, like the ones that evolved during the green growth and green energy production, such as for example public protests against installations of wind turbines, will once again appear causing the same negative chain reactions. When the scenarios can be clearly defined, simultaneously and diligently organized at a legal, environmental, economic and social level, only then the Blue Energy technologies can reach their full potentials. Under well-balanced decisions, Blue Energy concept and technologies could bloom to their full growth and offer to Greece and to every Mediterranean country a prosperous, environmentally friendly and sustainable future.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Optimal Design of Overtopping Breakwater for Energy Conversion (OBREC) Systems Using the Harmony Search Algorithm

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The European Union, in its Framework Strategy for A Resilient Energy Union, as described in the "Clean Energy for all Europeans" package of measures, marked its energy priorities for transition to a low-carbon, secure and competitive economy. Following this direction, the paper deals with the exploitation of one of the most significant and extensively available energy sources, that of nearshore waves. More specifically the paper emphasizes in the optimal design of Overtopping Breakwater for Energy Conversion systems, known as OBREC, using a novel and very effective, meta-heuristic optimization technique, the Harmony Search Algorithm. The proposed methodology is based on the combined application of wave propagation equations that simulate the compound wave field near coastal structures where the waves are subjected to the combined effects of shoaling, refraction, diffraction, reflection—total and partial—and breaking, with an optimization algorithm, aiming at the identification of the optimal dimensions of an OBREC reservoir. In order to demonstrate the effectiveness of the methodology, the port of Heraklion in the island of Crete in Greece, is used as a case study. The results of the application are very promising and strongly support the statement that the proposed methodology provides a new concept in the design of OBREC systems.

Keywords: optimization, OBREC, waves, renewable energy, breakwaters

INTRODUCTION

The excessive use of conventional energy resources has resulted in significant reduction of their availability, posing a constant and increasing effect on climate. The utilization of Renewable Energy Sources (R.E.S) is essential in order to meet contemporary energy needs. Research in the ocean wave energy exploitation has received attention over the past decade and development on this field is evolving, with noteworthy studies presented and experimental Wave Energy Converter systems (WEC's) designed and improved in order to provide a reliable and sustainable alternative to the energy equilibrium. A wide variety of wave energy technologies exists, resulting from the different ways that energy can be absorbed and also depending on the water depth and on the location (shoreline, nearshore, offshore) (Falcao, 2010). Offshore wave conditions provide a larger energy content, yet the energetic amount of the nearshore wave conditions is more exploitable (Zhongxian et al., 2013).

Offshore wave energy converter devices can be characterized as systems placed on water depths >25 m. As previously mentioned, the advantage of this type of systems is the larger wave energy exploitation potential because of the energetic content of offshore waves. For this purpose, floating devices are constructed, connected with wire ropes that are anchored in the sea bed. An essential disadvantage for this type of converters is the grid connection. Wave energy converters that are constructed nearshore, in depths smaller than 25 m are usually fixed to the sea bottom ensuring the required stability during operation. A common device type is the Oscillating Wave Surge Converter (OWSC), where a flap device exploits the nearshore horizontal wave motion for electricity production that is delivered to the grid (Folley et al., 2004). The produced energy is less, since the directional spreading of the wave climate is restricted nearshore and also phenomena as wave breaking, refraction, diffraction and shoaling alter the energetic wave content. The shoreline wave energy converters pose a great advantage since the produced energy can be transferred to the grid more easily but also the device is founded in a protected environment against storm conditions. Furthermore, easier installation and maintenance classifies them as attractive systems. The Oscillating Water Column (OWC) is a typical shoreline wave energy converter type that consists of a partly submerged hollow structure that is open on top. The principle of this converter system is the air compression due to the oscillating motion of incoming waves inside the device that acts like a piston, operating an air turbine that is placed lower and drives an electrical generator. The disadvantage of this converter type is the lower energetic wave content that can be partly compensated by selection of wave concentrated locations for the placement of the device.

An important wave energy converter device category is based on the principle of wave overtopping. In this case, a collector accumulates the water from breaking waves into a reservoir and a low head turbine exploits the stored water for the purpose of electricity production. The Overtopping Wave Energy Converters (OWEC's) can be used in offshore (Wave dragon, Kofoed et al., 2006) as well as in nearshore locations (Gravas et al., 2012; Vicinanza et al., 2012, 2014; Buccino et al., 2015). The combination of wave energy converter systems with coastal structures, such as breakwaters and seawalls, forms an attractive system that provides the necessary protection to the coastal regions together with energy production (Vicinanza et al., 2014, 2019). The most recent full-scale device of OWEC embedded intro a rubble mound breakwater has been installed at the port of Naples (Italy) in 2015 (Contestabile et al., 2016).

In conclusion, the exploitation of wave energy can lead to significant energy production levels, forming an efficient option for Europe (for example in the present study case the annual energy performance for an indicative energy breakwater length of 100 m, is estimated to be order of 2,000 MWh). The use of renewable energy resources can form an important tool for covering part of the energy needs. Over the past years, the wave energy conversion technology has developed continuously. The offshore devices that have been already tested can convert a larger energy amount compared to the nearshore systems. However, several operational issues, demand further need for research. The overtopping wave energy converters pose significant advantages, as they are able to be integrated in existing coastal structures, minimizing the cost while maintenance is easier. These devices can lead the way into the exploitation of the wave energy potential, offering important energy profits even though the energy supply is not continuous. The construction of this type of structures is of order of 10% more expensive than the conventional type breakwaters. The main additional cost is the cost of maintenance, due to the unfriendly marine environment. In addition in islands (i.e., as in Crete and the small islands of the Aegean sea), the cost of energy production using oil, is 3–6 times more expensive than in the continent, making an OBREC to be an advantageous solution (considering also that it is a renewable environmentally friendly method). Furthermore, increased protection is also provided as the existing coastal structures are strengthened against sea level rise. Regions with strong wave potential can accommodate this type of devices, while proper design can lead to efficient energy exploitation. The present study proposes an optimization methodology that provides the optimal dimensions of a wave energy converter device named as Overtopping Breakwater for Energy Conversion (OBREC) in order to maximize the generated energy amount.

DESCRIPTION OF OVERTOPPING BREAKWATER FOR ENERGY CONVERSION SYSTEMS

The Overtopping Breakwater for Energy Conversion system, known as OBREC, exploits wave overtopping in order to produce electricity. An illustration of the device is presented in **Figure 1**. The converter is being placed in the front of a breakwater and consists of a specially designed reservoir, accumulating the overtopping water. The energy is generated using a low-head turbine, which exploits the difference in water levels between the reservoir and the mean sea level (MSL), creating the necessary head difference to generate flow and run the turbine. In the end, in the rear side of the breakwater, water flows back into the sea at MSL. The front side of the reservoir shares the same inclination with the breakwater, to minimize energy losses. Wave overtopping inflow is calculated by a proper equation, based on the characteristics of the device. OBREC can be even placed on existing breakwaters with relatively low cost. The device combines the advantages of energy exploitation from renewable sources with the protection of the area, against wave energetic conditions.

Critical design parameters are the crest freeboard R_c (m), that describes the height between the upper point of the sloping plate of the front reservoir and MSL, and the reservoir width B_r (m), both illustrated in **Figure 2**. These two parameters should be selected in conjunction, allowing maximum wave overtopping inflow, and forming along with the length of the device, the suitable capacity of the reservoir, based on the prevailing wave conditions of each area. Furthermore, the length of the sloping plate, ultimately affects the behavior of the incoming water, as it determines R_c. Finally, careful design is required to avoid overtopping at the rear side of the structure.

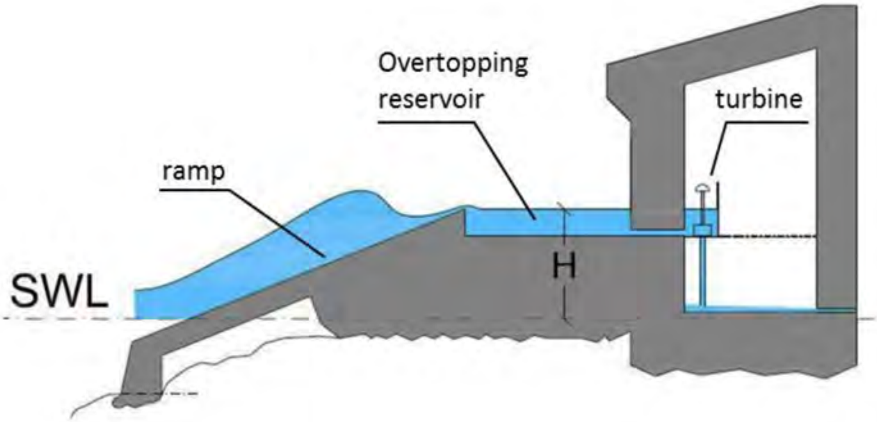

FIGURE 1 | OBREC illustration (Source: Iuppa et al., 2016).

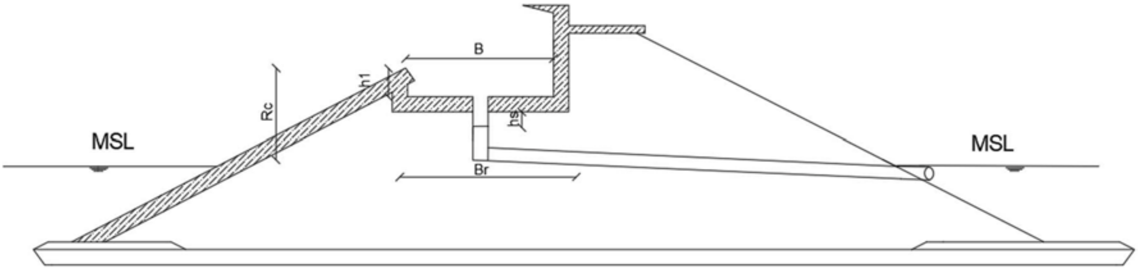

FIGURE 2 | Depiction of OBREC parameters.

The aim of OBREC devices is to maximize the amount of wave overtopping inflow in the reservoir, creating a sufficient water column height, in order to produce energy. The efficiency of the device is proportional to the amount of water that enters the tank as well as to the hydraulic height of the water above the water turbine, H_k. The latter comprises the water column in the reservoir, denoted as h_1 and the water column inside the pipe above the water turbine, denoted as h_s. The elevation of the water turbine must be at least at the level of MSL or above, ensuring water flow.

Kaplan turbine is the most efficient option for such small head systems as OBREC, as it can maintain a high efficiency of the device in the varying wave field. To maximize the generated energy amount, careful design of the reservoir must precede for the proper and combined selection of the dimensions of crest level R_c and the width of the reservoir B_r, per m length of the device, allowing maximum inflow and ensuring the necessary hydraulic load.

The wave overtopping equation that is used in this study, q, applies in the case of smooth steep low crested structures, according to EurOtop Manual (2007):

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = 0.2 \cdot exp(-2.6 \cdot \frac{R_c}{H_{m0}}) \tag{1}$$

where: q defines the mean wave overtopping inflow ($m^3/s/m$), H_{m0} defines the incident wave height (m) and R_c defines the crest level (m).

The range of implementation of this equation is described by the following inequalities:

$$1.0 < \alpha < 4.0 \ \& \ 0.5 < R_c/H_{m0} < 3.5 \quad \text{(2a and 2b)}$$

The above inequalities refer respectively to the slope of a breakwater, measured in rad, and to the dimensionless relative wave height, which is defined by the ratio R_c/H_{m0}. According to the EurOtop Manual, the reliability of the above equation is expressed considering that the factor (−2.6), which appears in Equation (1), is a stochastic variable that follows a normal distribution with mean (−2.6) and standard deviation $\sigma = 0.35$.

The power of the water turbine is given by the following equation:

$$P_{k,el} = n_{hydro} \cdot \rho \cdot g \cdot q_{k,s} \cdot H(\mathrm{W/m}) \tag{3}$$

where $\rho = 1{,}000$, is the water density (kg/m^3), g = 9,81, is the gravitational acceleration (m^2/s) $q_{k,s}$, describes the inflow and in this problem is identified with wave overtopping inflow, q ($m^3/s/m$), H_k, defines the hydraulic height of water above water turbine (m) and n_{hydro}, defines the hydraulic efficiency of the water turbine.

The hydraulic efficiency of the OBREC device, n_{hydro}, is defined as the proportion of the hydraulic power and the wave power and indicates how much percentage of wave power can be harvested every times the wave is acting on that structure. It is described by the ratio (Kofoed, 2000; Lander, 2012): $n_{hydro} = \frac{P_{hydro}}{P_{wave}}$. P_{hydro} defines the power of collected waves and P_{wave} defines the initial wave power that runs in the breakwater, calculated by the following respective equations:

$$P_{hydro} = \rho \cdot g \cdot q \cdot Rc\,(\mathrm{W/m}) \tag{4}$$

$$P_{wave} = \frac{\rho \cdot g^2}{64 \cdot \pi} \cdot (H^2 \cdot T_p)(\mathrm{W/m}) \tag{5}$$

The hydraulic efficiency of devices such as OBREC usually ranges between 10 and 30% (Kofoed, 2000; Lander, 2012; Musa et al., 2016).

OBJECTIVE—PROBLEM CONFIGURATION

Introduction

The proposed methodology aims to identify the optimal combination of crest height and width of OBREC reservoir, in order to maximize its performance, through an optimization methodology. Initially, wave data from the case-study area of application, the city of Heraklion in the Greek island of Crete, will be presented. Then the structural features of the OBREC device and the breakwater are being defined (energy breakwater OBREC). Afterwards, the configuration of the optimization model is developed, through the identification of the objective function, the decision variables and the constraints of the problem.

The optimization problem is solved using a specially designed optimization software based on Harmony Search Algorithm (HSA). This software was selected after being extensively tested on benchmark optimization problems and was considered adequate and efficient enough to meet the non-linearities of the OBREC design problem. Finally, further analysis and evaluation of the exported results from the program will be performed, aiming to find the overall optimal solution.

Case-Study Area: The Port of Heraklion, Crete

Crete's energy supply system is isolated from the mainland and presents significant energy supply problems due to the limited coverage of the island's electricity needs especially during the summer months and the so far limited introduction of Renewable Energy Sources (RES). At the same time, the ongoing impacts of climate change, calls for the need to redesign the harbor structures, as well as the effort to cover the area's energy needs in accordance with the principles of sustainable development. Heraklion, because of its wave and wind field, is the ideal location to examine the performance of OBREC device in a breakwater (see **Table 1**).

TABLE 1 | Significant wave height, peak period, and frequency of appearance offshore the Heraklion port and in front of the breakwaters.

Wind speed (m/s)	Frequency of appearance (%)	Deep water H_{OS} (m)	Nearshore H_S (m)	T_p (s)
NW waves				
4.40	6.368	0.47	0.46	3.646483
6.70	8.707	1.114	0.97	5.552599
9.35	2.796	1.86	1.58	6.789673
12.30	0.725	2.44	2.04	7.453164
15.50	0.095	3.08	2.65	8.062796
18.95	0.029	3.77	3.30	8.632966
22.6	0.002	4.49	3.99	9.165787
26.45	0.000	5.264	4.81	9.669
30.55	0.000	6.081	5.85	10.155
Total	18.722			
N waves				
4.40	5.449	0.47	0.46	3.646483
6.70	4.954	1.11	1.02	5.552599
9.35	2.081	1.66	1.68	6.290233
12.30	0.924	2.18	2.10	6.904918
15.50	0.212	2.75	2.69	7.469707
18.95	0.064	3.36	3.28	7.997936
22.6	0.006	4.01	3.91	8.491563
26.45	0.000	4.689	4.72	8.958
30.55	0.000	5.416	5.48	9.408
Total	13.690			
NE waves				
4.40	0.864	0.479	0.448	3.646483
6.70	0.263	1.11	0.97	5.552599
9.35	0.076	1.62	1.40	6.205843
12.30	0.027	2.13	1.81	6.812281
15.50	0.002	2.69	2.29	7.369493
18.95	0.000	3.29	2.81	7.890635
22.6	0.000	3.92	3.80	8.37764
26.45	0.000	4.594	4.14	8.838
30.55	0.000	5.306	4.86	9.282
Total	1.232			

It becomes apparent that apart from its contribution to the energy requirements of the area, OBREC will contribute also to the protection of the port, whose needs are growing due to climate change. The prevailing winds that affect the behavior of the energy breakwater are N, NW, NE directed. OBREC performance is examined for all representative significant wave heights created by the aforementioned wave directions and for a wind strength range of 3–11 Beaufort (Bf). This leads to a total number of 27 wave conditions for which the optimal dimensions of OBREC are sought.

Design Characteristics of OBREC System

The breakwater, in which the OBREC device will be placed, follows the principles of a conventional breakwater with inclined slopes. The optimization can be achieved through the construction of a smooth, impermeable, low steep crested structure, which is described by water overtopping inflow Equation (1). The breakwater slope is defined as 1:2, a value that is expected to contribute to the optimal functioning of the structure. The dimensioning of the breakwater is based on the worst expected significant wave height that prevails in the study area, $H_s = 6.081$ m and accounting for shoaling and refraction phenomena, the design is ultimately carried out for a wave height of $H_s = 5.294$ m. The crest height is set at 5.80 m while its width at 5 m. The construction of a smooth impermeable layer of reinforced concrete on the open sea side is proposed for assisting wave climbing. The armor layer of the energy breakwater is made of artificial rocks and its construction depth is set at 10 m.

A pre-selected water turbine of Kaplan type is considered and it is placed at a level of +0.05 m above MSL. The size and efficiency of the turbine of the energy breakwater remains stable and does not interfere into the results produced by the present study. The height of the water turbine column is set at 0.40 m, while the water column above the water turbine is set at 0.40 m, ultimately forming the elevation of the bottom of the reservoir at a level height of +0.85 m, counting from MSL. The water flows out through a tube with a small inclination in the level of MSL. Finally, the construction of a "nose" is proposed at the back of the device, in order to increase water input in the reservoir and to reduce the number of waves that overtop in the rear side of the structure, up to 50–60%. **Figure 3** forms a graphical demonstration of the described energy breakwater OBREC.

In the following paragraphs the nearshore wave transformation simulation model and the harmony search optimization algorithm used in this application are briefly presented.

Nearshore Wave Transformation Model

Linear wave propagation is simulated by applying a mild-slope model (Copeland, 1985; Watanabe and Maruyama, 1986), derived without the assumption of progressive waves. The model is based on the hyperbolic-type mild slope equation and is valid for a compound wave field near coastal structures where the waves are subjected to the combined effects of shoaling, refraction, diffraction, reflection (total and partial) and breaking. The module consists of the following pair of equations (Copeland, 1985; Watanabe and Maruyama, 1986):

$$\frac{\partial \eta}{\partial t} + \frac{c}{c_g} \nabla \frac{c_g}{c} \mathbf{Q}_w = 0 \qquad \frac{\partial \mathbf{U}_w}{\partial t} + \frac{c^2}{d} \nabla \eta = \nu_h \nabla^2 \mathbf{U}_w \tag{6}$$

where η is the surface elevation, $\mathrm{U_w}$ the mean velocity vector $\mathrm{U_w} = (U_w, V_w)$, d the depth, $\mathrm{Q_w} = \mathrm{U_w}\ h_w = (Q_w, P_w)$, h_w the total depth ($h_w = d + \eta$), c the celerity, and c_g the group velocity. The term ν_h is an horizontal eddy viscosity coefficient introduced in order to include breaking effects based on the formulation of Battjes (1975):

$$\nu_h = 2d \left(\frac{D}{\rho} \right)^{1/3} \tag{7}$$

where D is the dissipation of wave energy expressed as:

$$D = \frac{1}{4} Q_b f \, \rho \, g H_m^2 \tag{8}$$

where H_m is the maximum wave height, ρ the water density, f the wave frequency, and Q_b the probability for a wave to break at a depth, expressed as $(1–Q_b\_/(\ln Q_b) = (H_{rms}/H_m)^2$ according to Battjes and Janssen (1978). The mean square wave height H_{rms} is calculated from $H_{rms} = 2\ (<2\eta^2\ \ >)^{1/2}$, with the brackets denoting a time-mean quantity.

The present model is a linear one, and it is not capable of describing waves in the swash zone, i.e., wave propagation on dry bed ('negative' depth). The water depth from the rundown point (i.e., depth equal to $R/4$; R is the runup height) and up to the runup point (i.e., depth equal to $-R$) is considered to be constant and equal to $R/4$.

The model is adapted for applications based on the following:

- The input wave is introduced at a line inside the computational domain according to Larsen and Dancy (1983) and Lee and Suh (1998).

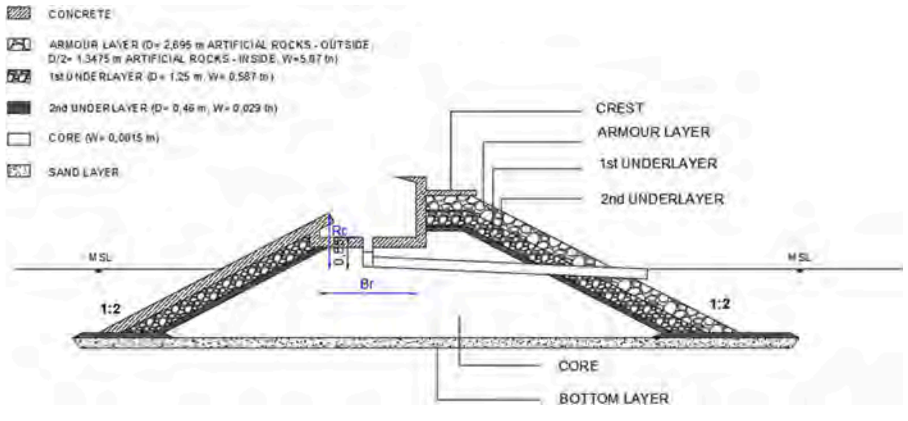

FIGURE 3 | Graphical demonstration of a typical energy breakwater OBREC.

- A sponge layer boundary condition is used to absorb the outgoing waves at the four sides of the domain (Larsen and Dancy, 1983).
- The presence of vertical structures is incorporated by introducing a total reflection boundary condition ($U_w = 0$ or $V_w = 0$).
- Partial reflection is also simulated, by introducing an artificial eddy viscosity coefficient ν_h. The values of ν_h are estimated from the method developed by Karambas and Bowers (1996), using the reflection coefficient values given in the literature.

The numerical solution is based on the well-documented explicit second order finite difference staggered scheme using a mid-time method (Watanabe and Maruyama, 1986).

Using the wind data for the specific area from the Greek Metereological Service and applying the JONSWAP wave prediction method, the significant wave heights, the peak periods, and the frequencies of appearance of offshore waves were deduced (Liapis and Pantelidou, 2014). **Table 1** shows the results of the JONSWAP method (deep water wave significant height H_{os}, offshore the Heraklion port) and the numerical model (H_s in front of the breakwater).

The computational domain covers a nearshore area of 4,000 × 1,800 m. The grid spacing is dx = 2.0 m and the time step 0.025 s. The offshore wave input is taken from **Table 1**.

HARMONY SEARCH ALGORITHM

The Harmony Search Algorithm (HSA) is a metaheuristic optimization method inspired by music harmony. It was first introduced by Geem (2000) in his Ph.D. thesis. This algorithm is based on a stochastic random search technique whose natural corresponding system is the process for the search of a better harmony by musicians. The Harmony Search Algorithm was inspired by the way a musician plays within a music group. During rehearsals or a concert, a musician has three choices:

i. To play the known—basic melody of the musical piece. This melody is known as the "theme" and it characterizes every piece. It is obviously known and already in the memory of the musician.
ii. To play something similar to the basic melody. To slightly change the "theme" enriching the piece with notes never played before.
iii. To start an improvisation by selecting new note sequences that will form a completely new music material.

TABLE 2 | Optimal solution for OBREC device scenario 4.

Objective function	Value (W/m)
$P_{k,el}$	1854.87
Decision variables	**Value (m)**
X_1 (Rc)	1.19
X_2 (B_r)	2.33
X_3 (h_1)	0.34

The Harmony Search Algorithm is a stochastic meta-heuristic method based on the sequential production of possible solutions. It belongs to the category of "neighborhood meta-heuristics" that produce one possible solution per iteration. This procedure is completely different from that of the population methods that produce a number of possible solutions in every iteration (e.g., genetic algorithms).

Every possible solution consists of a set of values of the decision variables of the function that needs to be optimized. Each one of these sets of values is called a "Harmony." During the optimization process, a number of "harmonies" equal to the "Harmony Memory size" are stored in the "Harmony Memory" (HM), a database that includes the produced set of solutions. The algorithm ends when the predefined total number of iterations has been achieved.

The simplicity, the fast convergence and the ease of programming of the algorithm have contributed in the spreading of the applications of HSA in various fields. HSA applies the three following procedures in every iteration. Procedure "b" is used (in a percentage) only if procedure "a" is activated. Option "c" is applied every time procedure "a" is not selected:

a) HSA is choosing any value from HS Memory. This process is defined as Memory Consideration and it is very important because it ensures that good harmonies (values that give good results) will be considered through the solution. Moreover, these "good" harmonies will be the material (similar with parents in Genetic Algorithms) for the creation of new, even better harmonies. In order to use this process effectively, Harmony Memory Considering Rate (HMCR) was defined. This index will specify the probability that a new harmony will include a value from the historic values that are stored in the Harmony Memory. If this rate is too low, only few elite harmonies will be selected. As a result HSA will converge slowly. Of course an HMCR value of 1.0 is not recommended because the exploration of the entire feasible range will be obstructed and optimization will fail. Typical values of HMCR are always >70%.
b) Every component of the new harmony chosen from HM, is likely to be pitch-adjusted. For example a Pitch Adjusting Rate (PAR) of 10%, indicates that algorithm will choose neighboring values for the 10% of the harmonies chosen from HM. The new harmony will include the value x_i^{new} which will be:

$$X_i^{new} = X_i \pm \text{Random} \cdot \text{bw} \tag{9}$$

where, x_i is the existing pitch stored in HM, Random is a random number between 0 and 1, and bw is the bandwidth of the adjustment.
c) The third choice is to select a totally random value from the possible value range. Randomization occurs with probability (100-HMCR)% and increases the diversity of the solutions. Although pitch adjustment has a similar role, it is limited in a local area. Randomization can drive the algorithm to explore the whole range and attain the global optimality.

The contribution of the authors of this paper to the development of the Harmony Search Algorithm as a widely recognized, highly credible optimization method for the solution of hydraulic engineering related problems is significant as expressed through a number of publications (Kougias and Theodossiou, 2011, 2013; Kougias et al., 2012, 2014, 2016; Theodossiou and Kougias, 2012; Theodossiou et al., 2016; Antoniou et al., 2017).

OPTIMIZATION MODEL

The aim of the present study is to maximize the energy that is produced from OBREC. Because of this, the objective function of the problem is defined as:

$$P_{k,el} = \max \tag{10}$$

which takes its final form after further elaboration of Equation 3:

$$\begin{aligned} Pk, el \quad &= \frac{X_1 \cdot 64 \cdot \pi}{H^2 \cdot \ Tp} \cdot \rho \cdot \sqrt{g \cdot H^3} \cdot 0,2 \cdot \ \exp\left(-2,6 \cdot \frac{X_1}{H}\right) \cdot \\ &\left(X_3 + hs\right) (\mathrm{W/m}) \end{aligned} \tag{11}$$

The decision variables are included in both the objective function (Equation 11), and the constraints (Equation 13), in order to be determined by the optimization software. The decision variables of the problem are defined as the crest height R_c (m), $X_1 = R_c$ and the width of reservoir B_r (m), $X_2 = B_r$. In addition, a third decision variable is used which represents the height of the water in the tank, $X_3 = h_1$. Its presence is necessary as it appears on the objective function and indicates the water height in the reservoir in every scenario. Also, through X_3, the width of the reservoir is being calculated manually, after the programme results. HSA programme calculates the values of the decision variables X_1, X_3. The problem is formed based on the cross-sectional surface area of the reservoir of OBREC per current meter length, as shown in the graphic representation of **Figure 3**. According to that, the width B_r (m), will be calculated through the cross-sectional area of the reservoir per current meter length and hence will result from the well-known equation of trapezoid area, which after conversions ends up in the following equation:

$$B_r = \frac{A}{h_1} + \frac{h_1}{2\mathrm{tana}} (\mathrm{m}) \tag{12}$$

The constraints defining the problem are:

$$a)\ X_1 > X_3 \ \ b)\ X_2 = \frac{A}{X_3} + \frac{X_3}{2\mathrm{tana}} \ \ c)\ X_1 \geq X_3 + 0,85 \tag{13}$$

The HSA software has been executed for all the prevailing wave conditions in the area of study, emerging a total of 27 different size scenarios of the OBREC device. Each scenario presents the geometric shape of the reservoir that maximizes the power of the turbine, for the steady wave condition that has been introduced as input to the programme. Therefore, the results are not final and must be further processed by analyzing the behavior of the reservoir of each scenario in all wave conditions annually, so as to assess the real behavior and performance of OBREC.

An indicative calculation of the programme is presented in **Table 2** for the OBREC device scenario 4 (considering the corresponding representative significant wave height for a NW prevailing wind of 6 Bf scale).

From the output results it was concluded that in any scenario, the dimensions of the reservoir are determined in order to allow maximum water storage. Therefore, in the problem it is considered that the cross-sectional area of the reservoir equals the wave overtopping inflow per meter and per second.

ANALYSIS OF THE SCENARIOS

The behavior of OBREC reservoir must be tested for all the representative wave conditions that describe a full annual cycle in the area of study. Because water overtopping inflow coincides with the cross-sectional area A of the reservoir that stores the overtopping water per meter and per second, $q = A$ holds in any case. So, this can be compared every time with the required water amount in order to fill the area of the reservoir for each scenario, defined as A_{full}. In each representative wave of the prevailing wind conditions, if the area filled by the incoming water is greater than A_{full}, it means that the cross-section of the reservoir overflows and subsequently A_{full} is used in the objective function in the place of q. Otherwise, the q value is used. **Figure 4** presents the results of this application for wave scenario 4 that represents a NW wind condition of 6 Bf.

The process described above investigates the behavior of each OBREC device scenario in all waves induced by the prevailing wind conditions. However, in order to calculate the annual performance of OBREC in every scenario, wind occurrence frequency should also be taken into account, so that in the end, the cumulative performance per meter of length of the structure could be calculated. Also, an application of the annual performance of a total of 100 m length energy breakwater will be presented, for which the results of the energy performance over an annual cycle for each scenario of the OBREC reservoir will be assessed in order to select the optimal solution. The annual energy performance is calculated by the equation:

$$\mathrm{P}_{\mathrm{output}} = n_{gen} \cdot P_{k,el} \cdot f \cdot 24 \cdot 365 \ (\mathrm{MWh}) \tag{14}$$

where:

- $\mathrm{n}_{\mathrm{gen}}$, defines the performance of the electric generator. The value selected here is $\mathrm{n}_{\mathrm{gen}} = 0.45$, as a realistic and expected value of performance.
- $\mathrm{P}_{\mathrm{k,el}}$, defines the power of the water turbine.
- f, defines wind frequency (%).

Figures 5A,B, present the annual energy performance for all the different scenarios of the OBREC device, as well as the corresponding annual energy performance for the indicative energy breakwater length of 100 m.

It should be noted that apart from each scenario's performance, the extra energy that can be produced because of the swell wave phenomenon can also be taken into account.

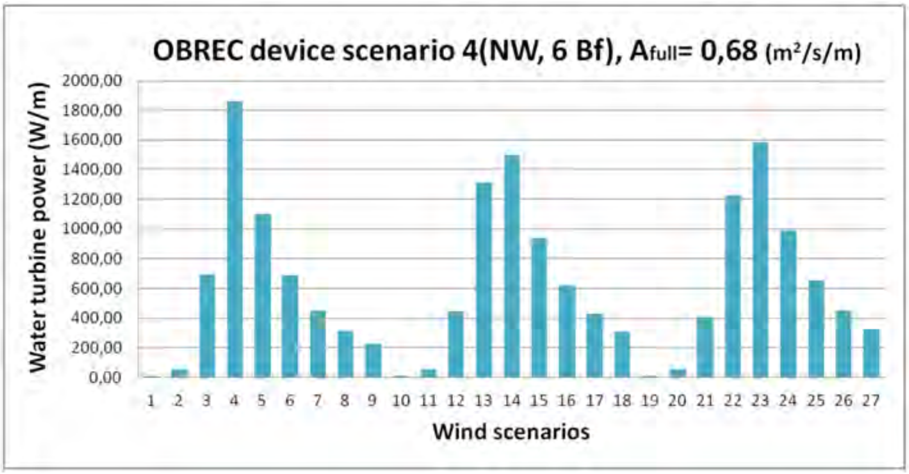

FIGURE 4 | Analysis results of the indicative OBREC device scenario 4.

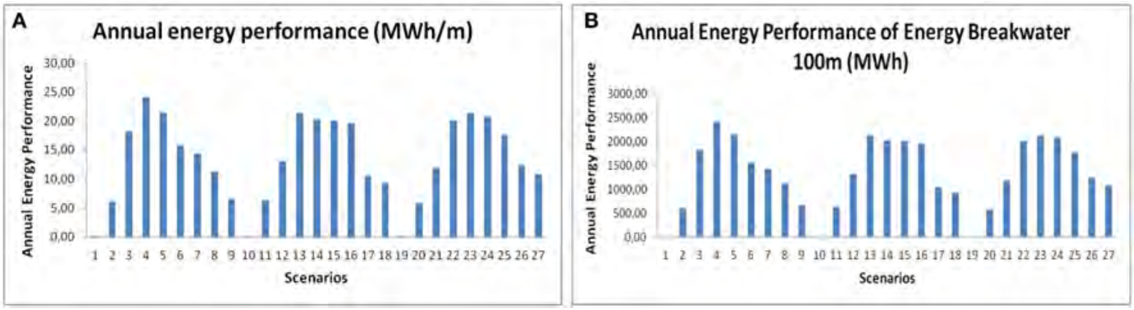

FIGURE 5 | (A) Annual energy performance for every OBREC device scenario per current length. **(B)** Annual energy performance for every OBREC device scenario for an energy breakwater of 100 m length.

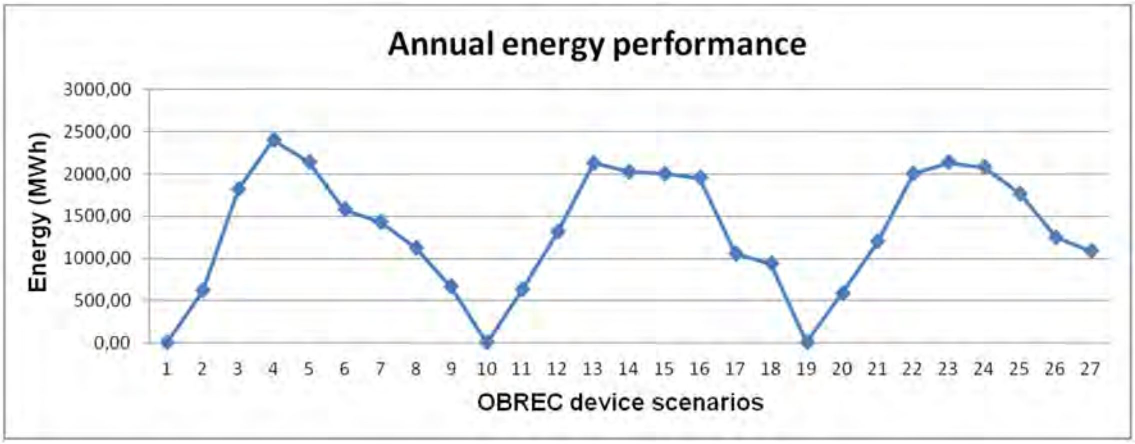

FIGURE 6 | Annual energy performance for all OBREC device scenarios.

Swell wave is defined as a wave that is not generated due to weather phenomena observed over time, but due to former wind conditions in the region, sometimes even days before, or even in another area. No adequate data exist yet to estimate the extra energy that can be generated by this phenomenon, however experimental tests have emerged that OBREC might render about 20% more energy in each scenario, due to swell waves. **Figure 6** presents the overall final results of the annual energy production for all the OBREC device scenarios for an energy breakwater length of 100 m.

ASSESSMENT OF SCENARIOS AND OPTIMAL SOLUTION

The first criterion will assess the resulted OBREC device scenarios for an energy breakwater length of 100 m based on their maximum annual energy efficiency. According to **Figure 6** and based on this criterion only, the optimal scenario is 4, with an annual performance of 2404.60 MWh. A group of solutions will also be considered acceptable at this point, whose results have little deviation from the maximum performance of the device scenario 4. This group is formed by the scenarios that show annual performance >2,000 MWh. The selected scenarios based on this first criterion are shown in **Table 3**.

In order to select the optimal solution, further processing will be conducted, based on two simple but significant criteria that can effectively assess all scenarios. This methodology could lead to different scenarios, ones that did not appear to be good choices or were not initially selected based on the first criterion, to be assessed as optimal solutions.

Initially, criterion E_{ff} is being defined as $\frac{annual\ energy\ performance}{reservoir\ capacity}$. This ratio determines a simplified concept of efficiency of the device. However, it is a significant parameter that shows the importance of the energy generated by the device, based on its capacity. Thus, high values of E_{ff} show that each reservoir scenario produces a significant amount of energy, given its capacity.

In the present study emphasis is given on the generated energy, without using data related to transport, storage and distribution of this energy amount. So, a full economic evaluation has not been conducted at this stage and could be the suggested as future research on the topic. However, it becomes apparent that the optimal solution is not necessarily the one that provides the maximum energy amount, if it could be possible to design a smaller, but more efficient reservoir, thus reducing the overall cost. Since some costs are constant, any financial difference will emerge from the circumferential length of the reservoir cross-section in each scenario. Given the selected length of 100 m of the structure, the feature that changes the capacity of the reservoir is the circumference of its cross-section. The colored part, defined as L_{OBREC}, is what varies in each scenario's reservoir (**Figure 7**) and changes the cost of its construction.

The combination of L_{OBREC} parameter with the E_{ff} index will further assess the accepted scenarios based on the first criterion while it is possible to highlight some others. What will determine

TABLE 3 | OBREC device solutions based on maximum annual energy performance criterion.

Dominant optimal solution	Annual performance (MWh)	Rc (m)	Br (m)
Scenario 4	2404,60	1.53	2.33
Good alternative solutions	**Annual performance (MWh)**	**Rc (m)**	**Br (m)**
Scenario 5	2140.14	1.53	2.08
Scenario 23	2135.65	1.43	1.79
Scenario 13	2126.52	1.11	2.31
Scenario 24	2077.82	1.61	2.14
Scenario 14	2023.09	1.51	1.70
Scenario 15	2005.80	1.66	2.13
Scenario 22	2003.98	1.15	1.93

TABLE 4 | Final optimal solutions.

Dominant optimal solution	Annual performance (MWh)	Rc (m)	Br (m)
Scenario 4	2404.60	1.53	2.33
Good alternative solutions	**Annual performance (MWh)**	**Rc (m)**	**Br (m)**
Scenario 13	2126.52	1.11	2.31
Scenario 22	2003.98	1.15	1.93
Scenario 23	2135.65	1.43	1.79

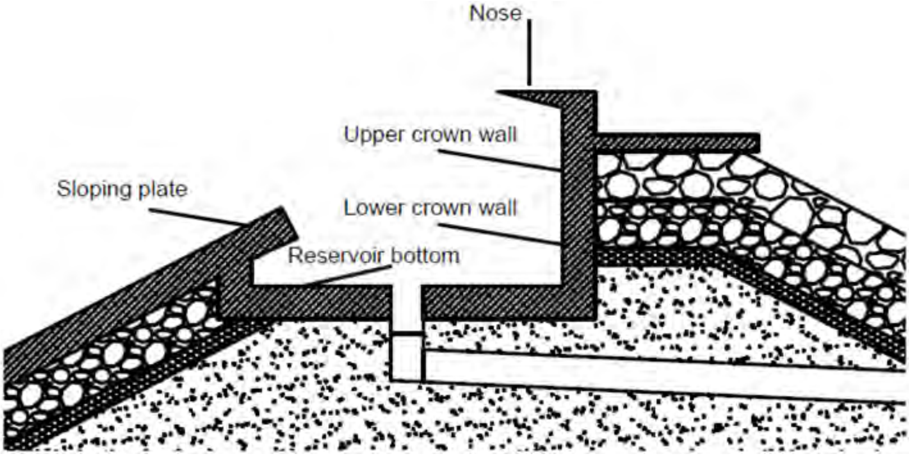

FIGURE 7 | Definition of L_{OBREC} (based on: Contestabile et al., 2015).

the optimal scenarios will be the comparatively high values of ratio E_{ff}, combined with comparatively smaller length values of L_{OBREC}.

By applying these criteria in all considered different OBREC device scenarios, the results showed that the alternative solutions that combined higher prices of the E_{ff} criterion, with smaller values of index L_{OBREC} and with high annual energy performance values, are amongst the same scenarios that were selected during the first stage of the assessment.

However, scenarios 4, 13, 22, 23, as shown in **Table 4**, are those whose behavior is deemed most optimal according to all three criteria, forming the final acceptable group of optimal scenarios. The performance of all the final selected scenarios is expected to be high.

CONCLUSIONS AND PROPOSALS

The proposed methodology highlights a group of good alternative, "efficient" and acceptable OBREC device scenarios combined with the derived optimal solution, whose energy performance is considered satisfactory. According to Eurostat data, the proposed optimal scenario 4, can meet the needs of approximately 687 households. Also, due to swell wave phenomenon, the estimated performance of OBREC may raise even by 20%. Finally, it was observed that in cases of N and NW winds, that are the most frequent in Heraklion, OBREC performance maximized in all scenarios, ensuring the proper exploitation of wave energy of the area.

For further optimization of OBREC systems, a careful selection of electrical equipment is proposed. Also, the selection of the appropriate pipe diameter is necessary, based on the dimensions of the reservoir. Alternatively, the device can include more than one tubes in the reservoir. The number of the tubes that will operate should depend on the incoming amount of overtopping water. Finally, the increased requirements of installation and maintenance of the device are a dominant prerequisite in order to ensure high performance of the system.

The proposed wave energy converter, OBREC, is an option with high estimated energy performance, while considered as an economically sustainable solution, where its cost is covered by the benefits of its operation both as a work of protection, and as an energy producing device. The proposed methodology aims to highlight the great contribution of optimization to the improvement of the performance of OBREC device. The integration of optimization techniques in the design of OBREC system is absolutely necessary in order to ensure in all cases proper operation and high energy performance.

AUTHOR CONTRIBUTIONS

V-EK was responsible for executing the calculations. NT was responsible for the implementation of the optimization model. TK was responsible for the implementation of the wave propagation model.

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Wind Energy in the Mediterranean Spanish ARC: The Application of Gravity Based Solutions

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Almost 90% of the world's marine renewable energy is generated in Europe, however the contribution of the Mediterranean Sea in the energy mix is practically negligible. On this sense, the present article presents the advantages of implementing a Blue Energy Project (offshore wind farm) in the Mediterranean Spanish Arc using certain type of technology: Gravi3®, a gravity based solution for the foundation of Wind Turbine Generators (WTGs). The analysis of the renewable energy potential and the boundary conditions of the case study analyzed (Cadiz) vindicates that the viability from both the technical and economic point of view can be assured.

Keywords: marine renewable energy, offshore wind energy, Mediterranean Sea, gravity based solutions, hybrid structure, self-buoyant structure, self-installing structure

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INTRODUCTION

The necessity of fostering renewable energies lies in the well-known adverse effects brought about by the world's reliance on fossil fuels: (i) greenhouse gas emissions that exacerbate climate change, (ii) diminished reserves of carbon fuels, and (iii) geopolitical wrangling over the control of the oil and gas reserves, which has led to many conflicts and all-out wars in the last decades. In addition, the variability in oil and gas prices has a deleterious effect on the global economy. These arguments, and the international treaties and protocols signed to foster the efforts against climate change, call for the development of renewable energy sources.

Among renewable energies, the potential of the different sources of Marine Renewable Energy (MRE) is widely recognized (Drew et al., 2009; Bahaj, 2011; Astariz and Iglesias, 2015), so much so that it is poised to become a fundamental pillar in the EU energy policy, cf. the European Strategic Energy Technology Plan (SET-Plan) described in European Commission (2007). In fact, the MRE industry has established for ocean energy (wave and tidal) and offshore wind a target of installed capacity for 2050 of 188 and 460 GW, respectively (Association, 2010; Jeffrey and Sedgwick, 2011; Moccia et al., 2011), which are ambitious goals given that the figures for 2020 are 3.6 and 40 GW (EWEA, 2012).

It can be readily observed that to meet these objectives, the development in the Mediterranean Sea must be fostered (Abanades and Torregrosa, 2018). This is reflected in the wind energy figures, a resource more mature than the rest: by the end of 2016 with a total of 18 GW installed in Europe, 3 GW were installed in the Irish Sea, 2 GW in the Baltic Sea, and 13 GW in the North Sea (Wind Europe, 2017). Although, there were obvious singularities that limited the development of wind energy in the Mediterranean Sea in the past, with the current technology and knowledge acquired, these shortcomings are being overcome and wind energy will become a reality in the near future. Similarly, this can be applied to other renewable energy resources.

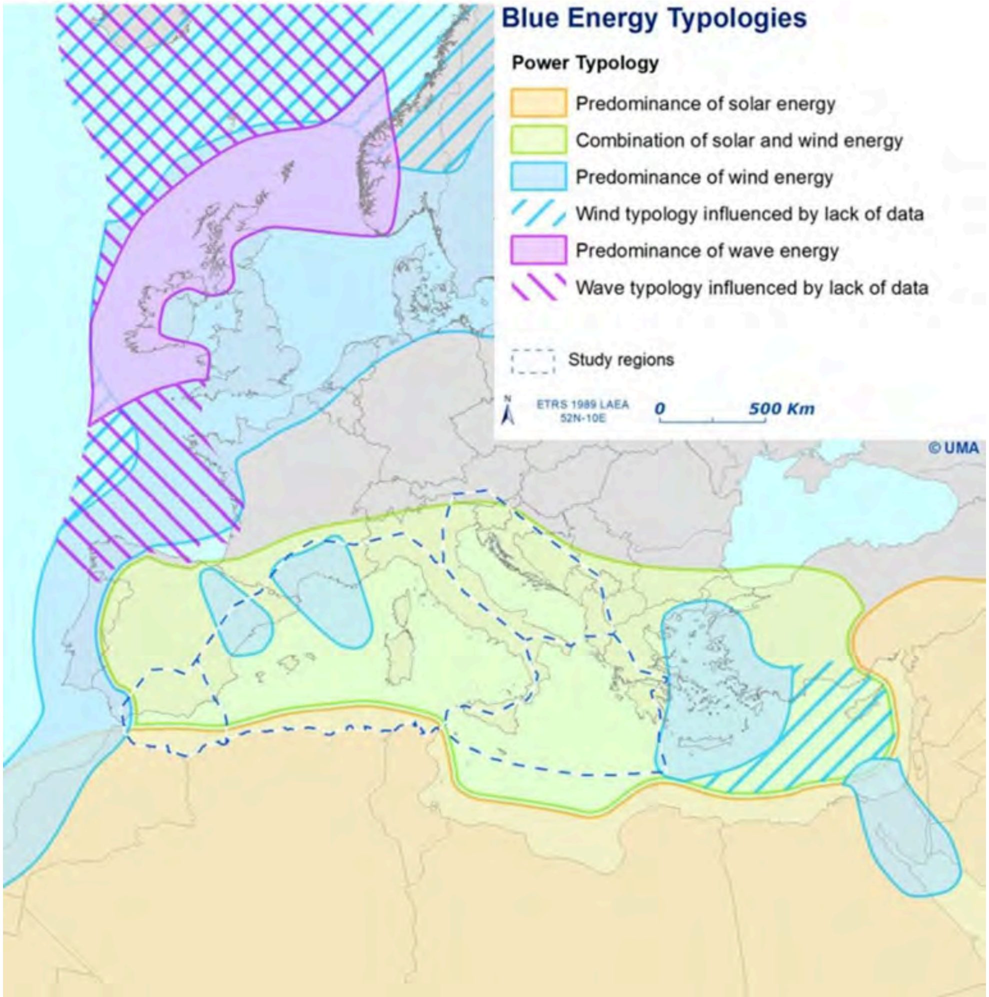

FIGURE 1 | Blue Energy Typologies in Europe. Reproduced from ASME (Abanades et al., 2018a) based on information of Aqua-RET project.

The interest of the Mediterranean Sea is reflected by the large number of studies evaluating its abundant and diverse natural resources. Wind energy has been evaluated from different scales: from the transnational one (Lavagnini et al., 2006; Menendez et al., 2014; Zountouridou et al., 2015) to the national one (Sahin et al., 2005; Shata and Hanitsch, 2006; Westerberg et al., 2013). Similarly, the wave energy resource has been also deeply analyzed by different authors (Arena et al., 2013; Liberti et al., 2013; Vicinanza et al., 2013; Sierra et al., 2014; Besio et al., 2016; De León et al., 2016).

These studies vindicate that the resource in the Mediterranean Sea can be very valuable in certain areas, as shown in **Figure 1**. It cannot be overlooked the potential synergies associated to harness marine renewable energy resources, since this type of project can bring about positive impacts, not only from the economic point of view, but also from the environmental one. For example, it has been proven that the development of wave energy can lead to the reduction of erosion in the beaches behind the wave farm (Abanades et al., 2014, 2018a; Mendoza et al., 2014; Bergillos et al., 2018). This is a clear example of development that will act on the root of the climate change (reduction of CO_2 emissions and increase the renewable energy share in the energetic mix) and on the consequences (increase of erosion on the beaches). Other advantages that could generate the development of offshore platforms are the dual application for the harnessing different renewable resources (Stoutenburg et al., 2010; Astariz et al., 2015a,b; Abanades et al., 2018b) and/or the combined application with aquaculture farms (Firestone et al., 2004; Buck et al., 2010).

However, although to meet the objectives of energy mix it is of particular relevance the utilization of the valuable sources provided by the Mediterranean Sea, this is a great

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Abbreviations: MRE, Marine Renewable Energy; EU, European Union; MED Area, Mediterranean Area; GBS, Gravity Based Solution; GBF, Gravity Based Foundation; TLP, Tension Leg Platform; HLV, Heavy Lift Vessel; GBF, Gravity Based Foundation; WTG, Wind Turbine Generator; OWTG, Offshore Wind Turbine Generator; ULS, Ultimate Limit State; RAO, Response Amplitude Operator; NM, Nautical Miles.

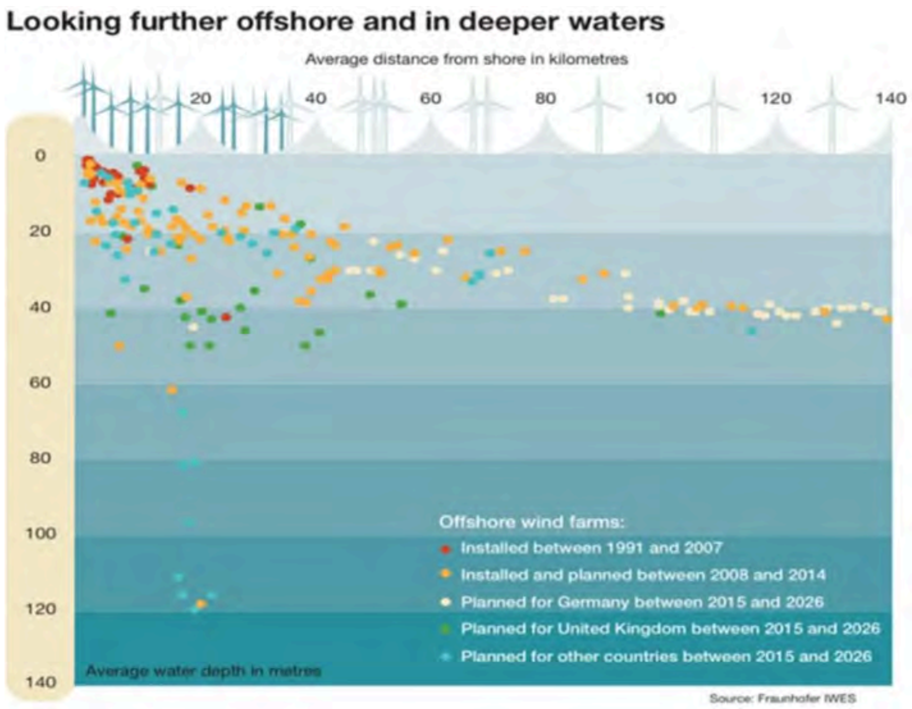

FIGURE 2 | WTG Foundation vs. water depth. Reproduced from Fraunhofer IWES and obtained in the following link of Grid-Arendal: http://old.grida.no/graphicslib/OpenFile.aspx?id=09ffa8b4-86ca-4d5e-983f-42269b279226.

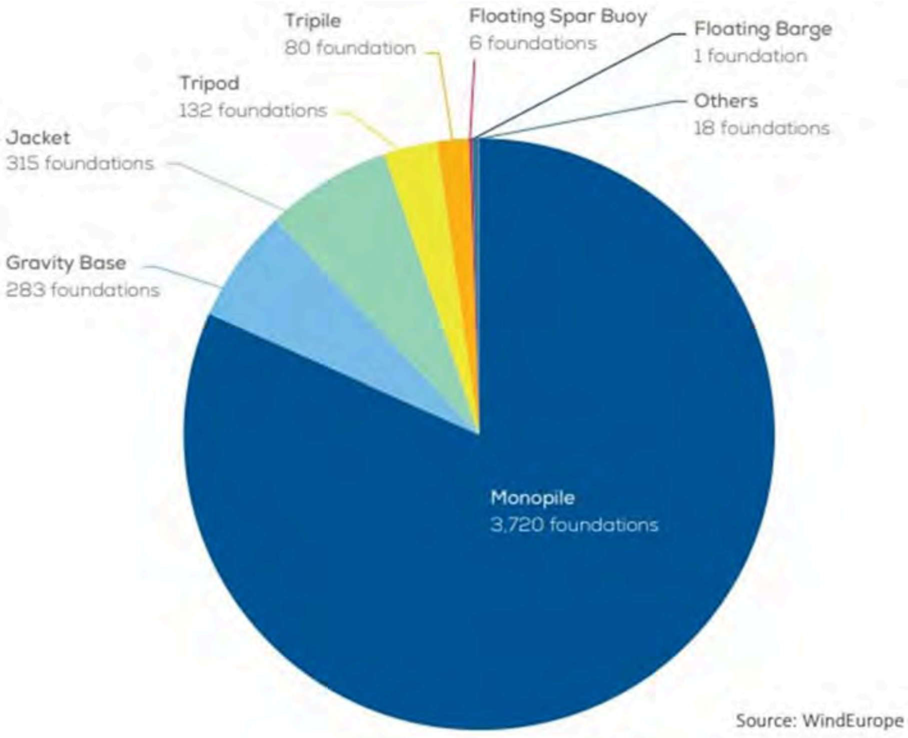

FIGURE 3 | Number of foundations according to its type. Reproduced from WindEurope.

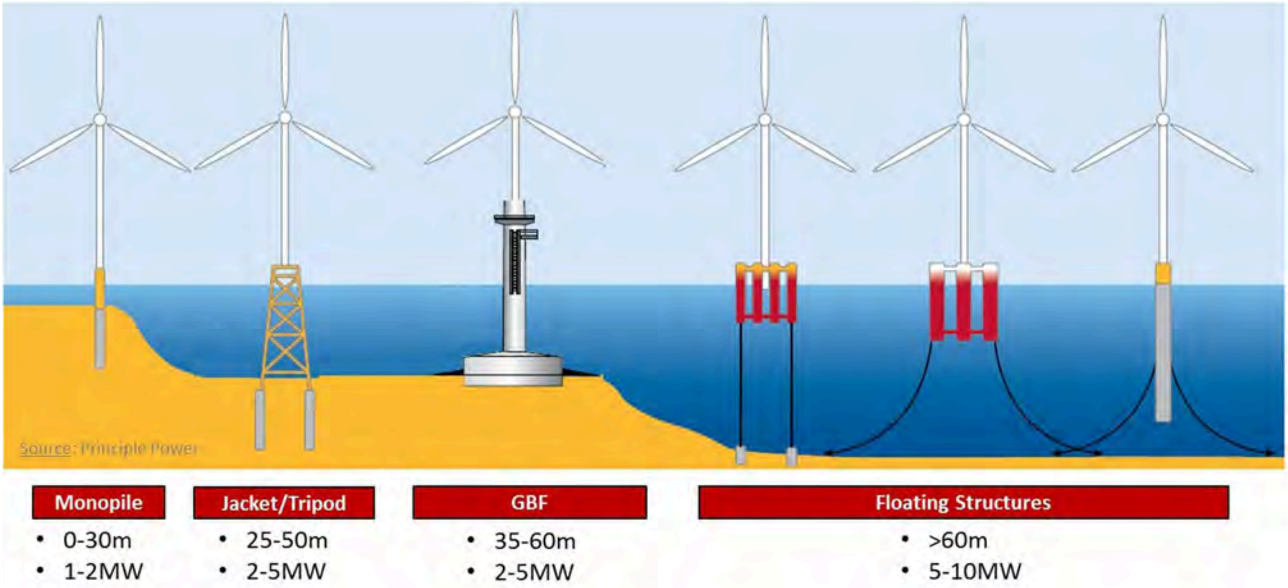

FIGURE 4 | WTG Foundation types.

FIGURE 5 | Floating dock.

challenge as blue growth has to be carefully planned due to the singularities of this area compared to others. A wider range of variables and constraints must be taken into account, such as legal aspects, environmental and landscape issues and potential affection on the tourism or other activities as fisheries.

It must be noticed that the MED area comprised the whole Mediterranean Arc plus the South Spanish and Portuguese Coast until Cape Saint Vincent. Actually this area constitutes a prime location for the development of such projects due to its large continental platform. Indeed, several projects have been promoted by different developers for the installation of the first offshore wind farm in Spain, but all finally ended up in their cancellation by several reasons. The complexity of the development of Marine Renewable projects in the Med Area is reflected in the Southwest Coast of Spain (Cadiz), in which a project of 1 GW was planned and was finally rejected by the opposition of the city councils, fishermen's unions and the tourism industry, whereas the regional and national administrations were favorable to its development (Todt et al., 2011). This proves the necessity of engaging the whole society in the decision making process.

The present article aims at evaluating the potential of the Mediterranean Spanish Arc for the development of a wind farm, considering a type of foundation: gravity based. This technology presents a large number of advantages, particularly in Spain, as it can takes advantage of the well-developed technology of the floating docks. The article is structured as follows; the advantages of gravity based solutions are presented through a foundation type: Gravi3®, the area of study of the potential of the Spanish Mediterranean Arc is studied and finally the synergies between the type of foundation and the boundary conditions are analyzed.

STATE OF THE ART

Wind Turbine Foundations According to the Water Depth

The main reason that may lead to a slowdown in the growth of offshore wind energy is the depletion of the ideal positions for the installation of wind turbines (depths of <20 m), since the areas with larger continental platforms (e.g., North Sea) are currently close to saturation (**Figure 2**). For this depth, the monopile technology (use of large diameter individual piles) is optimal both in terms of cost and constructive feasibility.

In fact, the market is clearly led by the monopile (**Figure 3**) with a share always higher than 70% since 2011 (Wind Europe, 2017). However, at greater depths, the monopile does not become the ideal technology and there is a need to develop new solutions that are as competitive as the monopile at lower depths.

In this area, different solutions appear whose technical and economic viability depend on the range of depths (**Figure 4**). Shallow waters are defined as depths between 5 and 20 m; the intermediate waters for depths between 20 and 60 m; and the deep waters to those >60 m. Solutions by gravity (known as GBS), tripods and jackets have the highest market share at intermediate depths. For greater depths, the cost of foundations is increased and current market trends are similar to those applied in the oil industry (e.g., Spar, TLPs or floating) (Higgins and Foley, 2013).

Gravity Based Solutions

One of the types of GBSs is based on caisson-type solutions. Most of GBS have been used in wind farms located in shallow waters (<20 m), in which the geotechnical conditions of the sea bed make piling unfeasible. In case of shallow waters, the most popular manufacturing process for GBS consists in the construction, in port water, of several units on a barge which is then towed to site by means of tugs. A Heavy Lift Vessel (HLV) is required to lift each unit from the barge and lower it to the final position. This process was employed in the construction of wind farms such as: Nysted commissioned in 2003, Lillgrund in 2007, Sprogø in 2009, Rødsand in 2010, and Kårehamn in 2014.

An example of GBS in medium waters is represented by those installed at Thornton Bank, in Belgium's North sea water at a depth of around 30 m. In this case, the six concrete GBSs were constructed on the dock, moved by means of self propelled modular transporters to the end of the dock where they were loaded by an HLV. The HLV transported the structures that could not float, in a partially submerged configuration to allow the buoyance force to partially counteract the gravity load.

All examples above needed HLVs to accomplish the transport and installation processes of GFBs. Since HLVs have very limited availability, they have very high charter rates and the necessity of using them jeopardizes the economic competitiveness of GBSs. For this reason, the most recent designs of GBSs are self-buoyant structures that can be towed afloat using tugs, a type of ship very common in the market.

On this basis, it can be concluded that, when GBSs are compared with other foundation types suitable for intermediate waters (30–50 m) such as steel tripods and jackets, the possibility of making the former self-buoyant represents a crucial advantage respect to the latter since it offers a way to make their installation independent from the HLVs. Moreover, while the complete installation of a tripod or jacket foundation takes 2–3 days from its arrival at site, the complete installation of a gravity base foundation generally requires <24 h. This reduction in the installation time has a positive effect on the number of time windows available for the installation of the foundation and, a result, on the final cost of the energy.

Caisson-Type Solutions

Caissons are concrete prisms whose dimensions can vary as a function of the water depth (its height) and the wave climate (its width and length). They are formed by cellular structures empty inside that allow them to be self-buoyant after their construction. The filling of these cells, either by means of water or granular materials, provides the necessary weight to support the action of the waves. Although, they can be built in dry docks, the most common approach is to the employ of floating docks (**Figure 5**). This method presents several advantages: (i) for the dimensions of the caissons (30–40 m) the necessary draft of the dry docks would limit the number of feasible ports and therefore the costs would be too high, (ii) the launching of the caissons using dry floating docks simplify this operation, (iii) simultaneous floating dock can operate at the same time, which is very unlikely in the case of dry docks.

On this sense, the employ of floating docks results in very high ratios of production. A typical value assumed for the caisson construction is 3 m of caisson height per day. As the caissons have

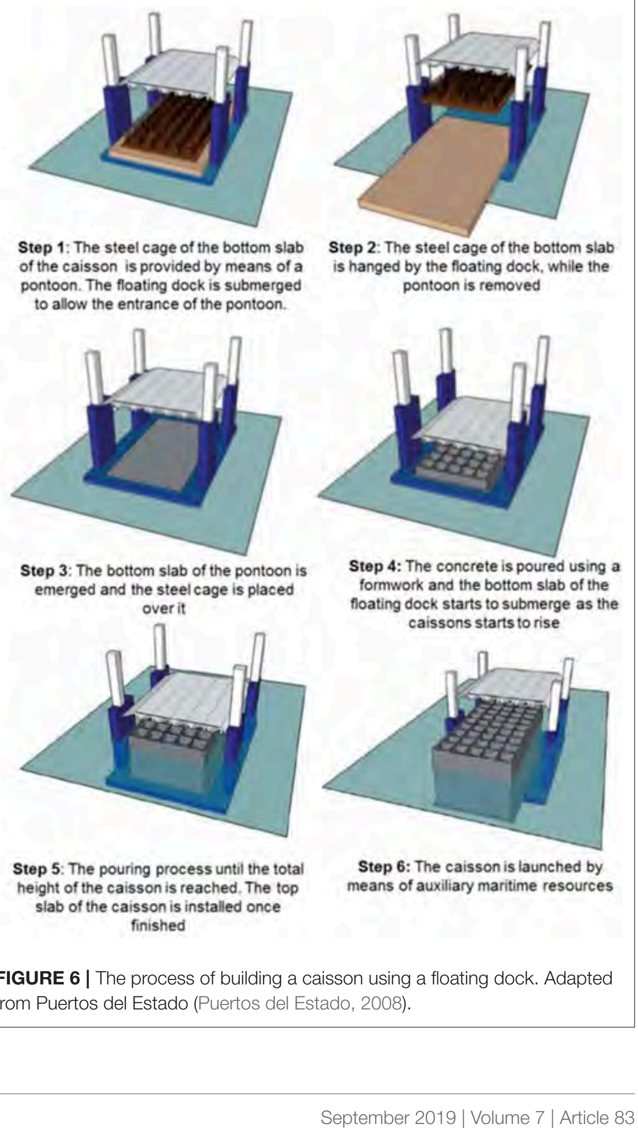

FIGURE 6 | The process of building a caisson using a floating dock. Adapted from Puertos del Estado (Puertos del Estado, 2008).

a total height of approximately 30 m, approximately the duration for building a caisson would be 10 days. In addition to this, the lunching of the caisson and the preparation for the next one is estimated in a couple of days, which makes a total duration of caisson fabrication of 12 days (**Figure 6**).

Beyond the utilization of caissons in breakwaters, the well-mature technology for the caisson construction has led this type of elements to transcend to other fields, namely the offshore winds, thanks to the savings in the maritime resources for the installation of these elements. TYPSA has been pioneered in the employ of the typical caissons of breakwaters for foundation purposes. The meteorological masts of Moray Firth and Inch Cape (Scotland) were supported by hybrid foundations formed by a concrete caisson and a steel shaft, which ends in a deck structure that connects the foundation with the Meteorological Mast (**Figure 7**).

The main advantage of this foundation is the limited number of maritime resources to perform the operation. On this basis, TYPSA continued developing the concept of using caissons for supporting structures and this came up a with a ground-breaking foundation solution for Offshore Wind Turbine Generators (OWTGs): Gravi3®.

This concept consists in an innovative hybrid concrete-steel, self-buoyant bottom standing gravity based foundation (GBF) for offshore wind farms positioned in water depths between 35 and 60 m. The foundation lies in 3 concrete caissons that are connected through a steel tripod. The complete unit (turbine and foundation) will be built and assembled onshore and towed while floating to the deployment site, where it will be submerged by an innovative patented process on a controlled way without the need for external support or heavy lift vessels.

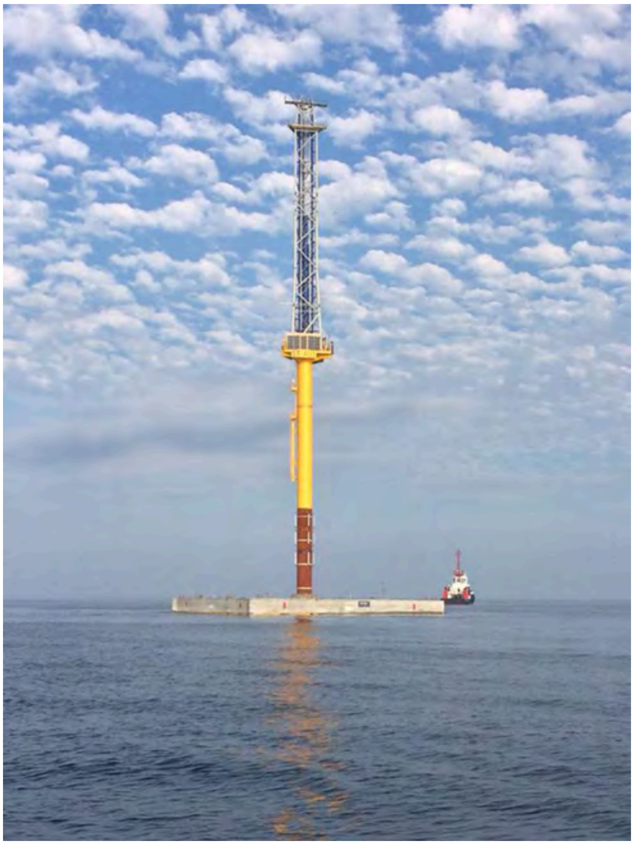

FIGURE 7 | Towing of the Meteorological mast foundation of Moray Firth.

GRAVI3®: A New GBS Concept

All the GBFs concepts presented in the previous section present one or more of the following restrictions: necessity of a yard at the base port for their construction onshore, slow construction rates due to the use of standard climbing formworks, necessity of using solid ballast to obtain the required self-weight for geotechnical verifications at the Ultimate Limit States (ULSs), and impossibility to transport the wind turbine fully assembled.

The GRAVI3® foundation has been designed to overcome all these restrictions. It is a self-buoyant GBF formed by 3 reinforced concrete caissons which support a steel tripod (**Figure 8**). The key aspect of this design is that it does not require the use of HLVs and jack-ups in any phase of the project implementation. The reinforced concrete caissons are built on a floating dock using sliding formworks not requiring onshore construction yards and maximizing the construction rate.

The combination of the tripod and reinforced concrete caisson typologies permits exploiting simultaneously the permeability of the tripod, which greatly reduces the wave induced loads on the structure, and the high dead load of the caissons, which avoid the need for piling into the seabed, thus eliminating the issues related

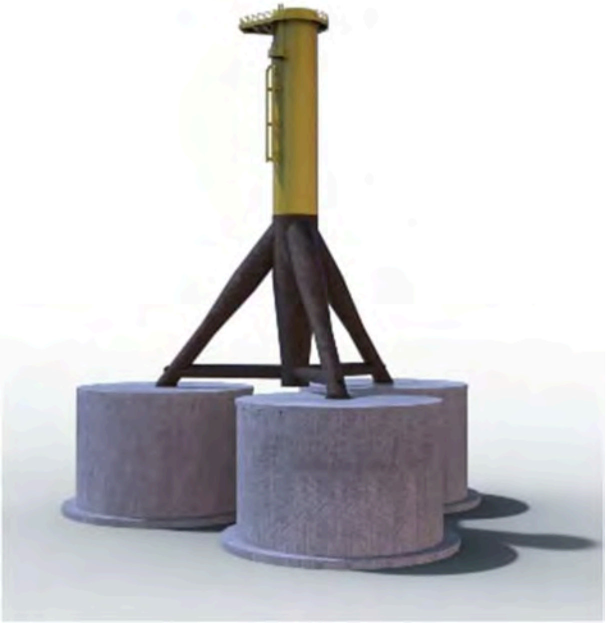

FIGURE 8 | GRAVI3® Foundation.

with the noise generated by piling and making the foundation well-suited for hard and rocky sea bed. For softer materials, sea bed preparation shall be conducted.

This three leg concept provides naval stability to the whole structure allowing its transport fully assembled (WTG included). In service conditions (as bottom fixed foundation), the three caissons improve the behavior of the structure against overturning and minimizes the stresses transmitted to the foundation soil. GRAVI3® can be installed by means of filling the caisson cells with water, and no solid ballast is required to provide additional weight. This feature of the design simplifies the decommissioning operations of the structure since it can be re-floated pumping out water from the caissons.

Other advantages that this solution presents are, among others: (i) the minimization of the use of port area for construction and storage (see supply chain of the solution in **Figure 9**), (ii) the possibility of installation at any period of the year (as the operation does not last long, a weather window of 24 h is sufficient to conduct such operation), and (iii) the possibility of decommissioning as the pumps installed for the installation can serve for the re-floating process.

One of the most challenging aspects of the design of this structure was the assessment of the hydrodynamic loading.

FIGURE 9 | GRAVI3® Supply Chain.

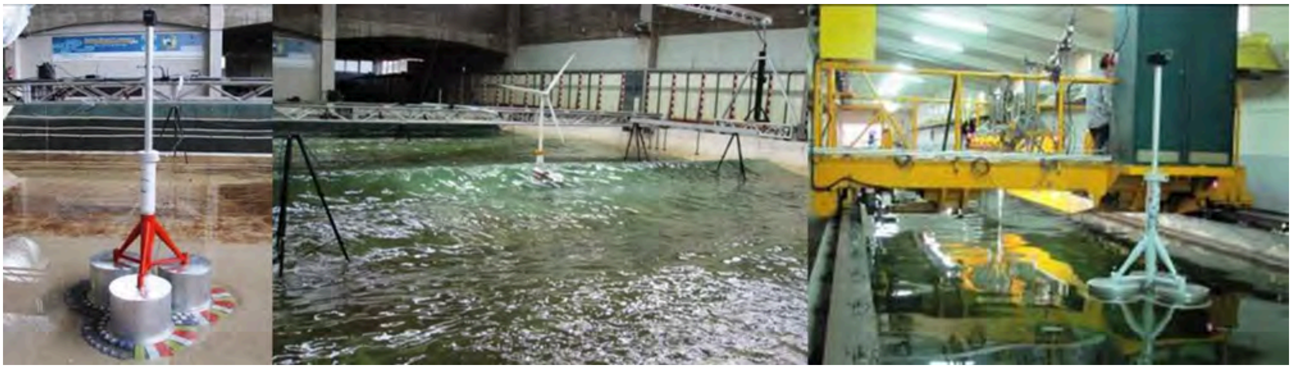

FIGURE 10 | GRAVI3® Physical campaign conducted at HRL-UPM and CEHINAV.

The structure is comprised of three caissons (elements of great dimensions), whose movements during the transport were driving the loads of the tripod (slender elements). Whilst the waves pass through the slender element, their patters are not altered; the caissons modified completely the wave behavior. Then different wave theories were used: Morison equation for the slender elements and diffraction theory for the caissons.

Furthermore, the methodology considered varied significantly as a function of the scenario studied: floating (transport and installation) or fixed (service life). For calibrating the different numerical models, physical campaigns (for the different phases of the project: towing, installation and bottom fixed) were conducted at a scale of 1:50 in the most cutting-edge facilities of Europe (**Figure 10**).

In the case of the towing, the calibration of the numerical model was carried out by means of additional Morison elements integrated on the caissons in order to simulate non-linear effects, particularly the viscous damping. For this purpose, the Response Amplitude Operators (RAOs) obtained in the physical campaign were established as the target of the numerical model output. Once calibrated the structure response, the wave loading was compared between the physical and numerical model, achieving a successful correlation between both models. Same accurate results were found with the fixed model during the service life and for the installation process.

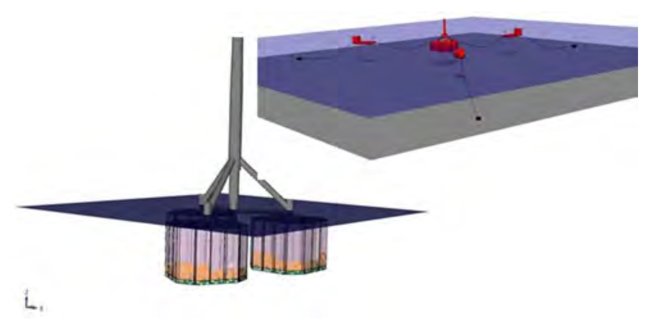

FIGURE 11 | Installation configuration and ballasting process.

Finally, regarding the installation a similar procedure than the one applied to the met masts installed in the North Sea (**Figure 7**) is employed. Three tugs are used to allow the corrections of the position and orientation. Finally, an automated system is developed for filling the groups of cells of the caissons with the objective of conducting a controlled descend of the structure. Then, the ballast process is used to correct any adverse trend that can occur during the process (**Figure 11**).

As can be seen, one of the main advantages of the solutions is its validity to a wide range of locations, as the solution can be used in a wide range of water depth, with different type of soils and at different coast-to-farm distances. On that sense, the following section will analyze its validity in the Spanish Coast.

CASE STUDY: POTENTIAL ANALYSIS IN CADIZ

The present section includes the analysis of the potential of an area for the implementation of a Marine Renewable Energy Project, in this case, more specifically about the development of an offshore wind

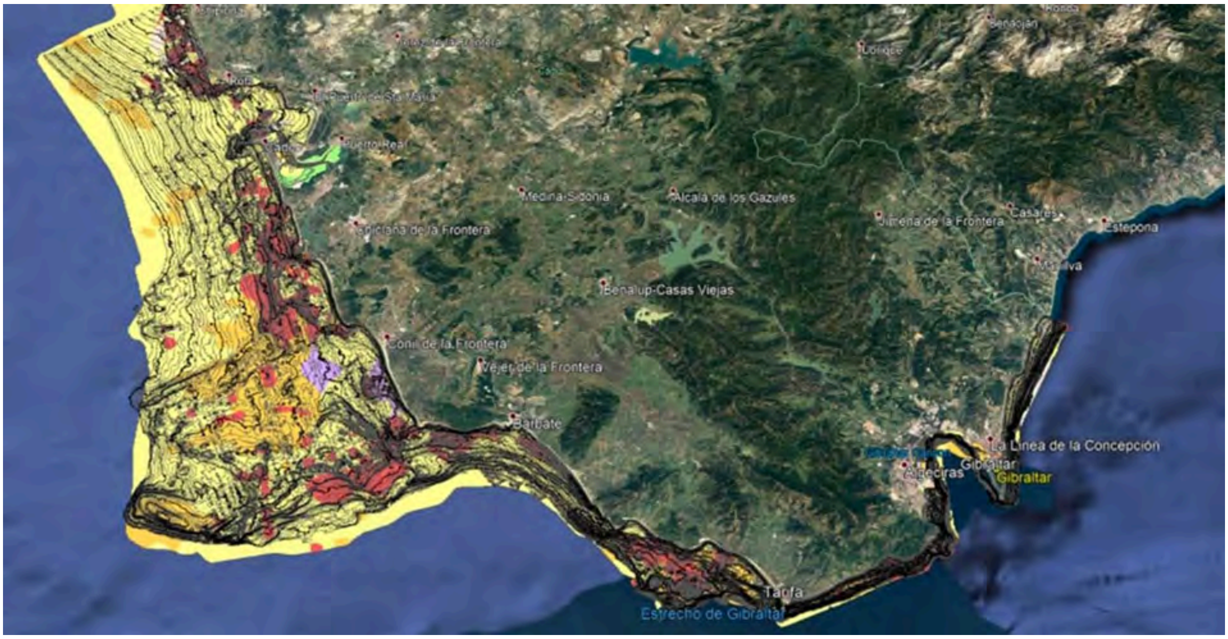

FIGURE 12 | Bathymetry and marine geomorphology along the Cadiz Coast (Spain). Map data: Google, DigitalGlobe; Data reproduced from Ecocartografias—Ecological transition Spanish Minister.

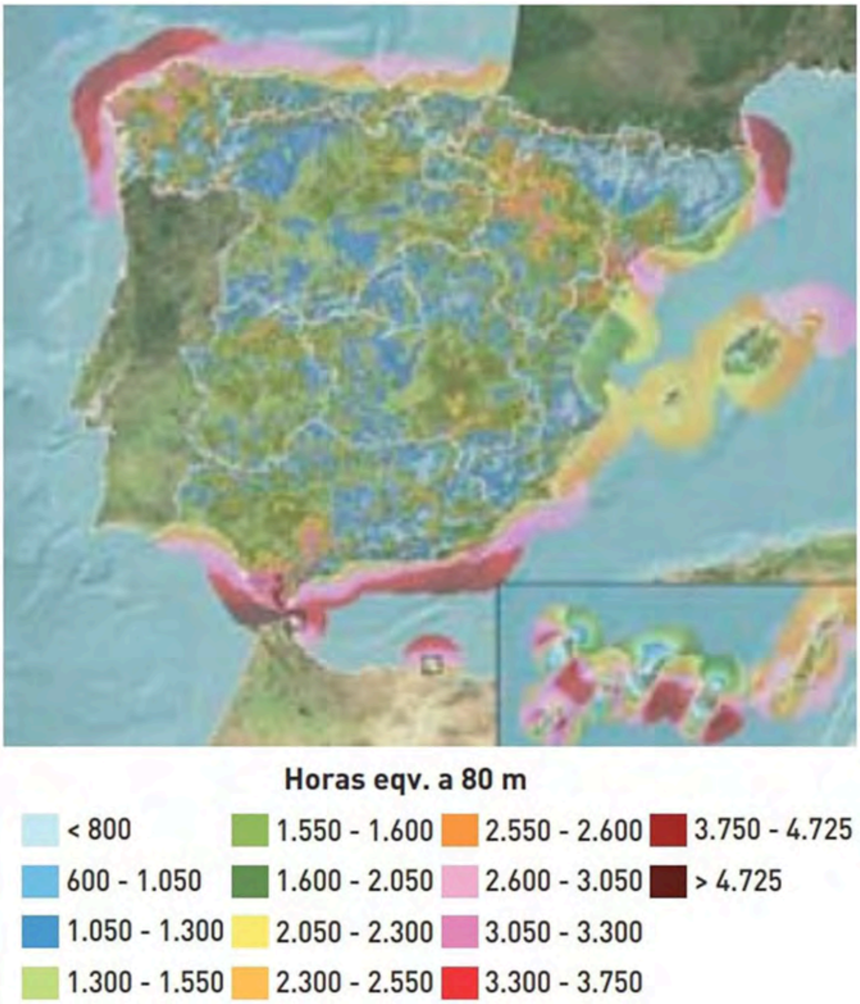

FIGURE 13 | Number of equivalent hours with full performance per year. Reproduced from IDEA.

farm. The case study selected is the West Coast of Cadiz (Spain).

One of the main shortcomings of the Mediterranean Area is the water depth, due to the absence of continental shell. In this sense, the first analysis for assessing the viability of a bottom-fixed foundation must be related to the bathymetrical and marine geomorphology analysis along the coast of Cadiz (South Spain).

Figure 12 depicts the area of interest for the installation of offshore wind, as it presents a shallow platform, with water depths lower than 50 m at a distance of 16 Nautical Miles (NM) from the Coast, which practically reduces completely any visual impact that could bring about an offshore wind project and therefore any impact in the tourism industry. Furthermore, the materials in the area are competent sands (yellow and orange materials) with the presence of rock (red) which are very competent for the installation of gravity based structures (enhancing like that one of the main capabilities of the area, which is the construction of concrete caissons). Actually, the presence of rock could limit the applicability of piled solutions (as jackets or monopiles).

It can be readily observed the differences between the East and West Coast of Cadiz. While, the platform in the west coast is very shallow (50 m water depth between 10 and 16 nautical miles), the east coast is very scarp with water depths >50 m in <2 nautical miles.

The interest of the area is corroborated with the wind resource analysis (**Figure 13**). This shows that in the case of Cadiz (nearby Gibraltar Strait), and other hot spots in Spain, the number of equivalent hours at 80 m height can reach near the 4,000 h per year, which is a similar value to the resource found in the North Sea. With this resource, and the current degree of development for the WTG, the economic viability of such a project is fully guaranteed.

Finally, to determine the potential of the area is necessary to evaluate the viability of the project according to the regulations and the protected areas. **Figure 14** shows that although there are several protected areas, mainly localized around the Gibraltar Strait, the area of the case study is not included in any special protected figure.

FIGURE 14 | Land cover along the coast and natural protected areas along the Coast of Cadiz (Spain). Map data: Google, DigitalGlobe. Information reproduced from Ecocartografias—Ecological transition Spanish Minister.

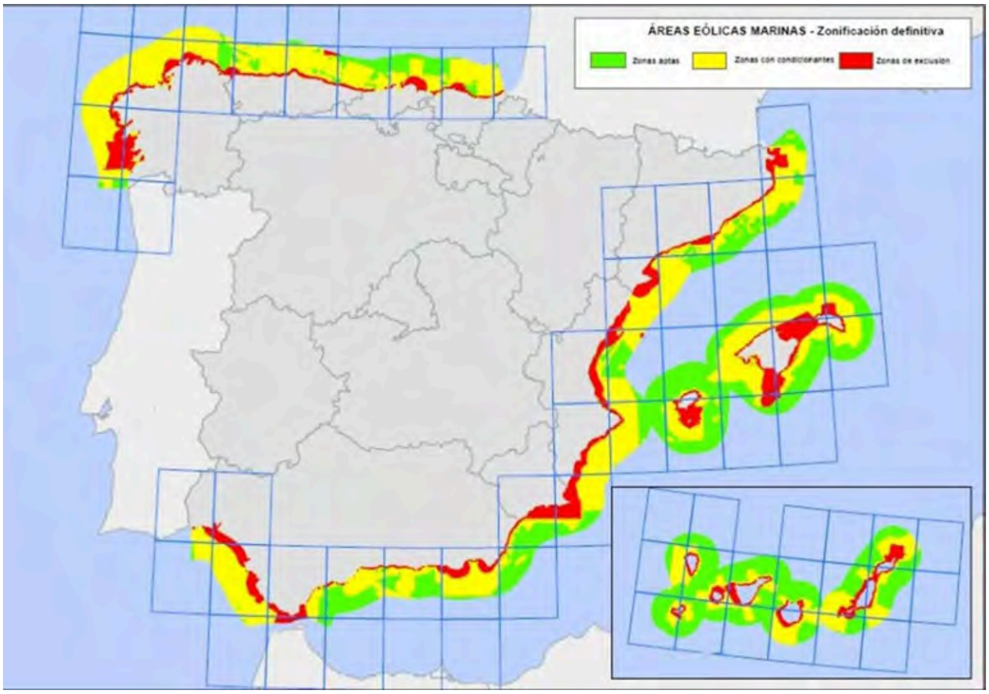

FIGURE 15 | Areas for the installation of offshore projects (green—apt, yellow—apt with conditions, red—excluded). Reproduced from Spanish Ministry (Spanish Ministry of Energy, 2009).

As for the regulations, the Spanish Ministry of Energy determined the areas that are apt for the installation of offshore projects (**Figure 15**), and the area showed as example is not excluded, but marked as yellow, which means that is apt for the installation of a wind farm but particular considerations must be accounted for.

In sum, the area of Cadiz would be constituted as a primed location for the installation of offshore wind energy, as the existing technology can be applied without need of modification, the legislation allows this type of project and the conditions (resource, bathymetry and geomorphology) are ideal. This was already found during the project of "Mar de Trafalgar," which was finally rejected due to the lack of social acceptance. In this new scenario, using a gravity based foundation (that would generate a lot of job positions in the area), placing the wind farm in a greater farm-to-coast distance (that would reduce the visual and environmental impact) and engaging all the strata of the society, the success of the project is more likely to be reached.

CONCLUSIONS

The ambitious objectives of the European Union for reducing CO_2 emissions and for increasing renewable energy contribution in the new energy mix, made necessary the contribution of the wide and vast renewable resources of the Mediterranean Sea. The case of the Mediterranean Spanish Arc is the perfect example of the current absence of exploitation of these resources. In the case of offshore wind energy, Spain presents in certain areas one of the largest wind resources of Europe; however, no current projects are foreseen to harness it.

The present paper describes the potential of Spain for developing this kind of projects through a technology type: gravity based foundations, and more specifically the solution patented by TYPSA: Gravi3®) and a case study in the Southwest coast of Spain (Cadiz). The paper clearly states the viability to conduct such a project in the Mediterranean Spanish Arc; however, it is also evident that a full agreement between all the strata of the society is necessary to move forward this type of projects.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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frontiers
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REVIEW
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State of the Art and Perspectives of Wave Energy in the Mediterranean Sea: Backstage of ISWEC

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According to the European Commission, sea waves have a great potential as renewable energy source. Despite wave energy technology is a field in continuous development, it is not yet competitive with the other renewables, due to the small quantities of devices sold, most of them being prototypal solutions at level. So far, various Wave Energy Converter concepts have been developed and some of them tested in full scale. The most recurrent test environment is the North Atlantic Ocean, which possesses high energy potential. The Mediterranean Sea on the other hand is less energetic, but also possesses less dangerous extreme conditions. It represents a favorable starting point to develop technologies that later will be scaled up to more powerful sites. This article illustrates the wave energy potential of the Mediterranean and analyses the wave energy converters engineered according to sea states characteristic of the Mediterranean Sea. Focus is brought to the Inertial Sea Wave Energy Converter (ISWEC) technology, which is one of the few Mediterranean concept to have reached Technology Readiness Level (TRL) 7. The article will document the deployment and the following open sea test campaign of a full-scale prototype off the shore of Pantelleria Island, Italy.

Keywords: Wave Energy, Mediterranean Sea, Wave Energy Converters (WECs), State of the Art, ISWEC

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INTRODUCTION

The sea has always exerted its inevitable fascination on human beings. Waves that break on cliffs or on a beach allow to grasp the power available in this continuous surface movement. This continuous power, so much distributed in the World and relatively easy to access, makes wave energy an interesting phenomenon, so to be counted among the most promising renewable energies (European Commission, 2012). It is precisely from the comparison with other forms of energy that the exploitation of this form of energy can be responded to and motivated. The different power densities of some of the most well-known renewables can be explained with the wave-forming process: waves are mainly generated by the interaction between the wind and the sea surface; constant mechanical action of the wind, acting as a tangential effort, leads to the formation of waves (World Meteorological Organization, 1998). The wind itself is a derivative of solar energy.

The process of these physical phenomena brings with it an increase in the energy density, seen as the available resource power per meter. About the geographical distribution of the resource, we can take two different approaches:

- On one hand onshore devices such as wind, solar, and others give the possibility of having the source close to the place of use, to the network, so distributed and easily accessible to operators of maintenance.
- On the other hand, wave energy from the sea gives the possibility to avoid land use, which is widely discussed from public opinion. Installations could be in fact in areas close to the coast unused or of low tourist value, or at a distance enough to eliminate the visual impact for man.

Another factor of comparison concerns predictability: the wave resource is characterized by a high degree of predictive reliability with respect to solar and wind resources. On this purpose, several theoretical aspects involved in the estimation of wave energy statistics have been developed to represent the source in terms of mean wave power and return value of typical and extreme events in various coastal areas (Arena et al., 2015). This makes easier the integration of renewable energy in the continental or insular power grid and it consists in a reliable generation node in smart grids.

One last consideration lies in the availability of the resource: wave energy can be harmoniously integrated with solar and wind systems. Indeed, a very rough sea state usually is not contemporary with a day of intense sunshine and frequently comes as a result of an intensive wind phase. This allows to create an integrated energy mix, distributed over time.

It is worth to consider that nowadays technological achievements and energy potential in the Mediterranean Sea of some of the other well-known blue energy sources, in order to understand the advantageous characteristics of the wave energy in comparison to them:

- Tidal range and current: present a low power density in Mediterranean Sea as discussed by Soukissian et al. (2017) with some exception for Straits of Dardanelles, of Gibraltar and Strait of Messina.
- Salinity gradients: although some specific sites in Mediterranean Sea are suitable there is no technology currently developed to exploit this energy source (Alvarez-Silva et al., 2016).
- Thermal difference: a thermal difference of 20°C is needed to guarantee a good efficiency of the device. In Mediterranean Sea the temperature difference between sea surface and 1,000 m depth is below than 12°C (Soukissian et al., 2017).

The ENEA wave analysis forecast reported in **Figure 1** shows that the Mediterranean wave potential, is regard to Italy, is mainly concentrated on the Italian West coasts, in particular Sardegna, then the Channel of Sicily. Indeed, the Mediterranean basin is almost surrounded by mountain ranges except for France where the wind can freely blow from west to east under the Coriolis effect.

THE PANTELLERIA CASE

The territories most interested in energy security are obviously the most remote, and among them the most fragile from the landscape point of view are the islands. For this reason, our activity has focused on an island of the Mediterranean Sea: Pantelleria.

The island of Pantelleria is in the center of the western part of the Channel of Sicily about 110 km southwest of Sicily and 70 km east northeast of Tunisia. When, 10 years ago, the group of the Department of Mechanical and Aerospace Engineering of Polytechnic of Turin had to decide on a site for technology testing, Pantelleria seemed immediately an interesting candidate to host the device, mainly because of its availability: Pantelleria has a wave resurgence consisting in an annual average of about 7 kW/m, as can be seen in; secondly, the absence of an electricity connection between the island and the national electricity distribution.

The island should therefore independently provide to its energy production and currently such production is obtained mainly through fossil fuels and the consequent problems of pollution and fuel supply. Moreover, the cost of energy in Pantelleria and more generally in Italian minor islands, is three to five times higher than the cost on the mainland[1], which makes small islands a favorable area for the implantation of renewables.

The Ministerial Decree concerning small islands fixes some clear targets for 2020 (Ministry of Economic Development, 2017) for instance Pantelleria, the biggest of the small islands of Sicily that is not connected to the grid, with 7,700 inhabitants and an annual electricity production of 44,170 MWh from diesel generators must achieve the following objectives within 2020:

- 2,720 kW of RES installed power;
- 3,130 m^2 of solar thermal panels.

Furthermore, the Economic Development Ministry will fund with 10 million euro two innovative projects able to decrease by at least 20% the annual electricity production from fossil fuels.

To this end, studies have been carried out to represent the best energy scenario that contemplates the optimal RES mix based on the available resources. Given the need to reduce the impact on the territory as much as possible, the focus has been strongly on the energy of the sea waves. Since 2010, prior to any activity, a status monitoring was carried out in the most energy-intensive area of the island: a wave gauge was installed about 800 m from the port in the area north west of the island, exposed to the wind (and thus the waves) prevalent direction: the mistral (N).

In the proximity of the detection point it was then decided to install the power generation device (**Figure 2**).

From the data acquisition it was possible to identify the waves characteristics distribution on an annual basis. These data allow to define the power and therefore the energy available on the installation site. Following the acquisition of the above information, the team proceeded to the design phase of the machine to be installed.

In the following paragraphs, after the analysis of the state of the art, the design, and installation phase of the technology in test will be illustrated.

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[1] Italian Republic. Decree of the Ministry of Economic Development 14/02/2017: "Disposizioni per la progressiva copertura del fabbisogno delle isole minori non interconnesse attraverso energia da fonti rinnovabili". OJ of the Italian Republic, 18/05/2017.

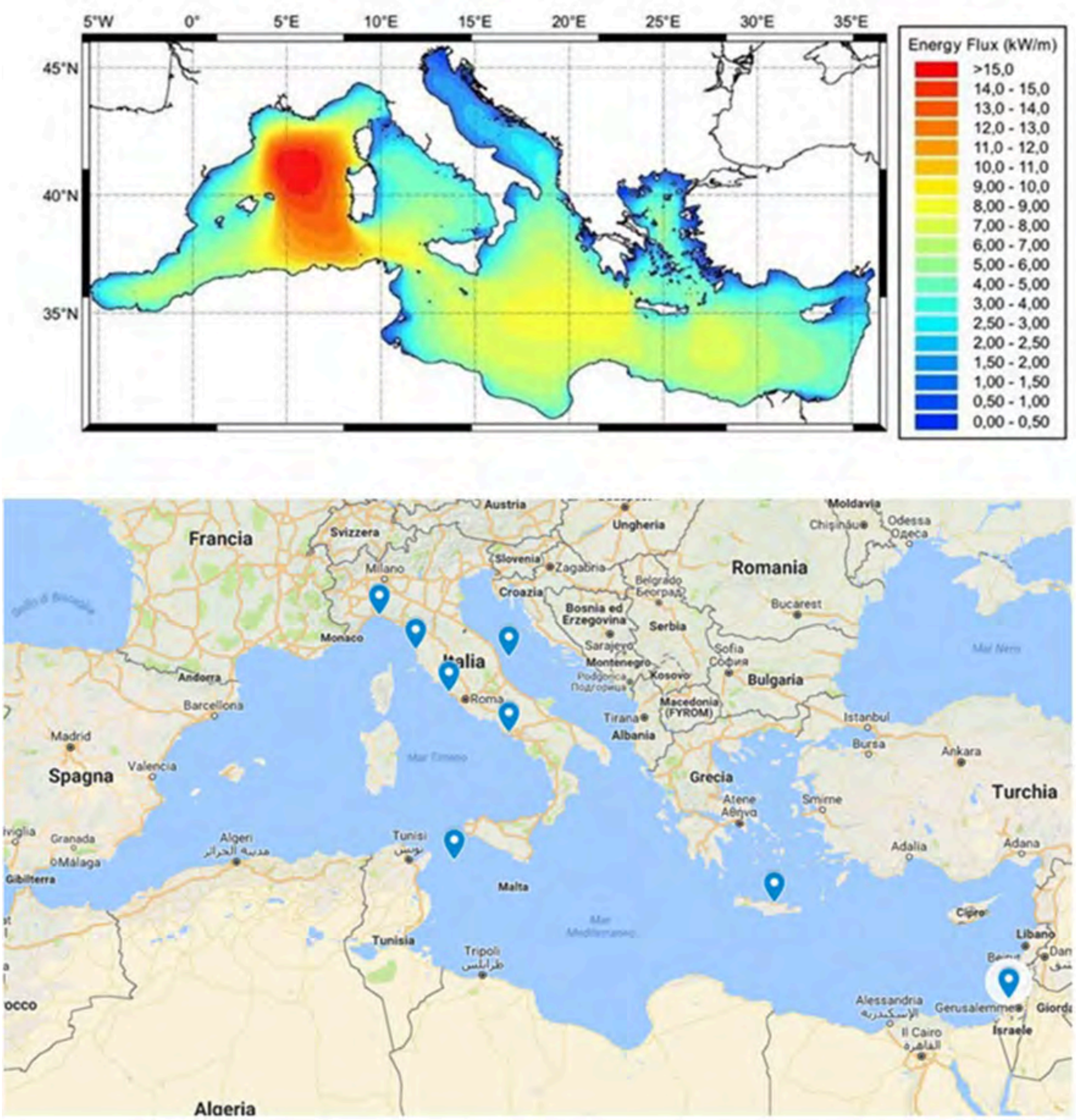

FIGURE 1 | Mediterranean wave resource **(Top)** and Map of Mediterranean showing the places where the projects took place **(Bottom)**. Map data ©2018 GeoBasis-DE/BKG (©2009), Google, Inst. Geogr. Nacional, Mapa GISrael, ORION-ME.

THE MEDITERRANEAN TECHNOLOGIES

REWEC3: Resonant Wave Energy Converter

REWEC3 (Resonant Wave Energy Converter) is an oscillating water column (OWC) wave energy converter, which is equipped with a U-shaped duct used for connecting the water column to the open sea field as represented in **Figure 3**. This characteristic allows to increase significantly the hydrodynamic performance in comparison to traditional OWC plants. REWEC3 was developed by Mediterranean University of Reggio Calabria and a small prototype with scale 1:10 and length 16.2 m was installed at the Natural Ocean Engineering Laboratory NOEL of the Mediterranea University of Reggio Calabria (Malara et al., 2017; Moretti et al., 2019). The estimated average electrical energy produced during 1 year from a Rewec plant with total length of 1 km in central Mediterranean Sea is 6,000–9,000 MWh[2]. At present the first full-scale prototype is under construction in the Civitavecchia's harbor in the Tyrrhenian Sea (Arena et al., 2017).

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[2] Wavenergy.it Srl. Available online at: https://www.wavenergy.it/about/ (accessed August 30, 2019).

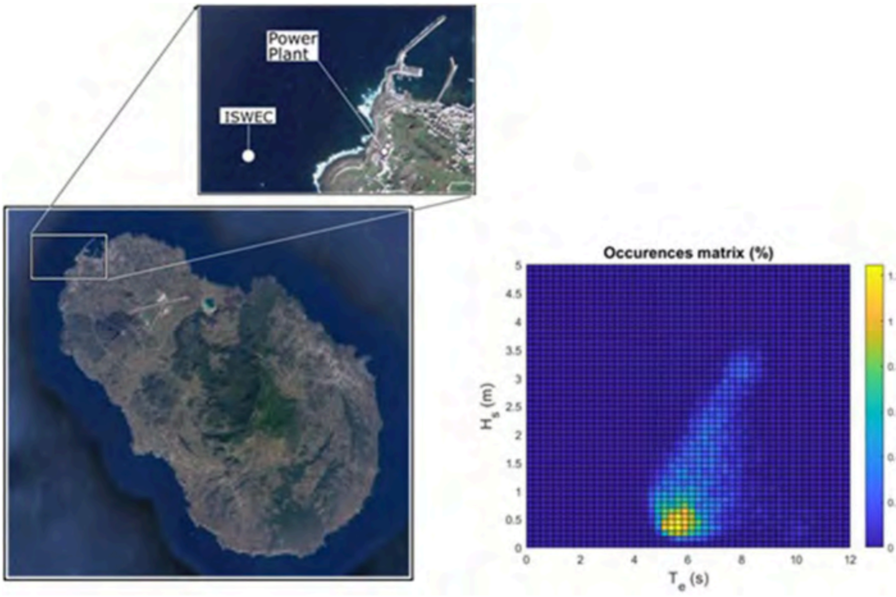

FIGURE 2 | ISWEC deployment site **(Left)** and Pantelleria's Scatter Table **(Right)**.

Poly-OWC: Polymeric Oscillating Water Column

Poly-OWC (Polymeric Oscillating Water Column) introduced the new category of Polymeric Wave Energy Converters, characterized by the usage of Dielectric Elastomer (DETs) as shown in **Figure 4**. The working principle of Poly-OWC is the variable capacitance electrostatic generation principle, where the voltage of the charges lying on DET is increased by the deformation of the membrane. Poly-OWC was developed by Scuola Superiore Sant'Anna of Pisa; at the present the Technology Readiness Level (TRL) is 3/4 and a first small scale prototype has been built (Moretti et al., 2018; Chen et al., 2019).

University of Florence—OWC

University of Florence and AM3 Spin Off Srl are developing an OWC wave energy converter WEC. The hull is designed as a motion attenuator device for large floating platforms with the additional benefit of providing an efficient renewable energy source as show in **Figure 5** (Left). The technological readiness of the device is TRL4 and the technological concept has been validated through CFD modeling and laboratory experiments. CFD simulations are provided in **Figure 5** (Right) (Cappietti et al., 2019).

Generma wec

SME Generma Srl has developed another wave energy converter based on the attenuator concept. The technology consists of unit elements connected by hinges in a floating modular structure. The relative rotation of modules under wave motions moves hydraulic pistons that compress fluid in a closed circuit. As a result, energy conversion is achieved by a modified Pelton turbine and an asynchronous generator. Initially, a small-scale device 5 kW was tested in laboratory and in 2016 a near-scale prototype 80 m long and 1.9 m wide with nominal power 150 kW has been realized in order to make field tests in Adriatic Sea, as shown in **Figure 6** (Generma.com, 2016).

Sea Spoon

Seaspoon is a wave energy converter developed by the University of Genova, in collaboration with RINA Consulting with TRL 6. The Seaspoon device captures the wave energy by mean of a horizontal axis rotor orthogonal respect to the incoming wave direction. The "spoon" device, a plate stiffly coupled to the rotor, boosts the conversion efficiency of the rotor immersed in the particle flux, the small scale prototype and the schematic representation are show in **Figure 7**. The Seaspoon full scale device was installed in the open sea in front of Genova city in 2015 with nominal capacity 1kW and 2 m wave length after having been tested in University campus, instead the small scale device has 10 W rated power and 0.6 m wave front length (Di Fresco and Traverso, 2013).

Gel System

Gel system is a wave energy converter developed by SEAPOWER scrl and it is designed to function near the coast or in shallow waters. The device consists of a floating body linked to a fixed frame that is left free to oscillate around a horizontal axis under the action of waves. Inside the hull there is a permanent magnet electric generator which is integrated in the PTO (Power Take Off) system that results the transformation of linear motion induced by the waves into rotary motion of the generator rotor. A 1:5 scale and a full-scale prototype with a PTO realized by Umbra Group S.p.A. as shown in **Figure 8** (top) was tested in the wave tank located at the University of Naples "Federico II." The technological readiness of the device (TRL) is 5 and it is ready

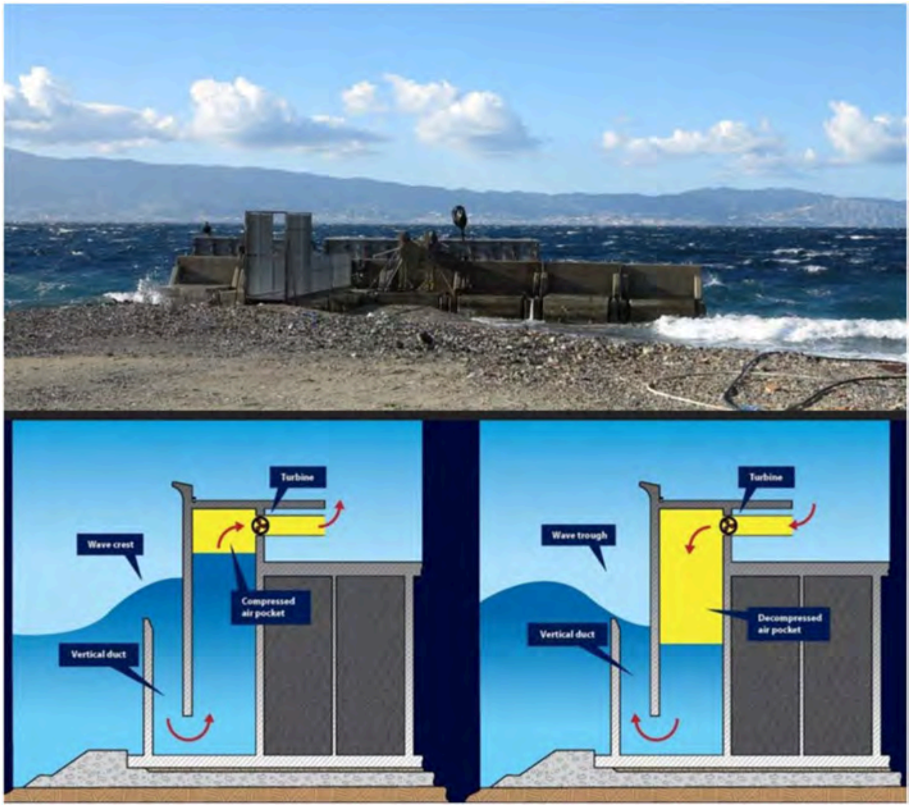

FIGURE 3 | 10 REWEC3 scale device (**Top**—from www.noel.unirc.it) and schematic representation of REWEC3 **(Bottom)**.

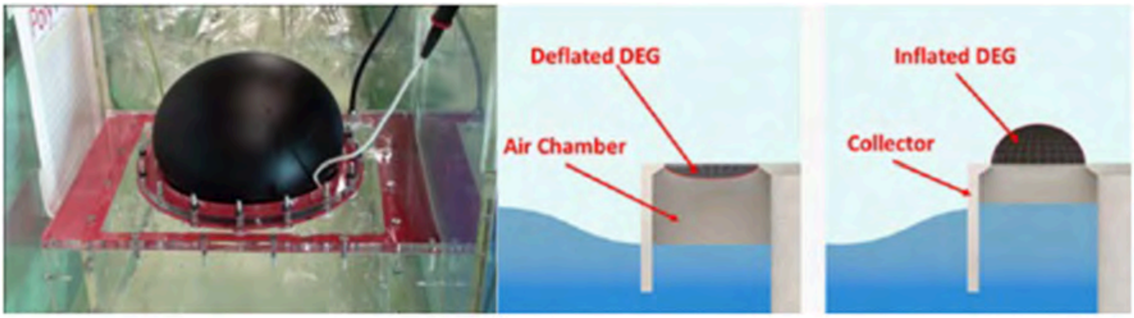

FIGURE 4 | Poly-OWC small scale device **(Left)** and schematic representation of Poly-OWC **(Right)**.

for testing in real sea conditions (SEAPOWERSRCL, 2017; Coiro et al., 2018, 2019).

Wavesax

WAVESAX is an innovative wave energy converter developed by RSE S.p.A. It belongs in the OWC category and the TRL of the technology is 5/6. The device is integrated in coastal structures (harbors, ports, etc.) and it consists of a vertical pipe in which water moves upward and downward, following the wave motion a prototype and an application are reported in **Figure 8** (bottom). A small scale (1:20) was tested in HMRC (Hydraulic Marine Research Center) in Ireland and another one with scale 1:5 was tested in at the ECN Hydrodynamic and Ocean Engineering Tank, France (Peviani, 2015).

Obrec

OBREC (Overtopping BReakwater for Energy Conversion) is a wave energy converter developed by the Università degli studi di Campania "Luigi Van-vitelli." The device is embedded into a breakwater and the working principle is based on the wave overtopping process. A small scale prototype (1:30) was tested at Aalborg University in Denmark during two experimental

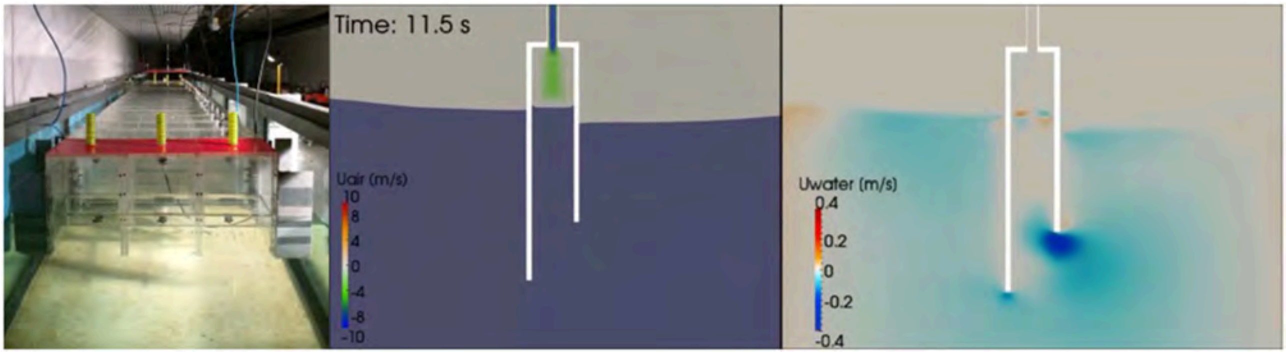

FIGURE 5 | Small scale prototype **(Left)** and CFD simulations of the OWC **(Right)**.

FIGURE 6 | Full scale Generma WEC **(Left)** and schematic representation of Generma WEC **(Right)**.

FIGURE 7 | Small Scale prototype **(Left)** and schematic representation of Seaspoon **(Right)**.

campaigns in 2012 and 2014. A full scale of 6-m length was installed in the port of Naples in 2015 along the San Vincenzo breakwater, full scale OBREC and his schematic representation are reported in **Figure 9**, where the sea depth is about 25 m and the available power is estimated to be 2.5 kW/m. Currently the TRL is 5 (Contestabile et al., 2016).

40South Energy H24

40South Energy H24 is a wave energy converter assembled in two parts: a 12-m long guide and a mobile component left free to slide on it. The plant is constituted of multiple modules mounted 12 m deep and fixed to the seabed. The device is activated by the force of the waves impacting the mobile component and causing its relative motion with respect to the guide. The H24 WEC was developed by 40SOUTH ENERGY Srl. They've also built an energetic park in Marina di Pisa in 2015, where a plant of 50 kW, constituted of 4 H24 devices, has been deployed and connected to the grid for an experimental campaign (40South Energy, 2012).

Sinnpower Wec

SINNPOWER provides wave energy converter modules which are floating heaving point absorbers. Single devices can be installed and function in ports, offshore structures, fish farms, etc. However, a WEC array is also available which is constituted

FIGURE 8 | **(Top)** Full scale GEL prototype (Left) and schematic representation of GEL (Right). **(Bottom)** Full scale WAVESAX prototype (Left) and its deployment in Civitavecchia (Right).

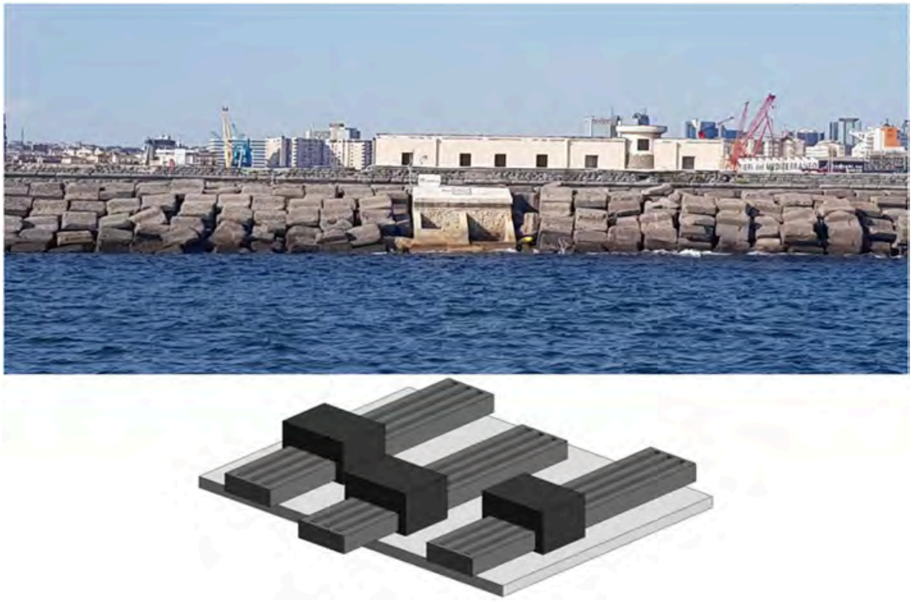

FIGURE 9 | Full scale OBREC in the port of Naples **(Top)**. Schematic representation of a 40 South Energy H24 wave energy converter plant **(Bottom)**.

by many single modules. Every module generates about 3 kW (SINN Power GmbH Wave Energy, 2017). In December 2015, SINN Power started operating the first wave energy converter module on the Greek island Crete and specifically on the port wall of Heraklion, a graphic representation of the whole system is shown in **Figure 10**. By 2019, the

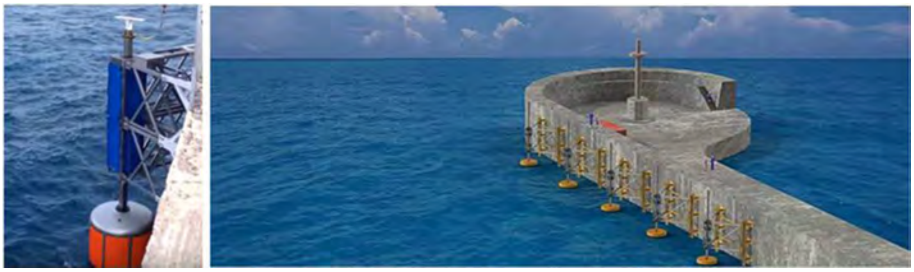

FIGURE 10 | WEC module **(Left)** and schematic representation of port of Heraklion, Greece **(Right)** © SINN Power.

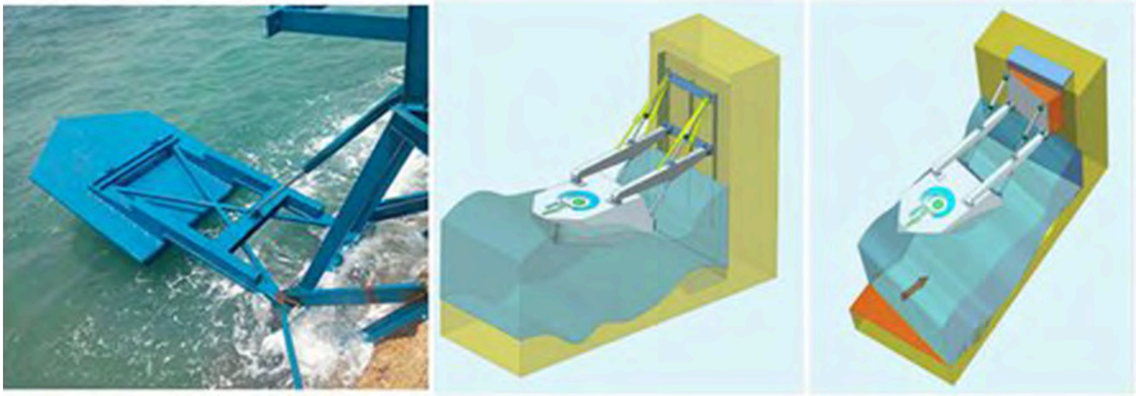

FIGURE 11 | EWP device **(Left)** and schematic representation of EWP Convertor **(Right)**.

company plans to install three more WECs at the port of Crete (Knappik, 2018).

Eco Wave Power Convertor

EWP Convertor (Eco Wave Power Convertor) absorbs energy from wave power using uniquely shaped floaters which follow the elevation of the water when a wave passes. The devices are attached by robust arms to any man-made structure such as break waters, jetties, piers, poles, and floating and fixed platforms, as shown in **Figure 11**. The company has installed a 10 kW research and development power station in Jaffa port in July 2015[3] (Techtime.news, 2015).

Pendulum Wave Energy Converter (PeWEC)

PeWEC (Pendulum Wave Energy Converter) is an offshore, floating, pendulum-based Wave Energy Converter developed by W4E, Polytechnic of Turin and ENEA, with TRL5. It is mainly composed of a floating hull moored on the seabed and a pendulum connected to the shaft of an electrical generator which is integral with the hull structure. Likely in the case of ISWEC device, pendulum, electrical generator and all other equipment necessary for the device functioning are enclosed in the hull. At present a full-scale devise is under construction, how you can notice in **Figure 12** (Pozzi, 2018).

ISWEC (Inertial Sea Wave Energy Converter)

It is a device based on the technology developed by the Polytechnic of Turin and implemented by the company Wave for Energy Srl (Bracco et al., 2011). It consists in floater anchored to the seabed with a loose mooring, allowing the pitching movement and orientation to follow the main direction of the front wave. Outside it looks like a completely closed hull, with the only electric cable that, through a joint, passes through the hull and connects with a static cable positioned on the seabed and reaching as far as the beach, in a transformer cabin to the island network[4] (Bracco et al., 2011). Unlike the other devices, PEWEC and ISWEC equipment are enclosed inside the hull avoiding the contact with the sea water that results in an increase of the durability of the device. Also, the device is modular so for instance the gyroscopic unit can be changed in order to vary the nominal power of the converter.

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[3] Eco Wave Power Technology. Available at: http://www.ecowavepower.com (accessed June 17, 2019).

[4] Wave for Energy Srl Company. Available online at: http://www.waveforenergy.com

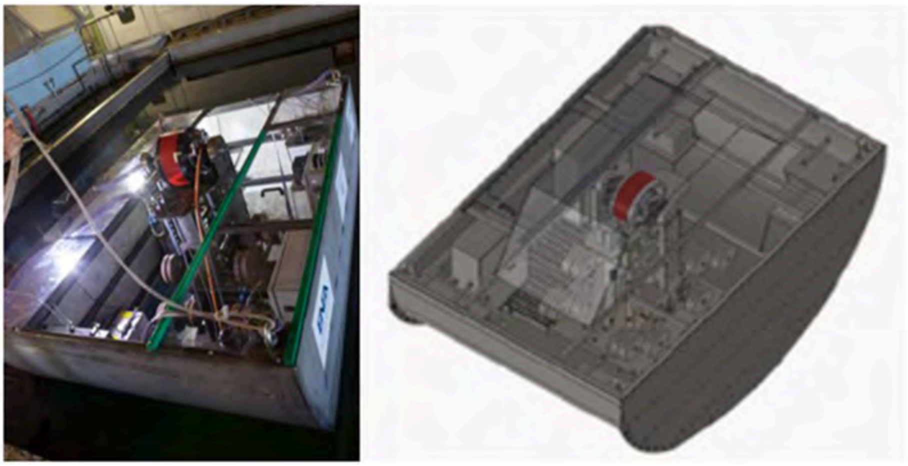
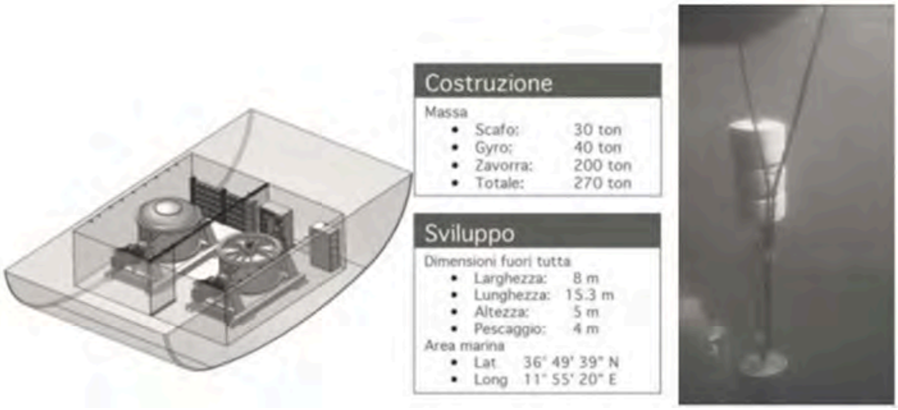


FIGURE 12 | 1:45 PeWEC scale device **(Left)** and schematic representation of PeWEC **(Right)**.



Costruzione	
Massa	
• Scafo:	30 ton
• Gyro:	40 ton
• Zavorra:	200 ton
• Totale:	270 ton

Sviluppo	
Dimensioni fuori tutta	
• Larghezza:	8 m
• Lunghezza:	15.3 m
• Altezza:	5 m
• Pescaggio:	4 m
Area marina	
• Lat	36° 49' 39" N
• Long	11° 55' 20" E

FIGURE 13 | ISWEC hull and principal components. Dimensions and features of the device **(Left)** and picture of mooring **(Right)**.

The heart of the machine is the gyroscopic system: two flywheels of 10 tons placed in rotation that generate the inertial reaction torques that arise from the interaction between their speed and the pitching motion of the hull on two internal precession shafts, on which the permanent magnet electric generators are keyed[5].

The possibility to vary the angular velocity of the flywheel allows the device to adapt and maximize performance for different sea states, increasing the flexibility of the converter. Some features of the machine deployed in Pantelleria are presented in **Figure 13** (Left).

During the device operation the mechanical power contained in the movement of the waves is transferred to the hull, thus causing the motion of the latter and the pitching motion is the most evaluable response. The angular velocity of the hull, combined with the angular momentum of the flywheel placed in rotation, causes a gyroscopic moment that causes the transfer of mechanical power between the hull and the inner shaft of precession, on which the electric PTO is mounted.

As mentioned previously, the flywheel speed is adjusted accordingly to the working sea conditions in order to maximize energy absorption. The angular velocity in working conditions and the regulation law of the absorption PTO is updated hourly, using the forecasts provided by ENEA: every day the sea state forecasts are transmitted and received automatically from the device for the next 3 days with hourly resolution.

The Mooring System

As mentioned above, the energy production system is bound to the sea bottom with loose mooring to guarantee that the dynamics of the hull are not compromised; at the same time the moorings constitute the constraints of moving the machine, as well as the main safety features.

At the time of launch, in the absence of electrical connection with the distribution network, the hull was left free to orientate itself to the direction of the wave, rotating around the constraint

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[5] Wave for Energy Srl Youtube Channel. Available online at: https://www.youtube.com/channel/UC1imzSpUaWpRatfttVppt_Q

on the bottom: this condition occurs using a single mooring line that engages the bow of the device obtaining a situation very similar to the commonly defined "wheel boat." At present the electric cable connecting to the network is being installed and at the same time two stern moorings are being installed in such a way that the system is aligned with the prevailing one with a variability of about ±20°.

This mooring configuration does not significantly compromise the device's productivity as the wave characteristics of the sleeping installation site are characterized by an extremely declared directionality.

Figure 13 (Right) shows an image of the bow mooring in which the constituent elements are distinguished: catenary, jumper, and counterweight. The presence of these elements, appropriately sized, ensures the non-linearity of the force exerted by the mooring on the device in such a way as to preserve the mooring itself from "tears" which could cause damage.

ISWEC in Pantelleria

The launch of ISWEC on the island took place in August 2015. The installed system presented some partitions: there was no connection to the network (therefore the machine was in stand-alone operation) with elements of dissipation of the energy produced, and the system only saw one of the two gyroscopic units installed. The decision to proceed with subsequent steps of experimentation was born with the aim of proceeding to intermediate checks of the design choices been made. In **Figure 14,** a photograph during the transport on the job site and an image of the system while working are shown.

FIGURE 14 | Transportation of ISWEC to the installation site in Pantelleria. August 2015 **(Top)** and ISWEC deployed at sea **(Bottom)**.

In the first test phase of the system, the sea conditions encountered have become extremely challenging, with significant heights and peak periods characteristic of oceanic sites. This made it possible to test the tightness of the device and the mooring system.

In none of these phases the system has failed. At the same time, it was possible to verify part of the theoretical bases on which the design criteria were based with the validation of the predictive mathematical models of the behavior of the system, both from the dynamic point of view and from the performance point of view in terms of energy produced (Cagninei et al., 2015).

From an analysis of the trends the following considerations can be made:

The angular speed of the flywheel was 150 rpm, while the optimal speed for the 5 kW/m scenario is equal to 450 rpm. By observing the gross electrical power and the corresponding gross overall efficiency, a decrease in performance is obtained as the wave power increases: this phenomenon finds its explanation precisely in the choice, imposed by the experimenter, to keep the angular speed of the flywheel constant. The set speed allows the system good performance near a power of 3 kW/m. However, the angular velocity of the flywheel has not changed as the power of the wave has increased and the performance has therefore decreased.

The device operated with the following average characteristics:

- Average wave power density: 4.6 kW/m
- Gross electric power produced (Reference to the "Gross Pelect" size of the graph): 3.2 kW. At this average power corresponds a Relative Capture Width average ("Gross RCW") equal to 8.9%
- Device Machine losses in these conditions are 1.95 kW
- Net electric power produced (Reference to the "Net Pelect" size of the graph) is equal to 1.25 kW. At this average power corresponds a Relative Capture Width medium (Reference to the "Net RCW" size of the graph) equal to 3.4%.

The behavior is considered acceptable since it consists in a "border" zone of the envelope of machine operation. The sea states encountered from the end of September to December 2015 are presented in **Figure 15**.

About performance in terms of productivity, the results of the testing phase were in good agreement with those obtained previously in the simulation and design phase. However, the system has worked on the island (in this first phase without the connection to the grid due to the lack of the underwater cable) with the presence of only one gyroscopic and the tuning phase has taken place into the sea so the production, in this first experimental phase was limited.

At this moment the prototype is in the process of completing the upgrade procedure and currently has received the addition of the second gyro group and the installation of the electrical infrastructure (submarine cable and connection to the grid). Soon there will be a new launch, and the second test phase will therefore begin.

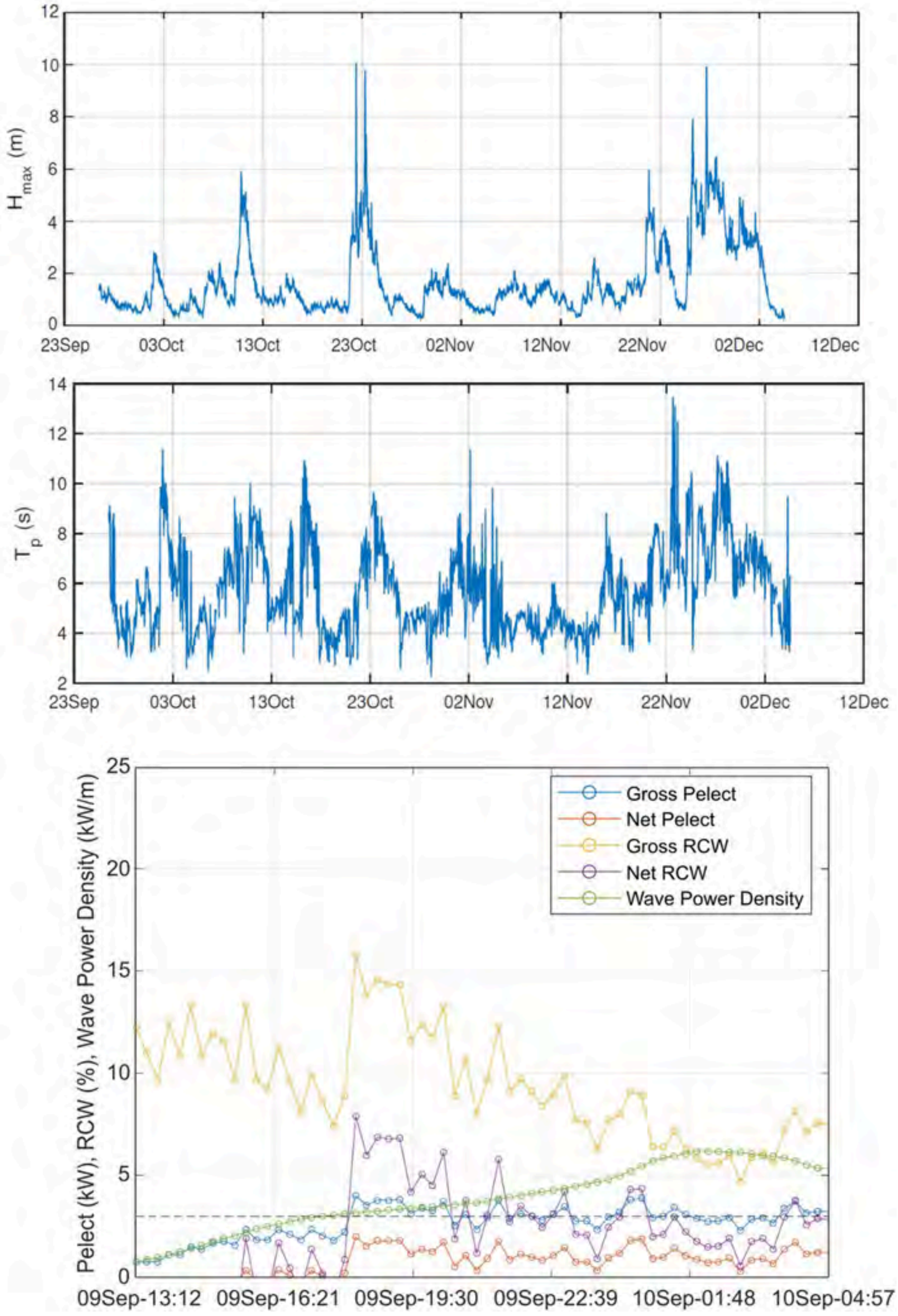

FIGURE 15 | Historical data of sea states encountered between September and December 2015 **(Top)**, experimental performance of ISWEC in Pantelleria **(Bottom)**.

CONCLUSIONS

The energy from sea waves remains today a very unbalanced issue toward applied research, but this application, like others already present at the prototype level in other installation sites, show how technologies are evolving toward solutions aimed at ensuring, in addition to performance, even requirements such as the safety and durability of the components. Each design choice is strongly conditioned by the future productive transferability of the devices hence the energy cost is included among the parameters to be optimized.

The Mediterranean Sea, due to the reduced wave energy potential, can be used as a cradle for more powerful seas, like the North Sea, where the wave period is comparable, but the wave height is much higher. The device tested in the Mediterranean behaves as a scaled device on a real test site, able to reproduce the full-scale system with smaller financial effort.

For some specific applications, the identified technological solutions are already competitive compared to the estimated costs of producing energy from fossil fuels. Obviously, when the sales volumes become large, it will be possible to obtain a further reduction in the cost of energy in order to offer the conversion of another renewable energy source to be integrated into the energy mix which will hopefully be the energy production of the future.

AUTHOR CONTRIBUTIONS

GM produced this review with the contribution of her reasearch team at Politecnico di Torino.

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