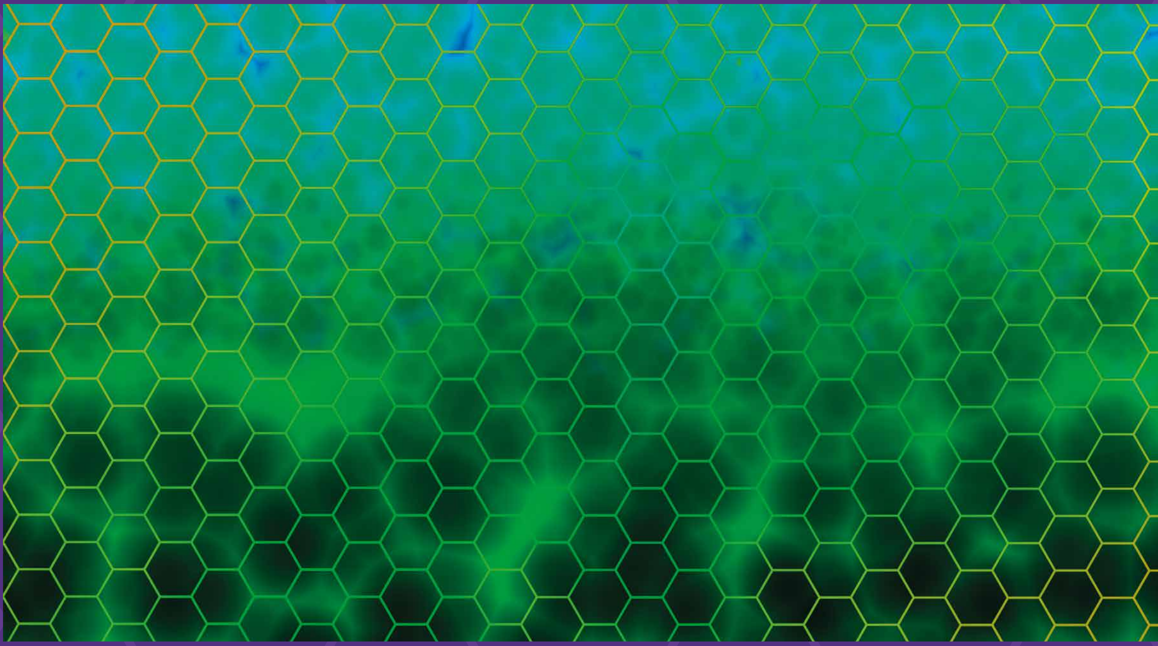
WIT Transactions on Ecology and the Environment

VOLUME 217, 2018

WIT PRESS



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WIT Transactions on Ecology and the Environment
International Journal of Sustainable Development and Planning

CATEGORIZATION AND GEO-LOCALIZATION OF MARINE RENEWABLE ENERGIES FOR THE MEDITERRANEAN AREA

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ABSTRACT

An energy transition towards renewable sources is fundamental to reach the goals established by the Paris Agreement. In recent years, marine renewable energies (MREs) are emerging as possible solutions to face the de-carbonization process. The Mediterranean area can be a hotspot for the development of Blue Energy. Understanding what Blue Energy is and which MREs could be involved in energy production processes is fundamental. In this paper, MREs will be investigated through a categorization and summarization of the more interesting existing case studies presented. The results of this investigation will be illustrated by means of a representative Web-GIS map, with the aim of showing the location of the main marine technologies in the Mediterranean area.

Keywords: global warming, Blue Energy, MAESTRALE, Web-GIS.

1 INTRODUCTION

In 2015, 195 states from around the world signed the Paris Agreement as a political response to climate change. One of the main aims of this document is to contain global warming, keeping the global average temperature below 2°C compared to pre-industrial levels, to commit efforts to not exceeding a 1.5°C temperature increase and to alleviate the possible negative effects and risks of climate change [1]. These goals imply, among others, a change in the national energy policy to reduce greenhouse gas emissions.

Alongside more traditional renewable sources (e.g. photovoltaic, wind energy, etc.), since 2014 the European Union has been promoting Blue Energy (BE). With its statement, "Blue Energy – Action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond" [2], the European Commission claims that BE is a fundamental sector to be deployed, encouraging states to pursue decarbonization paths exploiting marine, indigenous and renewable resources that advance the energy security in a sustainable way.

MAESTRALE is a European project within the Interreg MED Programme, involving 11 partners of 8 countries, whose final purpose is to lay the basis for a Maritime Energy Deployment Strategy through the investigation of legal, political, social, technological and environmental backgrounds within which BE could be developed, and through feasibility studies of 20 possible pilot technologies. The MAESTRALE research area is delimited to the Mediterranean.

The paper has three principal aims. Firstly, a categorization of marine renewable energies (MREs) will be carried out, adopting a more accurate technological perspective. Secondly, classifications proposed by the MAESTRALE project will be outlined in order to communicatee the MREs employed in the Mediterranean. Thirdly, a Web-GIS map with already implemented technologies in the Mediterranean area will be illustrated.

WIT Transactions on Ecology and the Environment, Vol 217,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SDP180361

2 DEFINITION AND CATEGORIZATION OF BLUE ENERGY (BE)

The concept of BE refers to the capacity of exploiting MREs. MRE, as affirmed by Castelos [3], is “a form of renewable energy deriving from the various natural processes that take place in the marine environment”. Thus, technologies that convert kinetic and chemical potentials or thermal properties of seawater are involved in the definition of BE. These sources of energy are generally termed “ocean energies” and derive from waves, tides, marine and tidal currents, and thermal and salinity gradients [4]. Together with these sources, MREs include offshore wind and algae cultivation.

2.1 Wave energy converters (WECs)

Wave energy derives from the wind that blows across the ocean, and once created they can travel thousands of kilometres with few energetic losses [5]. Wave energy converters (WECs) are technologies that are able to convert wave energy into a useful form, usually electricity. WECs are numerous and characterized by different features. Several categorizations have been made, based on four different criteria. The first concerns the location of technologies and their distance from the coast. In this perspective, technologies may be onshore, nearshore or offshore [6]. The onshore devices are installed on the coast, in the vicinity of ports or existing man-made infrastructures. Conversely, nearshore technologies are located in shallow water, but there is no homogeneous consensus on what depth “shallow” refers to [7]. Offshore devices, on the other hand, are installed in open-sea spaces, far from the coast, where seawater is deeper. Again, there is no comprehensive agreement on what exact depth technologies may be considered offshore, but the water depth should be at least 40–50 m [7].

The second criterion regarding WECs relates to their sea-level position, which, in turn, influences their structural installations. Indeed, technologies may be emerged, semi-submerged or submerged, and installations may be bottom-standing or floating with a mooring system [6].

The third criterion concerns the technological design and in its directional characteristics [8]. The orientation design may be a point absorber, attenuator or terminator. Point absorber designs capture the wave energy from every direction, while attenuator and terminator devices follow the wavelength and their axes are used to convert the wave energy. Each axis is positioned respectively, in parallel or perpendicularly to the wave collision with the technology [8].

The final criterion relates to the energy capture principles. Here, technologies are usually based on an oscillating water column, the Archimedes effect, overtopping, impact or a buoyant body with fixed or mobile reference principles [6].

2.2 Tidal range technologies

Tidal energy derives from the tidal movements that occur by virtue of gravitational and centrifugal forces between the earth, moon and sun [9]. Tides are predictable and repeat the same pattern daily. Devices that exploit the pressure exerted by high and low tides are called tidal range technologies [10]. To operate, tidal range technologies need a dam or a barrage in order to canalize the major quantity of water to activate turbines [11]. Tidal barrages can be located in the proximity of lagoons, rivers or wherever a tide is foreseen that differs significantly from the sea level.

The classification of tidal range technologies is based on the methods used to harvest the kinetic potential of tides – ebb, flood or two-way generation.

The method of ebb generation exploits the energy produced during the ebb phases, which occur twice a day. At the begging of the tide, sluice gates are opened in order to fill them with as much water as they can contain. Sometimes, pumps are used to increase the head difference. Then, when the optimum basin level is reached, the sluice gates are closed until the tidal level outside the gate is low enough. When the water level is lowered, the water contained in the basin is released into the sea. This mechanism subsequently activates a turbine that produces electricity.

The flood generation principle is the opposite principle of ebb generation. When the tide comes in, the sluice gates are kept closed in order to create a minimum head difference between the basin and the sea level. Once the minimum difference is reached, sluice gates are opened and water flows into the basin, activating turbines and producing electricity. The flood generation method can also produce electricity twice per day.

On the other hand, the two-way generation method is a combination of the previous techniques (ebb and flood). For this reason, the two-way technique is able to generate electricity four times per day, when water flows into the basin and when it goes out [12].

2.3 Marine currents

Marine currents are generated by winds and different thermohaline marine circulations [4]. Marine currents are predictable, but they occur with lower intensity. Among the different kinds of marine current technologies, we can also include tidal stream technologies. During the phase of ebb and flood, a flow of water in bays, harbours, estuaries and straits occurs. This flow is defined as a tidal stream. Thus, even if marine currents and tidal streams are caused by different phenomenon, they may be exploited by similar technological designs and features [4]. Since tidal streams and marine current technologies extract energy from a liquid fluid, they are compared to wind technologies. Current turbines base their design on axial-flow or cross-flow turbines [13]. Both turbines sweep through the current, tracking different areas. The first rotates parallel to the flow direction and encompasses a circular area, the second is perpendicular to the flow, so that water flows across each blade twice, and the defined area is rectangular [13].

2.4 Offshore wind

The technological principles used to extract offshore wind are the same for onshore wind technologies. The main diversities concern the foundations and the axis. Offshore wind devices capture winds in open-sea spaces and their structural design has to be adapted to the sea environment and to stronger wind speeds. Wind offshore farms can have vertical or horizontal axes (the latter are typical of onshore winds). A vertical axis is more capable of capturing wind energy and converting it into electricity. Bathymetry strongly influences the foundations of these technologies. Wind offshore devices can be fixed at the bottom of the seabed or they can float. In 2012, the average water depth in Europe was 22 m, with an average distance from the shore of 22 km. In 2016, the average depth was 29.2 m and the distance 43.5 km [14]. Thus, the general trend is to install new technologies farther from the shore and at higher depths. This condition will lead to the major development of floating technologies.

Floating wind offshore technologies can be divided into three main structural categories: semi-submersible platform, spar-buoy or tension leg platform [15]. When considering fixed wind offshore technologies, the most common structu is the monopole, but the tripod, the jacket and gravity-based structures are also used [16].

2.5 Marine biomass

Oceans and seas provide marine biomass, e.g. algae. Algae can be divided into two categories: micro-algae and macro-algae. Micro-algae are single-cell photosynthetic organisms that generate biomass thanks to solar light and inorganic nutrients [17]. Macro-algae are a series of multi-cellular, macroscopic, non-phylogenetic and eukaryotic organisms [18]. Micro-algae are divided in four main classes: diatoms, green algae, blue–green algae and golden algae, while macro-algae are classified into brown, red and green seaweed [19]. Several micro- and macro-algae species exist in nature; however, not all present the same energetic characteristics. Some algae are particularly suitable for producing biofuels. Usually, algae with a higher conversion yield contain the richest quantities of organic molecules, such as lipids and carbohydrates, which can be used to extract biofuels. More common biofuels are methane, biodiesel, biohydrogen and bioethanol [20]. Both micro- and macro-algae can grow spontaneously in fresh, brackish or salt water environments; however, the use of micro-algae foresees an alternative and productive cultivation method related to the use of photo-bioreactors, which encourage the non-selective micro-algae to grow, thus producing a greater yield [20].

Algae can be also used as feed stock for biofuel production following thermochemical or biochemical mechanisms for their conversion.

2.6 Salinity gradient

This source is based on the chemical potential that exists in terms of different salinity concentrations between salt and fresh water. Energy is produced through pressure across semi-permeable membranes. The conversion technologies work with respect to pressure-retarded osmosis and reversed electro dialysis principles. The first principles works through the separation of fresh and salty water using a membrane, aiming at creating pressures on salty water [21]. Instead of using the osmotic pressure, reversed electro dialysis is founded on the electrochemical reactions between salty and fresh water [22].

2.7 Thermal gradient

Technologies that use the thermal gradient are called Ocean Thermal Energy Conversion (OTEC) devices. OTECs deploy the difference between ocean surface and subsurface temperature [14]. OTEC can be installed on land or on a floating platform. The operational principles allow us to classify OTEC devices into three different groups, based on open-cycle, closed-cycle and hybrid-cycle mechanisms [23].

3 RESULTS

3.1 MAESTRALE project categorization

Within the MAESTRALE project, all of the aforementioned energies are referred to as BEs. Within the project, a simple categorization has been carried out in order to simplify BE for all the possible stakeholders interested in the BE field. Moreover, technologies are classified according to the most promising operating prototypes in the Mediterranean area. Thus, the technologies are categorized in the following six categories:

1. Wave energy:
   1.1. Onshore: WECs are installed in proximity to or using as infrastructures docks and breakwaters. The most common technologies used in the Mediterranean area

    include oscillating water column systems, which exploit the vertical water motion within a chamber to spin turbines by water/air pressure or overtopping technologies. The latter method gathers seawater in a top reservoir and allows it to flow down through conventional hydro turbines.

    1.2. Offshore: since the depth is high, WECs are usually employed in floating buoys that exploit the motion of oscillating bodies to push and pull pistons or drive mechanical gears. Electricity is generated through turbines or magnets within floating or underwater devices.

2. Marine currents: these technologies are constituted by submerged turbines, which are able to convert water flow of sea current into electricity. Their structures can be floating or fixed according to the sea-depth level.
3. Offshore wind farms: wind energy can be converted into electricity by virtue of a system made of a rotor and blades powered by the wind. Offshore wind farms can have fixed or floating structures.
4. Marine biomass: macro-algae can grow spontaneously or can be cultivated. Their biomass may be used to produce energy in the form of biofuels, such as bioethanol or biogas.
5. Salinity gradient: these devices work in accordance with osmosis principles and create semi-permeable membranes between salty (seawater) and freshwater (e.g. river or lagoon) that exploit the different concentration of ions, allowing the pressure to raise and the water to flow into reservoirs that spin hydraulic turbines.
6. Ocean thermal energy: these technologies use the gradients of temperature between seawater and the external air to provide a renewable source for hot–cold exchangers in order to supply building or district heating or cooling systems.

From these classifications, it is evident that tidal range technologies are excluded from use in the Mediterranean area because the tides there have very low potentials. In contrast, tidal streams can be exploited and they are considered marine currents.

3.2 MAESTRALE Web-GIS database and case studies

Within the MAESTRALE project, a Web-GIS database has been implemented in order to create a georeferenced map which is able to illustrate the state of the art technology of BEs through a visual support. In particular, on the Web-GIS database some of the most promising operating prototypes in the Mediterranean are represented (Fig. 1). Other functions of the Web-GIS map show the geography of the energetic potentials, the area subject to Natura 2000 directive and the presence of harbours or platforms.

Currently, the Web-GIS is still in an embryonic phase; however, some data may be observed. By clicking on the blue symbols in the map, it is possible to consult the technological explanation card of devices.

In the selected map, the main information that we can obtain concerns the existent prototypes or operational technologies in the Mediterranean area. Some observations can be made.

Firstly, from Fig. 1 it is possible to observe that the western Mediterranean area is proactive in the implementation of BEs. Some of the main producer countries are Italy, Spain and Portugal. Slovenia and Croatia also have a consistent concentration of technologies. However, even if the map can give an idea of the number and location of technologies, it is important to underline that there is the chance of possible deficiencies in the representation of already existent technologies or prototypes.

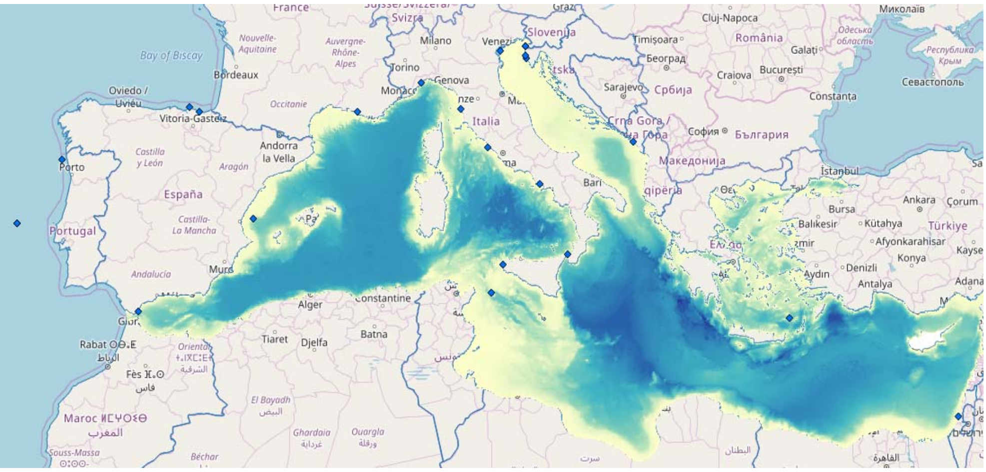

Figure 1: MAESTRALE Web-GIS database case studies representation [24].

Secondly, the presence of technologies should lead us to the conclusion that potentials in those zones should be good and exploitable.

Thirdly, the map can also give first indications about the technologies adopted. Indeed, in areas like the Gibraltar or Messina straits, it is evident that the technologies adopted regard tidal streams or marine currents. On the other hand, in open-sea spaces, the most common technologies may refer to offshore wind or wave sources.

Using the tool provided by the Web-GIS database, it is possible to investigate the most common technologies. What emerges is that Italy is oriented to develop WECs or current technologies. Similarly, Portugal and Spain are following the same path. Portugal is also active in the development of offshore wind farms. Contrarily, Slovenia and Croatia are promoting OTEC systems. This may be a symptom of weak BE potential from wave, tide and wind sources. In Greece, prototypes that simultaneously exploit wave and marine biomass have been designed. Considering Malta and Cyprus, data are not yet available on the Web-GIS platform.

The following sections briefly describe some examples of operating technologies in Italy.

3.2.1 WECs

From a screening of the case studies, it emerges that Italy's solutions in BEs are oriented towards the promotion of WECs and tidal technologies.

WECs are based on overtopping, oscillating water column energy and buoys' capture principles. Considering the overtopping system, Overtopping BReakwater for the Energy Conversion (OBREC) is a concrete top element installed in already existent breakwater structures [25]. The overtopping waves are captured in a reservoir and their kinetic force activates a turbine in order to produce electricity. An OBREC prototype is located in Naples, conceptualized and implemented by the University of Campania Luigi Vanvitelli.

Resonant Wave Energy Converters (REWECs) are another type of oscillating water column technology, created by the University of Reggio Calabria. REWEC is located in Civitavecchia harbour. It comprises 17 caissons containing an air chamber and a turbine [26]. Under the wave motion the air chamber is compressed and then decompressed. In this way, an alternate air flow is created and activates a turbine producing electricity. Considering the different types of offshore wave devices, one of the most promising may be ISWEC, designed by Wave for Energy. ISWEC is a floating body located in the Mediterranean Sea, close to Sicily. It does not need any rigid linking devices or foundations on the sea [27]. Moored at the seabed, it is able to convert wave energy into electricity by means of a gyroscope group [28].

3.2.2 Marine current technologies

In Sicily, close to the Messina strait, tides have good energetic potentials. In order to exploit the tidal energy, SEAPOWER has created the Kobold turbine. Kobold is a tidal stream turbine with floating body technology supplied by a vertical axis. The currents generated by the tide activate the turbine, thus producing electricity [29]. Besides Kobold, SEAPOWER has created another tidal stream technology named GEM – the "ocean's kite" [30]. GEM is a hydrokinetic turbine with a horizontal axis, moored at the seabed. When a tidal stream occurs, GEM aligns itself with the flow, exploiting the tidal currents to produce electricity.

4 CONCLUSIONS

MREs are an alternative and sustainable solution to the need to produce energy. Their use is encouraged in order to reduce greenhouse gas emissions. Technologies that are capable of exploiting MREs are various and work through different principles.

The MAESTRALE project aims to better communicate these innovative technologies, simplifying complex classifications and categorizations. The MAESTRALE Web-GIS map is a tool for such communication, providing a visual and quickly informative overview of the existent technologies to Web-GIS visitors.

The Web-GIS database indicates on a map the location of technologies, providing the spatial distribution of the development of BEs and of the main producer countries; however, the Web-GIS needs to be implemented with more updated data about technologies and energy potentials in order to provide more accurate information.

ACKNOWLEDGEMENTS

This research was performed within the MAESTRALE project (1MED15_1.1_M12_116) [31] and Interreg MED Programme, and was co-financed by the European Regional Development Fund.

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