Interreg
Mediterranean

EUROPEAN UNION

PELAGOS

Project co-financed by the European Regional Development Fund

Strategic Research Agenda towards innovation in Blue Energy

Promoting innovative nEtworks and cLusters for mArine renewable energy synerGies in mediterranean cOasts and iSlands

Title: **Strategic research Agenda towards innovation in Blue energy**

Programme: **MED INTERREG 2014-2020**

Priority Axis: **1. Promoting Mediterranean innovation capacities to develop smart and sustainable growth**
Objective: 1.1. **To increase transnational activity of innovative clusters and networks of key sectors of the MED area**
Project Title: **Promoting innovative nEtworks and cLusters for mArine renewable energy synerGies in mediterranean cOasts and iSlands**
Project Acronym: **PELAGOS** - Project Code No: **1373**
Lead Partner: **CRES**
Total Budget: **2,396,104€**
Time Frame: **1.08.2016-30.04.2019**

Authors: **Maria Vittoria Struglia, Adriana Carillo, Giovanna Pisacane, Gianmaria Sannino (ENEA), Colin Ruel, Patricia Marin (PMM-TVT), Celia Murcia, Jordi Solé (CTN), Hrvoje Mikulčić, Neven Duic, Hrvoje Stančin (UNIZAG FSB), Markos Damasiotis, Dimitra Barkouta, Christoforos Perakis (CRES), Athina Kokkali, Georgia Veldeki, Takvor Soukissian (HCMR), Sotiris Petrakides, Angelos Ktoris (Mar.In.E.M.), Donato Bedin, Filippo Mazzariol (UCV)**

Interested to know more about PELAGOS initiative, visit our website:
https://pelagos.interreg-med.eu/

You can also apply to become a member of the Blue Energy Cluster in the Mediterranean, 456 actors from 7 European countries are already involved: *www.be-cluster.eu*"

ΚΑΠΕ
CRES

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

UAlg
UNIVERSIDADE DO ALGARVE

CTN
marine technology centre

UNIONCAMERE VENETO

hcmr
ΕΛΚΕΘΕ

Maritime Institute of Eastern Mediterranean

PÔLE MER MÉDITERRANÉE

FSB

Table of Contents

Glossary

Array	Series of 4 or more devices experiencing wake interactions
BE	Blue Energy: it comprises Marine Energy and energy from marine bio-masses
BG	Blue Growth: EU long term strategy to support sustainable growth in the marine and maritime sectors as a w Sustainable use of ocean resources for economic growth hole
Blue Economy	Sustainable use of ocean resources for economic growth
EU	European Union
Farm	Wind/Ocean Energy Power plant composed of two or more turbine/ar-rays
FID	Final Investment Decision
FOW	Floating Offshore Wind
ICT	Information Communication Technology
kW	Kilo Watts
LCoE	Levelized Cost of Energy
ME	Marine Energy: Offshore Wind and Ocean Energy
MRE	Marine Renewable Energy
MW	Mega Watts
O&G	Oil and Gas
O&M	Operation and Maintenance
OE	Ocean Energy: energy from the ocean (wave, tidal, thermal/salinity gradi-ents)
OEE	Ocean Energy Europe
PTO	Power Take Off
R&D	Research and Development
R&I	Research & Innovation
Real sea condition	Deploy at sea, there is no control over the environment
Relevant environment	Deploy at sea, there is no control over the environment. Experiencing all the complex phenomena relevant to an ocean energy farm
SET Plan	Strategic Energy Technology Plan
SRA	Strategic Research Agenda
SRIA	Strategic Research and Innovation Agenda
TRL	Technology Readiness Level
WE	Wind Energy
WEC	Wave Energy Converter

TRL Definition

TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment (industrially relevant envi-ronment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive manufac-turing in the case of key enabling technologies; or in space)

Purpose of this document

This document contains the Strategic Research Agenda to Innovation on Blue Energy developed in the framework of the PELAGOS project (D.4.2.1). Relying on both the current Research & Innovation guidelines and priorities established at European level for exploiting in the most effective way the potential of Ocean Energy, and the knowledge acquired during the activities of PELAGOS project at Mediterranean level, this document considers the strategic focus areas related to the most promising Marine Renewables Energy technologies in the Mediterranean area.

The intervention priorities needed to support such growth potential have been identified, and the role of the Blue Energy Cluster, which is a main outcome of the PELAGOS project, has been highlighted.

An image of the first French offshore wind turbine is the Ideol's floating demonstrator Floatgen, deployed off Le Croisic on the Atlantic Ocean and equipped with a 2 MW turbine. It is delivering power to the grid, since September 2018

Credits: Ideol BYTP ECN V. Joncheray

Executive summary

The scope of this document is to capitalize the knowledge and the experience acquired during the three years of activity of the Interreg-Med PELAGOS project and to transfer such knowledge in order to focus the strategic areas and the priorities for Research & Innovation (R&I) that can boost in a more effective way the development and deployment of Blue Energy (BE) in the Mediterranean area.
Moving from the existing guidelines already stated in this sector at the European level, that by no means can be overridden, we will focus on the priorities that should be pursued on short, medium and long term for those technologies that are most promising for the Mediterranean environment. In the following of the document, we will refer to BE as to the complex of Marine Energy (ME) that has been the subject of the activities of the project. ME usually comprises offshore wind energy as well as 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).
In our opinion, a fair evaluation of such priorities must take into account both the Mediterranean marine energy resource potential in view of future local energy harvesting, and the already existing critical mass of research groups, spinoffs and start-ups involved in technology development, as well as in environmental protection research, that in any case will contribute to the worldwide European leadership in the renewable energy sector.
Relying on these observations, and on the past knowledge gained during the project activities, particularly the state of art of Marine Renewable Energy (MRE) technologies, the assessment of Mediterranean marine energy resources potential, the regulatory status across the partner countries and the current status of demonstration projects, which must be considered forming part of this document[1], we will consider with particular attention the following main technological sectors: offshore wind, wave and tidal stream".
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 analogues. Moreover, stronger and less disturbed winds are available offshore compared to on-land. The only commercial offshore wind farms use fixed foundations, and the first ever authorized farm in the Mediterranean will be deployed in Italy (Parco Eolico di Taranto).
On the other hand, floating offshore wind energy is a breakthrough innovation market that appears to be the one offering the strongest market potential in the short and medium term. Floating offshore wind technology appears to be particularly suitable for the Mediterranean (continental shelf, high depth). In the Lion's Gulf, that is the area in the Mediterranean where the maximum wind conditions are reached, 3 pilot sites have already been selected to host pilot projects of floating offshore wind farms by 2021. The first French offshore wind turbine is the Ideol's floating demonstrator Floatgen, deployed off Le Croisic on the Atlantic and equipped with a 2 MW turbine. It is delivering power to the grid, since September 2018.
Wave energy converters derive energy from the movement of waves. Energy output is determined by the height and period of the waves. Wave energy converters can be placed in different areas – on the shoreline and in ports, where they can act as breakwaters, near shore, typically in depths less than 20m, or offshore in greater depths. A wide variety of devices exists, ranging from TRL3 to TRL7. Further technology development, testing and demonstration are essential for this sector.

[1] Documents available at: *https://pelagos.interreg-med.eu/what-we-achieve/deliverable-database*

Tidal stream converters harness the flow of the currents to produce electricity. Energy output is determined by the speed of the currents. Tidal turbines can be fixed to the seabed or floating. Few locations in the Mediterranean have enough potential for an efficient harvesting, mainly in the largest Straits of Gibraltar and Messina. However, the technology has reached a quite advanced level of development and a number of devices have undergone full-scale testing and the first tidal farms have been deployed and connected to grid in northern Europe by the end of 2016.

We identified cross-cutting and single technology objectives, actions, relevance and priorities, that are discussed in dedicated paragraphs and summarized in tables at the end of each paragraph.

In general, the environmental concern, the social acceptance and the integration of MRE in Maritime Spatial Plans are common priorities for all technologies, while among the technological priorities the development of mooring systems is a common issue. This is not surprising considering the particular morphological and bathymetric characteristics of the Mediterranean Sea.

From a more technical point of view, the current survey shows that in all MRE sectors, (offshore wind, wave and tidal) the situation has similar characteristics.

There is a large variety of concepts, the resulting competitiveness represents an added value fostering faster improvement of the technologies, but on the other hand it slows down the achievement of standardization goals.

The main conclusion is that the whole sector needs to focus on those concepts that can ensure scalability and industrialization.

Given the current status of development (mostly around TRL6-7), the access to programs and facilities for the testing of devices in operational environment is capital to finally prove performance, survivability and reliability and it is necessary for the selection of “winning” technologies. In any case, an effective development of MREs cannot do without adequate investments. Actually, fund raising mechanisms remain an open challenge for all the sectors involved, even for those now at pre-commercial stage. Therefore, an adequate fraction of public investments in the field remains essential.

The transnational Blue Energy Cluster, built in PELAGOS based on the 4-helix model and involving SMEs, academia/research community, governmental bodies and the civil society, can play a role in the achievement of the proposed objectives, by promoting the desirable synergy between all its members that can boost MREs development at Mediterranean scale.

1 Introduction: European and transnational frameworks

1.1 The European Energy Union policy and the Strategic Energy Technology Plan

During recent years, the EU has progressively intensified its coordinated efforts to finally achieve the Energy Union's targets, which ensure a safe, viable and accessible to all energy supply.

The EU's Energy Union Strategy is made up of five dimensions: energy security and diversification, a fully integrated internal energy market, energy efficiency, the decarbonisation of the economy and the development of research, innovation and competitiveness.

Climate change challenges and the consequent decarbonisation objective have been important driving factors of the EU re-thinking of energy consumption, distribution and generation as whole.

According to the new rules on governance of the Energy Union, EU countries are required to develop integrated national energy and climate plans that cover these five dimensions for the period 2021 to 2030.

On 30 November 2016, the Commission published a proposal for a revised Renewable Energy Directive to make the EU a global leader in renewable energy and ensure that the target of at least 27% renewables in the final energy consumption in the EU by 2030 is met.

The Directive specifies national renewable energy targets for each country, taking into account its starting point and overall potential for renewables.

Since June 2018, the European Union revised these targets, and the share of renewable energy by 2030 has increased to 32% compared to the 27% originally proposed by the Commission in 2014. This is binding and will be subject to a revision clause in 2023.

According to this policy, the European Strategic Energy Technology Plan (SET Plan) aims to accelerate the development and deployment of low-carbon technologies, and among the available renewable sources, special attention has been devoted to both Ocean Energy and Wind Energy.

The SET Plan Implementation Plans for Ocean Energy and Wind Energy are both aimed to identify the challenges that these two sectors must face to reach fully industrial and commercial stages, and to address the technological, financial and environmental actions to be undertaken, as well as the timeline of such development.

The SET Plan Implementation Plans for Ocean Energy and Wind Energy identify the common targets to be achieved in the next years that are mainly the reduction of the Levelized Cost of Energy (LCoE) and the reinforcement of the European industry in these sectors.

Specific targets for the OE sector are:

1. to bring ocean energy to commercial deployment,
2. to drive down the LCoE,
3. to maintain and grow Europe's leading position in ocean energy,
4. to strengthen the European industrial technology base, thereby creating economic growth and jobs in Europe and allowing Europe to compete on a global stage.

For the LCoE of tidal stream and wave energy, quantitative targets were set:

- 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.

On the other hand, being the offshore wind sector at a more mature technological development level and having reached commercial status, the specific targets are:

1. to reduce the LCoE at final investment decision (FID) for fixed offshore wind by the improvement of the performances of the entire value chain to less than 10 ct€/kWh by 2020 and to less than 7 ct€/kWh by 2030;

2. to develop cost competitive integrated wind energy systems including substructures which can be used in deeper waters (>50m) at a maximum distance of 50 km from shore with a LCoE (the costs for delivering the electricity to onshore substations are taken into account within the levelised cost of electricity) of:
- less than 12 ct€/kWh by 2025
- less than 9 ct€/kWh by 2030, striving towards cost competitiveness.

In order to meet such objectives of LCoE reduction, the Set Plan Temporary Working Group recognized the necessity to combine the development of technologies (learning by innovation) and their deployment for mass production (learning by doing).

In order to achieve the development and deployment requirements outlined above there are also different forms of financial supports required during the different phases. In the earlier phase, there is a need for the "Technology Push" through mechanisms such as grants to stimulate the technology development to pre or early commercial stage. At that stage, it will be necessary to device support strategies that incentivise wider scale deployment, with particular attention to the supply chain development, ultimately targeting the LCoE reduction required for fully commercial stage.

1.2 The European Strategic Research Agenda for OE

Once it is recognised the fundamental role, played by the Research and Innovation community to meet the goals of LCoE reduction, it is capital to orient its activities defining the priorities to be pursued, especially for OE which has not yet gained the strength of a fully commercial sector.

The first ever European Strategic Research Agenda (SRA) for Ocean Energy has been delivered by TP Ocean on November 2016.

The SRA identifies challenges and defines research areas, prioritize the objectives and settles the actions to be undertaken in a transversal way, across all possible technologies.

A direct impact on LCoE reduction is given by increasing yield, which ultimately depends on appropriate performance (how much power is produced in certain ocean condition), survivability (ability to withstand extreme events) and reliability (ability to generate power when required) of the prototypes at demonstration and pre-commercial stage. The above-mentioned characteristics for a particular device may be verified only when it is placed in operation in the sea and the operation of full-scale devices in relevant environment is a prerequisite to the commercialization.

TP Ocean SRA focuses on four research themes, each one divided in priority areas, objectives and actions. Three degrees of priority have been given to these areas, according to their relevance: low, medium and high. Table 1 synthetizes these outputs, showing the relevance assigned to each one of the twelve priority areas, grouped under the corresponding main research theme.

Research theme	Priority area	Priority degree
Demonstration, Testing and Modelling	Deploy demonstration projects to generate learnings necessary for commercialisation	***
	Technology development through validated numerical models and small-scale prototypes	**
Materials, Components and Systems	Develop high quality seaworthy materials	**
	Condition monitoring systems to optimise operation and maintenance	**
	Validation of components and sub-systems	***
	Increase yield with improved power take-off	***
	Control systems to increase reliability and survivability	***
Installation, Logistics and Infrastructure	Access to ocean energy sites, design adapted processes and vessels	**
	Reduce uncertainty, risk and cost of foundations, anchoring systems and cables	***
Non-technological issues	Building a case for investment, including LCoE analysis	***
	Standards, health, safety and environment	**
	Develop manufacturing expertise for OE	*

Table 1: Research themes, priority areas and corresponding degree of priority for OE, as indicated by TP Ocean SRA

1.3 The BLUEMED Strategic Research and Innovation Agenda

Recently, in parallel to European strategies, several initiatives of coordination among the Mediterranean Countries have been taking place. The BLUEMED Initiative collects countries around the Mediterranean, supports and facilitates cooperation and coordination, not only among EU Members, in order to promote the blue economy, while protecting the environment and the fragile ecosystems that it hosts. In this framework, the BLUEMED Strategic Research and Innovation Agenda (SRIA) is a document designing a shared pattern to foster blue growth in the Mediterranean area.

SRIA identifies several challenges under three pillars: knowledge enablers, economy enablers and technology enablers. Among all the challenges, many are related to MREs development.

Under the economy pillar, the role of Maritime Clusters is recognized for the promotion of emerging markets, including offshore wind, and the need of including MREs while planning the use of Maritime Space is explicitly addressed. In particular, the following issues have been highlighted in order to promote MREs in the energy transition phase:

- to develop tools to evaluate and select optimal zones for the implementation of MREs farms with a multi-criteria approach;
- to develop MRE sub-systems for energy transition and identify guidelines for their sustainable operation involving both submarine (benthic) and subaerial environmental/ecological impacts;
- to develop large demonstration projects to sustain commercial MREs development, including Floating Offshore Wind Turbine which is particularly relevant in the Mediterranean.

Under the technology pillar instead, several technologies have been classified as relevant for the sector, including:

- Information Communication Technologies-ICT;
- technology design tools for MRE: impact of biofouling on components, behaviour of structures/components in

fatigue, innovative monitoring strategies, anchoring;
- digital tools to characterize and analyse interactions between all stakeholders and the environment, habitat modification, characterization and modelling of biofouling, contextualization of impacts related to MRE;
- development of appropriate methods to manage and exploit bio-resources in the vicinity of MREs plants;
- study and improvement of MRE projects acceptability through an enhanced knowledge of their environmental interactions and a thorough multidisciplinary evaluation including socio-economic dimension.

However the SRIA does not assign different priorities to the different challenges.

1.4 The wind energy Strategic Research and Innovation Agenda

Wind Energy (WE) sector has historically been at the heart of the European energy transition, and it offers a paradigm of how to bring new technologies to market and to reach competitiveness with other commercial energy resources. An appropriate plan of Research & Development accompanied by public support, proper financing tools and incentives are the key.
Although onshore wind energy is currently the cheapest renewable resource, it still needs support and a stable market outlook to fully mature.
To this end, the WE-SRIA has been recently updated and it outlines the cross-sectoral research priorities that should be fostered by public support. The document deliberately discards all those sectors where industry can carry out the research by its own means (e.g. turbine technology) and focuses on 5 Research and Innovation Priorities:

- Grid and System Integration,
- Operation & Maintenance,
- Next generation technologies,
- Offshore balance of plant,
- Floating wind.

Four cross-cutting themes were also identified: digitalisation, electrification, industrialisation and human resources.
Digitalisation deals with the best use of the huge amount of data that are already produced by operational plants and that aren't fully exploited. Such data could be mined with appropriate data analysis tools and would be valuable for O&M purposes, being of help in view of optimal lifetime management strategies of the devices. Moreover, data-sharing with research institutes could disclose new discoveries, albeit the necessary protection of sensitive data.
Industrialisation is needed in order to achieve economies of scale of the sector and further reduce the cost of production. Despite of the relevance of WE in the renewable energies sector, there is still a strong customization of the projects and a propensity to manufacturing rather than to an industrial standardization. So public funding is encouraged for projects that will:

- Enhance collaboration between all the different stakeholders in the value chain;
- Create common market requirements to trigger cost and time savings;
- Develop cross licensing as in other industries;
- Proactively encourage project-based collaboration.

Electrification would lead to avoid carbon intensive energy use by sectors like industry, heating and transport, thus contributing to the achievement of the European decarbonisation objectives. This goal demands for the ability to deal with the variable generation of renewable resources and its matching with the demand, finally by means of new grid solutions.
Last but not least, the further development of the sector and the new problems posed by those plants that will approach in the next few years the foreseen lifetime end, will require new skilled jobs and qualified human resources.

Differently from the preceding version of SRIA, floating wind is notably become a separate pillar due to its enormous potential, to the maturity of the sector and to the specific Research & Innovation needs. However, many different concepts of floating rotors and platforms exist, and the sector needs to focus on those of them more promising in terms of scalability and industrialization.
The key action areas identified by the WE-SRIA for the floating wind sectors are:

- Holistic floating wind turbine system design;

- Development of sectoral synergies (multi-use);

- Establishing a supportive regulatory framework for floating wind power plants;

- Development of a stable supply chain;

- Preparing floating wind for market uptake and wide scale deployment.

2 Strategic focus areas

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). In particular, The Occitanie Region plans to be a positive energy region by 2050 with 1.5 GW of Floating Offshore wind by 2030, and the SUD PACA Region to have 1 GW of Floating Offshore wind by 2030, overcoming the current French national multiannual energy program, which is below these objectives. However, such national objectives can be reviewed by the final decree.
The potential contribution of ocean energy to future energy budget 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, 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. Stepping up the role of OE 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). As a matter of fact, as highlighted by OEE (Ocean energy project spotlight - Investing in tidal and wave energy, March 2017), alongside utility-scale deployment, ocean energy devices plug into local and isolated energy markets. Smaller-scale wave or tidal energy devices can already compete in systems using diesel generators: meeting the power demand of an island, powering a desalinisation plant or fish farm out at sea. Moreover, out of 10 worldwide wave and tidal energy projects listed in the latter document, one is at work in the Mediterranean Sea, precisely at the Pantelleria Island, and is managed by Enel GP.
In this context, the Mediterranean Sea has been proved to offer substantial opportunities for both significant energy production (Zodiatis et al., 2014, Besio et al., 2016, Monteforte at al., 2015, Soukissian et al. 2017b) and technological development. The latter is mainly favoured by the milder climatic conditions with respect to the North Sea and the Atlantic Ocean, as it allows 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 (Witt et al., 2012, Margheritini et al., 2012).
The PELAGOS project offered an observatory across the whole Mediterranean, involving partners from countries with very different approaches to the matter and different interests.
France and Spain have also access to the potential of Atlantic Ocean that is by far privileged in the current activities of R&D in the MREs sector in these countries. Six bottom-fixed offshore wind farms are under construction in France in the Atlantic Ocean and there is one additional development zone in Dunkerque.

The results of this last call are scheduled for March 2019 with a price per MWh <70 €.
Floating offshore wind turbines will be tested both in the Atlantic Ocean and in the Gulf of Lions.
In the short term, the costs of electricity produced by offshore wind turbines seem to be of the order of 13-15 ct€ / kWh, in line with the European target of LCoE. This fact gives a dominant position to this type of technology with respect to others (wave and tidal) that will reach maturity only in the medium and long term. Although many subjects are involved in research and experiments on blue energy technologies, France focuses its innovation potentials for the Mediterranean Sea on offshore wind technologies.
Due to its geographic location with both Atlantic and Mediterranean coasts, Spain is a prime location for the development of Blue Energy as reflected by the number of projects developed during the last decade, not only at an experimental stage, but also at an operational stage.
Spain is particularly interested in exploiting offshore wind energy, tidal current energy and wave energy but mainly along its Atlantic coasts. Currently, Spain counts on several projects in the BE sector going from final demonstration state to concept. Specifically for the OW, the projects Elican, Nautilus and WIP10 are worth to mention. The first one, started in 2016 in Canary Islands, aims to upscale the Elisa project to the final demonstration state of the technology by the construction of a real scale fully operational offshore wind turbine in open water, in the PLOCAN area.
The latter two projects, started in 2016 in the Basque Country and in 2018 near Malaga respectively, deal with new technical solutions for floating structures.
The MUTRIKU power plant, operational since 2011 in the Basque Country, harnesses energy form waves and may provide around 500 MWh/year, while a prototype of a buoy which will take the energy from the wave oscillating movement has been developed in the framework of the project OCEANTEC OWC, also in the North Coast of Spain.
On the other hand, R&D in the countries bordering the Mediterranean alone has been oriented in developing technologies most suitable to the exploitation of locally available resources, thus fostering either the development of WECs and tidal current devices mainly in Italy or floating offshore wind farms in Greece.

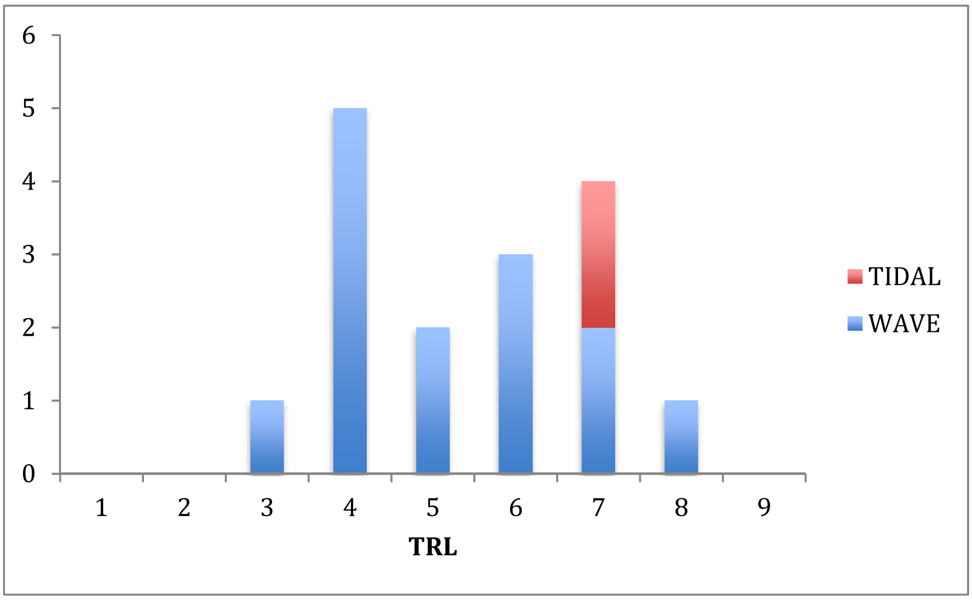

Figure 1: Histogram representing the total number of devices at different TRLs in Italy. Red: 2 devices at TRL7, blue: 14 devices at TRL 3-8

Only in Italy there are sixteen different devices designed for harnessing OE at TRLs ranging from 4 to 8 (elaboration from Sannino and Pisacane, 2017).
Most of them are WECs and two are tidal current devices, five projects out of the total are at a quite high level of development, i.e. demonstration and pre-commercial level. An important number of projects are at TRL 4, thus signifying the vitality of the sector, and that will hopefully increase their TRL in next years.
On the other hand, offshore wind energy is also a viable option in Italy, where the first approved project of offshore wind farm is under construction near Taranto, and where the Adriatic Sea offers the potentiality for fixed foundation wind farms due to its moderate depth as well as the possibility of taking advantage of already existing O&G platforms under decommissioning phase.
Wave energy technologies are also of interest for Cyprus that has recently made a liberalization plan of the electricity market that includes a contribution of 30MW of electrical energy from waves. Considering resources availability, floating offshore wind can also be an option for Cyprus in order to meet the targets regarding the share of energy produced from Renewable Energy Sources (RES) by 2020, fixed at 13% contribution from RES as a final use of energy and 10% contribution from RES in the road transport consumption.
Moreover, efforts have been undertaken towards the implementation of MRE technologies in the national action MSP.
According to this analysis, it results that offshore wind farms, either fixed or floating, are of common interest to all the PELAGOS partners' countries, among all the MREs technologies taken into account, with the great appeal of having reached or being very near to meet the targets of LCoEs, boosted by the long experience and technological development reached by onshore wind technologies. On the other hand, also the Wave Energy Converters sector has been gaining importance, currently reaching in most cases the pre-commercial status.
We conclude that these MREs have the potential of development in Mediterranean and are at the core of many services offered by PELAGOS, and the Blue Energy Cluster activities mainly focus on them.
In the following, we describe their current status of development and we make some considerations moving from general to more regional perspectives.

2.1 Offshore Wind

The cumulative connected European offshore capacity grew by 18% in 2018, reaching 18,499 GW at 31.12.2018 (4543 units connected in 11 countries: the UK represents 44% of the total capacity, followed by Germany at 34% Denmark, 7%, Belgium (6.4%) and the Netherlands (6%). Moreover, according to industry sources, there are 25 GW of consented offshore wind farms identified, and a further 65 GW of planned offshore wind farms are in the pipeline. According to the last position paper by WindEurope, the association of wind industries, onshore wind is today the cheapest new power generation technology in Europe in terms of Levelized Cost Of Energy (LCOE), whilst offshore wind holds the potential to become competitive with conventional technologies by 2025 depending on deployment volumes. The reduction of costs of offshore wind energy seems to be among the key priorities of wind industry.
However, with respect to Northern European Seas where the resource is abundant and accessible, only the Aegean Sea and two areas located south of France and Spain appear to be the most suitable areas for offshore wind deployment in southern Europe. See for instance, Boero et al. 2016, Soukissian et al. 2017a, Soukissian et al. 2017b. An overview of the MRE status in the Mediterranean Sea is presented in Soukissian et al. 2017c.
Regarding the available offshore wind energy technologies, they can be divided in two large groups depending on the type of foundation adopted, either fixed or floating, each one being further divided into sub-groups, according to their specific design.

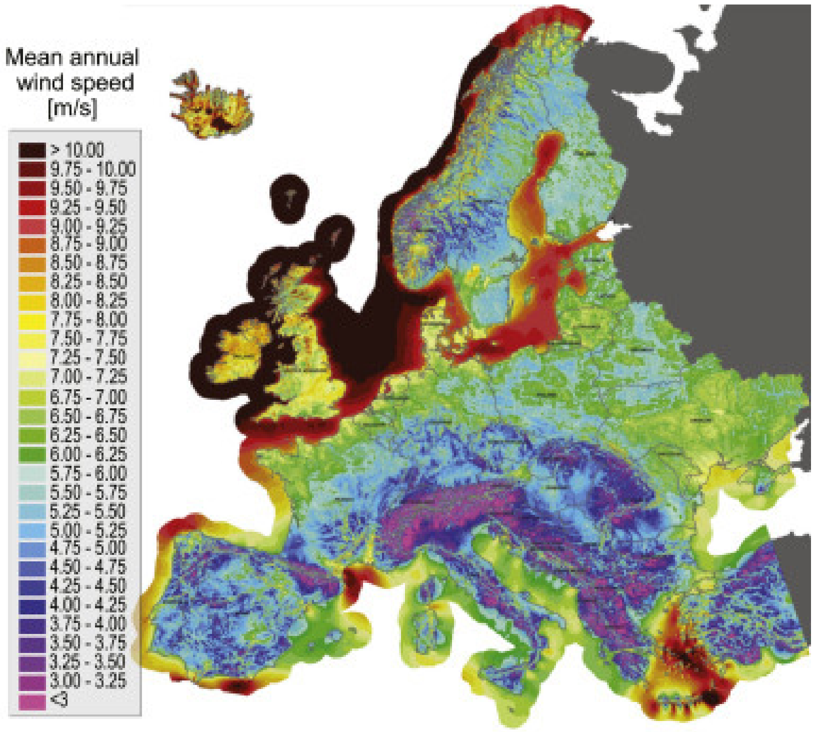

Figure 2: Annual European onshore and offshore mean wind speeds at an 80 m height

(AWS Truepower: https://aws-dewi.ul.com/knowledge-center/maps/)

As the industry evolves, offshore wind farms are built further from the coast and in deeper waters, mainly based on floating platform designs. Floating offshore wind on the other hand, is a breakthrough innovation market that appears to be the one offering the strongest market potential in the short and medium term. Floating offshore wind appears to be particularly adapted to the Mediterranean (continental shelf, high depth) as for example in the Gulf of Lions where wind is particularly high and persistent.

2.2 Wave Energy

The R&D activity in the wave energy sector started in the 1970s; however, the development of wave energy technologies has not yet reached the same degree of maturity of that of wind and tidal energy. The largest amount of wave energy is found at latitude higher than 30° in both hemispheres. In the Northern Hemisphere, the most energetic areas are found in the Atlantic Ocean, reaching the European coastline facing the Atlantic Ocean.

A study (Mørk, 2010) estimates that the total theoretical potential of wave energy is 32,000 TWh/year, about twice as high as the global electricity supply (17,000 TWh/year in 2008), which means that wave energy could cover the global demands on electricity.

While Western and Northern Europe theoretical potential of wave energy is 2800 TWh/year, Mørk does not include a relevant figure for other EU areas. In Liberti et al., 2012, the wave energy resource assessment for the Mediterranean is presented.

Although the Mediterranean Sea offers a lower level of wave energy with respect to Atlantic Ocean, it presents a potential for future development.

Despite this huge potential, the cost of wave energy is not yet competitive with respect to other renewable sources.

The central H2 scenario for 2015 estimates the LCOE of wave energy at around $ 500/MWh, whilst cost of other renewable energy sources are, for example, $ 174/MWh for offshore wind, $ 122/MWh for crystalline silicon photovoltaics, $ 83/MWh for onshore wind and $ 70/MWh in the case of large hydroelectric power.

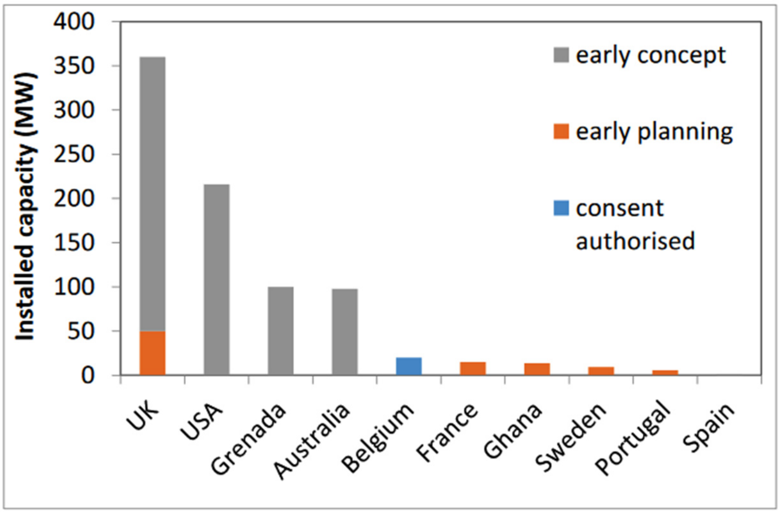

Figure 3: Wave Energy Installed Capacity in Development

(World Energy Council, 2016)

However, such costs are expected to halve for 2025, and to further decrease for 2030 and 2035 according to the targets set by EU (SET-Plan OE Implemetation Plan).
Worldwide several wave energy projects are under construction.
In 2016, 838 GW of wave energy projects in total were currently at different stages of development, of which only 20 MW of this had received authorised consent relating to a project at Mermaid/Bligh Bank in Belgium. In addition, there is 94 MW at the early planning and 725 MW at the early concept stage. Portugal's 5.6 MW SWELL project north of Peniche Peninsula was also at the early planning stage and planned to be consisted of sixteen 350 kW oscillating Wave Surge Converters.
Figure 3 summarizes this information.
At European level, only a handful of commercial wave energy projects has been delivered, reflecting the current immaturity and high costs of these technologies, as well as the challenging market environment in which they operate. In particular, one wave energy array commercial project accounting for 3 MW of capacity is operating in Sweden.
Another wave energy project was installed at the port of Heraklion in Crete (Greece) (www.mistralmaritime.eu). The project is located on the outer side of the jetty, at the edge of the port. It consists of two units of wave-to-electric power conversion that are fixed with metal bases in the breakwater, while next to them there is the base of the first unit that operated for about 2.5 years from 2015.
In the Atlantic Ocean, other wave energy projects are at different stages of development, with several prototypes currently undergoing the testing phase (GEPS Techno, PIWEC of PYTHEAS Technology, BILBOQUET of D2M).
In the Mediterranean Sea, the milder climatic conditions demand for ad hoc design of the Wave Energy Converters that currently reached in most cases the pre-commercial status.
Wave energy devices are broadly located in three different ocean environments: onshore, near-shore and offshore, their relative strengths and weaknesses are described below:

- Shoreline devices - integrated into a natural rock face or man-made breakwater having the advantage of both being close to the utility network and contributing to energy supply of the hosting infrastructure, and of a relatively easiness of maintenance. Less likely to be damaged as energy is lost due to friction with the seabed, on the other side the potential resource that could be captured is reduced.

• Near-shore devices - located in water shallow enough to allow the device to be fixed to the seabed either via pinned pile foundations or gravity mass, this in turn provides a suitable stationary base against which an oscillating body can work. Disadvantages are similar to shoreline devices.

• Offshore devices - located in water tens of metres deep and tethered to the sea bed using tight or slack moorings mass. Much greater potential energy resource versus near-shore but more difficult to construct, operate and maintain it must be designed to survive to more extreme conditions. However, they present the advantage to contribute to the attenuation of incoming waves, thus representing a protection measure for the coast.

This potential versatility of WECs and their visual impact lower than that of offshore wind farms make them interesting for the Mediterranean environment and for small islands in particular, where the touristic fruition of the locations must be also preserved.

2.3 Tidal Stream

Tidal stream turbines harness the flow of the currents to produce electricity. Tidal turbines can be fixed directly to and mounted on the seabed, or tethered/moored to the seabed and buoyant, floating on surface or in mid water. A number of device designs are at a late TRL stage and are feeding electricity into the grid in real operational environments – both individually and as arrays.

The energy potential of tidal currents is typically located in areas with the greatest tidal range. In the Mediterranean area the greatest potential for tidal energy is in correspondence of the main Straits: Gibraltar, Messina and Dardanelles.

At the end of 2016, Europe had 13 MW of installed tidal power capacity. Total of 21 tidal turbines were deployed in European waters at end-2016, while construction was in progress on 20 more with a combined capacity of 12 MW.

The ocean energy industry sees 100GW of tidal and wave capacity being built in Europe by 2050, providing 400,000 jobs and supplying 10% of the EU's current electricity needs.

France has one of the best tidal resources in Europe, a workforce with engineering skills, and coastal supply chains ready to service the deployment of this new industry.

The LCOE for early arrays (arrays of 10 MW following the first 10MW of installed capacity) ranges between 24–47 c€/kWh for tidal, whereas other established technologies range 8–15 c€/kWh. A lower LCOE is expected to be achieved through technological improvements and risk reduction.

Based on the Bloomberg New Energy Finance 2015 LCOE analysis of various technologies, the central H2 scenario for 2015 estimates the LCOE of tidal at approximately $440/MWh.

2.4 Multifunctional platforms

In the framework of this document, aimed to focus on the priorities of R&D for ME in the Mediterranean area, it is also worth to mention the potential of application of these new technologies in multifunctional platforms, whose importance has also been acknowledged by the last SET-plan.

Synergies between sectors, uses and activities are considered appropriate for the improvement of the operational and spatial efficiency. Under this framework, multi-use platforms could contribute to the achievement of the intended sustainable and efficient use of maritime space. Their combinations mainly include offshore structures (fixed or floating) or wave energy generation devices with the development of aquaculture and synergies with the oil and gas sector.

Several combinations are possible by including the sectors of OWF, wave, aquaculture, fisheries and O&G decommissioning, paving the way to a "Blue Growth" approach.

Up to now several European projects have dealt with this topic and pilot projects have been developed. Among them, the MUSES, MARINA, ORECCA, TROPOS, MERMAID and H2OCEAN projects have elaborated scientific, policy and socio-economic issues on synergies among different maritime economic sectors (wind, wave, aquaculture, maritime transport, leisure and oceanic observations).

3 Challenges and Intervention priorities

3.1 Cross-cutting themes

Basing on previous analysis, only three main categories of MREs result to be of interest in the Mediterranean: floating offshore wind, wave and tidal stream.

So we will separately consider their research and development priorities, although some common features must be highlighted.

The deployment of full scale devices in real sea conditions is a crucial phase to reach, in order to prove performance, survivability and reliability of any technology, and requires as a first step the identification of suitable test sites and then that of new sites for energy exploitation, as well as the development of adequate infrastructure and logistics in order to manage the operational devices within affordable costs.

No matter which technology is considered, an effort in environmental impact studies is necessary in order to define a common and standardised approach aimed to both make the best choice for new installation sites and to monitor the effects on the environment during the operation phase. To this end, one priority is the development of multi-criteria indexes, taking into account physical and biological stress factors, to be included in the implementation of Decision Support Systems. Such evaluations must base upon environmental vulnerability as well as upon existing pressures due to other human activities. The establishment of specific regulatory framework for MREs and its inclusion in the Maritime Spatial Plans (MSPs) is indeed a priority. The development of multi-purpose platforms in this framework would invigorate the enhancement of synergies among different economic sectors and the share of maintenance costs.

In this view, applications of habitat mapping studies, remote sensing technologies, algorithm development, database development supported by Geographical Information Systems (GISs), are all areas of interest for R&D in this context.

Adequate knowledge transfer and knowledge exchange are relevant at all levels and the development of common platforms for sharing data and high education programmes have been identified as needs. School education and awareness campaigns are also important in order to increase social acceptance of new technologies.

Another important issue, strongly linked to the aforementioned priority of optimal site identification, is to promote the facilitation of significant, cost effective commercial scale deployments in order to enhance the connections of Blue Economy businesses and high-tech clusters with the traditional know-how-based industries. Co-location of devices can bear large benefits with respect to infrastructure and represents an important opportunity over the short term with benefits from joint utilization of electrical infrastructure and potentially of O&M teams, vessels and infrastructure. It is important to find out the principal "hotspots" where a large amount of high intensity combined resource exist (wind and wave). Although combined platforms are at a conceptual phase and need further research and modelling, they constitute a cutting-edge issue of deployment facilitation.

Ports and harbours are also high eligible locations for the realization of deployment test sites, for different technologies offering at least infrastructure connections when not directly hosting onshore devices in existing constructions. For instance, ELEMED project (*https://www.elemedproject.eu/*) examined the importance of MREs for improving ports' operational energy needs as well as air quality in ports and adjacent coastal areas (for the case of Greece, the port of Piraeus and the port of Kyllini were used as case studies). A feasibility study regarding the available wind power potential combined with offshore and onshore solar energy in the ports of Piraeus, Kyllini and Limassol (Cyprus) was performed and the results were quite encouraging.

Moreover, according to the results of the EL-EMED project, ports may become the on-shore hubs for offshore wind energy-based system (including infrastructure connection, manufacturing sites, and operational centres for construction and maintenance of off-shore wind). Similarly, ports and their infra-structures could be used as HUBs also for other offshore MREs installations, as in the case of the Pantelleria Island project.

During July 2018 The MISTRAL test site oper-ated by France Energies Marines was inau-gurated off Fos sur Mer (SUD PACA Region). It is currently equipped with a buoy with many sensors and a LIDAR. It will be used shortly for environmental observation as part of the deployment of the Floating offshore wind.

As a main advantage, the integration of MREs in the electrical power supply systems may contribute to the electrification of ships and other harbour works. To this end, it is particularly relevant the promotion of smart grids for managing all energy sources (re-newable and non-renewable).

Advancements in this field will introduce au-tomations in energy management of off-grid small islands that suffer from instability of the RES grid due to constant change of weather, leading to an improved quality and increased capacity of the energy offered (e.g. less blackouts, reduction of energy cost and of energy loss, etc.). Automation will also al-low for an increase of the market penetration of renewable energy sources – including ma-rine renewable resources – in these areas.

The Mediterranean Sea is characterized by a steep bathymetry that imposes the use of floating devices for offshore energy harvest-ing.

Adequate and innovative mooring and an-choring systems are therefore high-level pri-ority issues for the SRA of the Mediterranean Sea.

Development of new environmentally friendly materials for coating and in general advancements aimed to improve survivabil-ity is of course highly desirable even in a milder climate such the Mediterranean one.

Last but not least, energy storage should be placed among the urgent priorities transver-sal to all technologies, as RES are character-ized by a variable production that limits high levels of penetration of this energy in the market.

According to the thematic and priority areas already identified at European level by the TP Ocean SRA, we summarize the above consid-erations, specialized for the Mediterranean Sea, in Tables 2, 3, 4 and 5, each table focus-sing on one of the specific research themes described in the TP Ocean SRA.

Based on the experience of each project partner and capitalizing the results and out-puts of the current project, we highlight the overall objectives to be pursued and we sug-gest (of course not exhaustively) the actions that should be undertaken in order to meet the objective goals.

The degree of relevance (high, medium and low) is given as well as a prioritization index on the short, medium and long term consid-ering the current status of maturity of tech-nologies and/or knowledge.

Research theme	Priority areas	Objectives	Action	Relevance	Priority
Non-technological research priorities	Standards, Health, Safety and Environment	Continuous Environmental Monitoring at all stages of MRE development (design, construction, operation, decommissioning)	Habitat mapping	***	Medium
			Use of satellite data	**	Long
			Multi-criteria indexes	***	Short
			Identification & Monitoring of the physical-biological coupling in the modifications induced by the MRE projects on the habitats. Modeling the reef effect locally and globally.	***	Medium
			Open DB of environmental variables and indexes	**	Medium
		Decision making tools	Tools to evaluate sites for MREs farms according the multi-criteria approach	***	Short
			Multi-criteria DSS based on multi-objective optimization for MSP of MREs	***	Medium
		Environmental impact reduction	Reduction of the environmental impact on birdlife especially migratory (shearwaters, etc.), and on cetaceans and fish	***	Short
		Decommissioning and recycling	Detection and characterization of anthropic objects	**	Long
		Regulatory frameworks	Establishment of a specific regulatory framework for marine renewable energies.	***	Short
			Include MREs in Maritime Spatial Plans	***	Short
	Knowledge transfer and social acceptance	High level education	Increase education and research exchange programmes through grants	***	Short
			Common platform for sharing environmental and technological data	**	Medium
		General public education	Awareness campaigns	*	Short
			Education at schools	**	Short

Table 2: Cross-cutting priorities under the Research theme “Non-technological research priorities”

Research theme	Priority areas	Objectives	Action	Relevance	Priority
Installation, Logistics and Infrastructure	Access to ocean energy sites, design adapted processes and vessels	Development of techniques for O&M in situ	Cableless underwater communication and monitoring systems	***	Short
		Development of techniques for O&M in situ Development of advanced mooring systems	Develop technology for O&M to mount on Remote Operating Vessels (ROVs) Swarms	***	Medium
			In situ measurements for characterization and monitoring of anchoring components	**	Short
	Reduce uncertainty, risk and cost of foundations, anchoring system and cables	Development of advanced mooring systems	Design methodology for a flexible anchoring system	**	Short
	Power transmission and array cable architecture	Optimise electricitytransmission to the grid	Development of smart grids for managing all energy sources	***	Long

Table 3: Cross-cutting priorities under the Research theme "Installation, Logistics and Infrastructure"

Research theme	Priority areas	Objectives	Action	Relevance	Priority
Materials Component and Systems	Develop high quality seaworthy materials	Biofouling Characterization and Quantification Methods for Sizing and Maintenance of MRE Systems	Provide target-oriented protocols for biofouling assessment in MRE contexts and assess the effects induced by biocolonisation on specific MRE components: corrosion and antifouling	**	Medium
		Develop novel materials with better properties for ocean energy device applications	Development of new materials / applications of new materials to new concepts of PTOs for MREs	**	Medium
			Investigate possible applications of new materials with particular mechanical and electrical properties to storage devices, components and electrical engineering sector	***	Long
	Increase yield with improved Power Take-Off	Smooth the power output	Electrical storage technologies specific to marine environment (Hydrogen,...)	***	Medium

Table 4: Cross-cutting priorities under the Research theme "Materials Component and Systems"

Research theme	Priority areas	Objectives	Action	Relevance	Priority
Demonstration, Testingand Modelling	Deploy demonstration projects to generate learnings necessary for commercialisation	Develop large demonstration projects to sustain commercial MREs development	Identify test facilities for single device and/or array deployment of TRL6 and higher technologies, and/or multi-use platforms	***	Medium
	Technology development through validated numerical models	Understanding ocean resources, determining best condition of operation	Improved wind-wave-current coupling in numerical models	***	Medium

Table 5: Cross-cutting priorities under the Research theme "Demonstration, Testing and Modelling"

3.2 Challenges and Intervention priorities in offshore wind

R&I efforts should capitalize on the progressive turbine size optimization and the positive cost reduction path of the industry. Capacity factors of new offshore wind turbines have been increasing and the average now stands at 42%. The industry is on track to deliver on self-imposed cost reduction targets (now between 50-70 €/MWh) and is working to make offshore wind cost-competitive by 2025. In particular, there is the notable case of Dunkerque, where costs are expected to be at € 60-70 MWh, and around € 120-130 per MWh for FOW in the next calls.

Research & Innovation has to contribute to a better understanding of and interaction between wind power plants and the power system, as well as to the development of stronger grids that are more capable of handling higher amounts of variable renewable energy that includes the development of energy system flexibility solutions, the strategic grid expansion planning and operation and the development of hybrid systems.

Operations & maintenance (O&M) is also considered as a pillar of the Strategic of Research and Innovation Agenda, with emphasis on smart wind farm operations, performance and lifetime management.

The development of next generation technologies would enhance the scientific base of the technology, with digitalization and big data management being among the key challenges. Other challenges on the same field, include data driven design and operation methods, development and validation of high-fidelity models, the development of next generation components, materials, towers and support structures, fundamental research into radical and/or disruptive innovations and material recycling.

Especially research and innovation are needed for the offshore balance of plant focusing on system engineering, offshore grid design, substructure design and the minimization of the uncertainty imposed by the site conditions.

For floating wind in particular, research should focus on holistic wind turbine system design, the development of sectoral synergies, the development of a stable supply chain and the preparation of floating wind for market uptake and wide scale deployment. According to the SET-plan for Offshore wind energy Research and Innovation, procedures on floating should include among others the concept Development of cost effective multi-MW multipurpose modular floating platforms made of concrete or steel (TRL 2-6), the development of new concept manufacturing procedures and standardization of floating platforms (TRL 6-9), and the development of advanced mooring systems (TRL 6-9).

System Integration is also considered as a significant Research and Innovation action with some indicative actions to be the electrification of an existing gas production platform (TRL: 6-9), the energy storage in depleted gas fields (TRL for phase 1: 1-3 and TRL for phase 2: 3-6) and the Power to Gas and Hydrogen Production (TRL for phase 1: 3-6 and TRL for phase 2: 6-9).
Research and Innovation in the field of wind energy industrialization should include the development of standardized methods for quantification of site and system conditions (TRL 4-7) and of numerical and test methods for accurate assessment of system and component reliability (TRL 2-7), while research and Innovation on wind turbine technology, would include among others the development of disruptive technologies (TRL 3-7) and the demonstration of large scale turbines >10 and 15 MW (TRL: 6-9).
Given the commercial level of FOW, dedicated environmental studies are particularly relevant in order to contribute to the social acceptance of projects, as also recommended by the Environmental Authority following the impact study of the project EolMed in Gruissan.

Action	Priority
Tests of floating wind turbine models in oceanic engineering basin to evaluate the stability, the dynamic loads on the anchors, the optimization of the concepts	Short term
Design methodology for a flexible anchoring system	Short term
Environmental impact studies on birdlife and migratory species	Short term
Local modeling of the reef effect	Short term
Environmental impact studies on cetaceans and fish population	Short term
Develop a socio-ecosystem approach to the environmental and socio-economic impacts of floating wind farms	Medium term
Lower the total cost of ownership of floating wind substations	Medium term
Study multi-use of floating wind substations in various areas such as: safety, scientific observations and measurement continuously, industrial tourism, garage of drones for inspection, repair, maintenance of wind parks, etc.	Medium term
Aquaculture associated with MREs especially IMTA integrated multi-trophic aquaculture	Long term

Table 6: Offshore wind priorities

3.3 Challenges and intervention priorities in Wave and Tidal Energy

Six key dimensions make up a wave energy device, which together ultimately convert the movement or flow of the oceans into electricity. These are equally applicable to tidal stream.

1. Structure and Prime Mover: the physical structure of the device, which captures energy and the main interface between the resource and the power, take off equipment within the ocean energy converter. The predominant structural material is steel, although certain concepts are exploring alternatives. Prime movers such as turbine blades are made of composite materials.
2. Foundations and Moorings: the method used to secure the device to the sea bed. This includes permanent foundation constructions such as gravity bases or pile-pinned foundations or could consist of moorings such as tight or slack moored systems.
3. Power Take Off: the means by which the mechanical energy extracted from the waves or tides is converted into electrical energy. Several types of Power Take Off (PTO) exist including mechanical, hydraulic, or electrical direct drive using permanent magnet generators.
4. Control: systems and software to safeguard the device and optimise the performance under a range of operating conditions. Control systems may adjust certain parameters of the device autonomously in order to ensure favourable operation.
5. Installation: the method of placing the structure and device at its power generating location. This includes all vessels and ancillary equipment needed to fully deploy an ocean energy device
6. Connection: the cables and electrical infrastructure for connecting the power output from the device to the electricity network. Alternatively, water is pumped ashore for conversion to electricity and/or desalinated water. Subsequently, power conditioning systems and transformers are needed to provide a grid code compliant electrical output.

The high, and almost comparable, Levelized Cost of Energy (LCOE) of both wave and tidal energy indicates the relatively low level of maturity of the current technologies that have been developed and partly the limited installed capacity, thus prompting further research and development.
Most of the technologies in the wave sector are at TRL 6 and 7, and according to the SET-Plan for Ocean Energy, a key action must be the device and array system demonstration at large scale device, as well as the demonstration of early wave energy demonstration arrays in real environments leading onto large scale deployment (TRL 7-9). This should be accomplished with transfer of knowledge across the sector and from other sectors and between Member States, Industry and academia.
To achieve the search for innovative solutions to the technical challenges facing the wave energy sector up to TRL8, SET-plan also foresees the selection (through a competitive procurement programme) of key subsystems, systems and devices, as identified based on the aforementioned action, and funding to progress. The ultimate aim is to produce reliable technology, which will result in cost effective wave energy generation. Last, but not least a targeted action aiming to a dedicated installation and O&M supply chain for ocean energy in order to optimise processes and reduce project costs considerably is foreseen in the SET-Plan. Developing best practice procedures for installation, operations and maintenance using the experience from the offshore wind sector and to share knowledge and experience across the industry will drive cost reductions.

The main challenges that R&D must face in wave energy sector are related to the difficulty of selecting few technologies among all the available ones (standard technology solutions), the lack of industrial cohesion and limited supply chains for the variety of components required.
Tidal technology is currently the most established blue energy technology. Many different devices have reached high TRL levels, with demonstrated performance in real operational conditions – in some cases as part of wider arrays. EU funds and loan support have been awarded from 2012 onwards, focusing on supporting single demonstration of tidal devices and pre-commercial farms at high TRLs. According to SET-plan for OE, key actions in this sector aimed to reduce LCoE should focus on identifying new promising technologies, and support demonstration in operational environment of the devices with highest TRL. In particular, tidal stream challenges involve improvement of the device survivability through the use of alternative materials, development of new and more efficient PTOs and reduction of the costs related to installation and O&M.

Action	Priority
Improve performance through new control Systems (dynamic tuning)	Short term
Design methodology for a flexible anchoring system	Short term
Development of sensors and fault detection systems for accurate condition monitoring enabling predictive and preventive O&M processes	Short term
Improvement on energy storage	Medium term
Development of new materials and components apt to increase performance of PTOs	Long term
Reduction of underwater acoustic emissions	Short term

4 Role of the Blue Energy Cluster

In order to achieve greater utilization of blue energy it is necessary in the short term to introduce real benefits and advantages, which may come out of the improvement of this sector. Absence of reliable information, co-operation and why not competition between SMEs, academia, policy makers and society related to this topic seem as a major drawback of greater activity in this sector. Benefits of blue energy should be introduced to all relevant parties that are included in the innovation process, but also topic should be introduced to all public figures, including the citizens. Lack of knowledge followed by the absence of reliable information cause resistance toward greater utilization of such technologies.

The establishment of national clusters based on the 4-helix model and involving SMEs, academia /research community, governmental bodies and the civil society, already showed a positive reaction of all the players toward innovation processes in this sector, also in those countries where the BE sector is barely developed.

On a higher degree, the creation of the transnational Blue Energy Cluster is aimed to achieve the desirable synergy between all the aforementioned stakeholders at Mediterranean scale that can boost MREs development and offer favourable opportunities to the achievement of the previously identified objectives and actions on the medium and long term.

Continuous communication, cooperation and competition strategies (co-opetition) between presented bodies could overcome the problems related to current legislative constraints and lack of know-how and funds for innovation processes. Furthermore, included parties should communicate and produce an individual strategy related to Blue Energy. Detecting the missing gaps and identifying the inner advantages is a key step toward successful development of this sector. Missing gaps are lack of experts and funds, as well as an absence of development strategy that would accelerate innovation processes.

Moreover, lack of communication between industrial players and academia consequently leads to absence of innovative ideas and processes. To prevail that, the Blue Energy Cluster can play a key role in facilitation processes between interested parties. The main idea is to use the cluster as a matching platform to connect industry and research organizations, as well as governmental bodies and society or to achieve intra-industrial collaborations. The Cluster and all the actions that accompany it, offer the possibility to all the participating members to illuminate the opportunities, keep track of obstacles, and better understand their position in the blue energy value chain.

The Cluster through specialised services provided to its members, assists to the development of the necessary skills needed, with a view to their orientation towards new innovative products and services related to blue energy, and the realization of synergies to develop the innovation required.

Indeed, the Cluster is an area of cooperation between its members giving them the possibility to strengthen their research and innovation capacities in marine renewable energy technologies and identify business and research opportunities in the field of blue energy technologies.

Introducing a whole concept of blue economy should be a long-term goal. Blue economy incorporates blue energy sector that is used as a push back for other industrial and economical activities. Blue economy is based on synergy between different economy branches with a goal to establish sustainable exploitation of maritime goods.

In general, a proper introduction of blue energy concept is an essential step toward greater utilization of this resource. At the moment, concept of blue energy is widely unfamiliar to different sectors, therefore lack of innovative ideas and processes is not unexpected. Recognition of all benefits and advantages that are included in blue energy concept could enhance development and growth of this sector.

Besides the obvious and natural functions of enhancing communication and favouring trans-national initiatives and knowledge exchange, the Blue Energy Cluster and the on-line platform, which is its main implementation tool, can contribute in a practical and effective way to the achievement of these R&D objectives. The BE platform could be enriched by new sections, besides the already implemented Cooperation and Technology ones. As an example, it could either host or facilitate access (e.g. by mirroring other sites) to innovative results of worldwide projects in MRE sector, exert leverage upon its members for the achievement of the objectives of this Strategic and Research Agenda, and physically host the "soft" tools among the identified goals of the SRA, such environmental variables databases and maps, multi-criteria index evaluation tools, or eventually the DSSs embedding them.

Survival and functionality of the on-line platform aimed to sustain the Actions identified in the PELAGOS SRA should be of course guaranteed by new investments and programmes.

5 Bibliography

AQUARETT, http://www.aquaret.com, EU Lifelong Learning Programme Agreement no LLP/LdV/TOI/2009/IRL – 515

Astriz et al. Towards the optimal design of a co-located wind-wave farm, Energy Vol. 84, pp. 15-24,1 May 2015

AWS Truepower. [Last accessed 4 March 2015]. [link] URL www.awstrue-power.com/knowledge-center/maps/

Besio, G., Mentaschi, L., Mazzino, A. (2016). Wave energy resource assessment in the Mediterranean Sea on the basis of a 35-year hindcast, ENERGY, 94, 50-63, http://dx.doi.org/10.1016/j.energy.2015.10.044

Bloomberg New Energy Finance, Levelised Cost of Electricity Update for the second half of 2015, https://ww.bnef.com/dataview/new-energy-outlook/index.html

BlueMed Strategic Research and Innovation Agenda (SRIA) (2018). BlueMed Coordination and Support Action H2020 - BG-13-2016 - GA 727453

Blyth-Skyrme R.E., (2010). Options and opportunities for marine fisheries mitigation associated with windfarms. Final report for Collaborative Offshore Wind Research into the Environment. Available at: https://www.thecrownestate.co.uk/media/5941/ei-km-in-pc-fishing-012010-options-and-opportunities-for-marinefisheries-mitigation-associated-with-windfarms.pdf

Boero, F., Foglini, F., Fraschetti, S., Goriup, P., Macpherson, E., Planes, S., Soukissian, T. and the CoCoNet Consortium (2016), "CoCoNet: towards coast to coast networks of marine protected areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential", SCIentific RESearch and Information Technology (Ricerca Scientifica e Tecnologie dell'Informazione), Vol 6, Supplement, I-II, doi: 10.2423/i22394303v6SpI, pp. 1-95

Buck B. H.,Krause G., Pogoda B., Grote B., Wever L., Goseberg N., Schupp M. F., Mochtak A., Czybulka D., (2017). The German Case Study: pioneer projects of aquaculture-wind farm multi-uses. Aquaculture Perspective of Multi-Use Sites in the Open Ocean

deCastro, M., Costoya, X., Salvador, S., Carvalho, D., Gomez-Gesteira, M., Sanz-Larruga, F.J., and Gimeno, L. (2018). An overview of offshore wind energy resources in Europe under present and future climate, Annals Of The New York Academy Of Sciences, ISSN 0077-8923, doi: 10.1111/nyas.13924

Drew B, Plummer AR & Sahinkaya MN (2009), A review of wave energy converter technology. Journal of Power and Energy, 223, pp.887–902. Available at: http://pia.sagepub.com/content/223/8/887.short?rss=1&ssource=mfr

Ecorys (2013). Study in support of Impact Assessment work for Ocean Energy, EC DG Maritime Affairs and Fisheries FWC MARE/2012/06 – SC C1/2012/01. https://webgate.ec.europa.eu/maritimeforum/sites/maritimeforum/files/Final%20Report%20Ocean%20Energy_0.pdf

EWEA. The European offshore wind industry—key trends and statistics 2013. Technical Report; 2014

Green R., Vasilakos N., (2011) The economics of offshore wind, Energy Policy,39 (2), pp.496-502

https://www.betterworldsolutions.eu/katanes-wind-wave-project-scotland/ and

https://www.dw.com/en/scotland-opts-for-wind-and-wave-power/a-16318988

http://www.troposplatform.eu/

http://www.h2ocean-project.eu/

https://cld.bz/BoPAqso/6/

https://cordis.europa.eu/project/rcn/93425_en.html https://cordis.europa.eu/project/rcn/94058_en.html

https://www.mermaidproject.eu

Johnson, K., & Dalton, G. (Eds.). (2018). Building Industries at Sea:'Blue Growth'and the New Maritime Economy. River Publishers, Chapter 4, pp. 140, https://www.riverpublishers.com/pdf/ebook/chapter/RP_9788793609259C4.pdf

Johnson K. R., Kerr S. A. (2018) Multi-use maritime platforms – NorthSea oil and offshore wind: Opportunity and risk Irati Legorburu∗, , Ocean and coastal management 160 75-85

Kafas A., 2017. MUSES Case Study 1A: Offshore wind and commercial fisheries in the East coast of Scotland. MUSES Deliverable D.3.3: Case Study Implementation-Annex 1, https://muses-project.com/wp-content/uploads/sites/70/2018/02/ANNEX-1-CASE-STUDY-1A.pdf

Kofoed J. P., Aalborg University, Wave energy converters - potentials, challenges and future trends, http://vbn.aau.dk/files/80476462/Recent_Advances_in_Wave_Energy_Generation.pdf , slides 29-32

Leira B., Multi-purpose offshore-Platforms: Past, present and future research and developments, Proceedings of the 36th International Conference on Offshore Mechanics and Arctic Engineering OMAE2017 June 25-30, 2017, Trondheim, Norway

Liberti L., Carillo A., Sannino G., (2013). Wave energy resource assessment in the Mediterranean, the Italian perspective. Renewable Energy 50 pp 938-949 http://dx.doi.org/10.1016/j.renene.2012.08.023

Margheritini, L., Hansen, A. M., & Frigaard, P. (2012). A Method for EIA Scoping of Wave Energy Converters Based on Classification of the used Technology. DOI: 10.1016/j.eiar.2011.02.003

Monteforte, M., Lo Re, C., Ferreri, G.B. (2015). Wave energy assessment in Sicily (Italy), Renewable Energy, 78, 276-287, http://dx.doi.org/10.1016/j.renene.2015.01.006

Mørk G et al (2010), Assessing the global wave energy potential. In Proceedings of OMAE2010 (ASME), 29th International Conference on Ocean, Offshore Mechanics and Arctic Engineering. Shanghai, China

MUSES (Multi-USE in European Seas) project v.3.0, MUSES Deliverable 4.2.1., Multi-Use Analysis, 30 April 2018

Ocean Energy exploitation in Italy: ongoing R&D activities. Position paper, 2017. Edited by Gianmaria Sannino, Giovanna Pisacane, ENEA. ISBN: 978-88-8286-355-5

Ocean Energy Project Spotlight, Investing in tidal and wave energy, 2017, Ocean Energy Europe

Onyango V. & Papaioannou E., 2017. MUSES Case Study 2. Marine renewables & aquaculture multi-use including the use of marine renewable energy near the point of generation (West Coast of Scotland – Northern Atlantic Sea). MUSES Deliverable D.3.3-Case Study Implementation-Annex 4,
https://muses-project.com/wp-content/uploads/sites/70/2018/02/ANNEX-4-CASE-STUDY-2.pdf

OSPAR, 2010. Quality Status Report 2010. OSPAR Commission. Available at: http://qsr2010.ospar.org/en/index.html and

Royal academy of engineering, 2018. Decommissioning in the North Sea. Available at: https://www.raeng.org.uk/publications/reports/decommissioning-in-the-north-sea

Piante, C. and Ody, D. (2015). Blue Growth In The Mediterranean Sea: The Challenge of Good Environmental Status, WWF Report.

http://d2ouvy59p0dg6k.cloudfront.net/downloads/medtrends_regional_report.pdf

Pérez-Collazo C., GreavesD. , Iglesias G., (2015) A review of combined wave and offshore wind energy, Renewable and sustainable energy reviews 42, 141-153

Pisacane G., Sannino G., Carillo A., Struglia M.V. and Bastianoni S., (2018) Marine Energy Exploitation in the Mediterranean Region: Steps Forward and Challenges, Front. Energy Res. doi.org/10.3389/fenrg.2018.00109

Renewable Energy Progress Report - Report from the commission to the European parliament, the council, the european economic and social committee and the committee of the regions

Rodrigues S.,Restrepo C., Kontos E., Teixeira R.,Pinto P., Bauer,(2015) Trends of offshore wind projects, Renewable and Sustainable Energy Revies, Vol. 49, September 2015, pp. 1114-1135

Sannino G., Carillo A., Pisacane G., Struglia M.V., Mikulčić H., Đukić A., Katulić S., Petranović Z., Duić N., Ruel C., Soukissian T. , Karathanasi F., Ballester Nortes R., Moyano Martín C., Perakis C., Damasiotis M (2017). Deployment potential assessment of Blue Energy technologies for MED key maritime industries. PELAGOS deliverable: pelagos.interreg-med.eu/what-we-achieve/deliverable-database/

Sannino G., Carillo A., Pisacane G., Struglia M.V., Mikulčić H., Đukić A., Katulić S., Petranović Z., Duić N., Ruel C., Sarantakos K., Karathanasi F., Soukissian T., Ballester Nortes R., Moyano Martín C., (2017) Existing Policy and regulatory status on MED Blue Energy development. PELAGOS deliverable: pelagos.interreg-med.eu/what-we-achieve/deliverable-database/

SI Ocean (2012), Ocean Energy: State of the Art. EU project Report, p.79. Available at: http://siocean.eu/en/upload/docs/WP3/Technology Status Report_FV.pdf

SI Ocean (2014). Wave and Tidal Energy Market Deployment Strategy for Europe, Intelligent Energy Europe.https://www.oceanenergy-europe.eu/wp-content/uploads/2017/10/SI_Ocean_Market_Deployment_Strategy_-_Web_version.pdf

SI Ocean (2014). Wave and Tidal Energy Strategic Technology Agenda February 2014, http://www.marineenergywales.co.uk/wp-content/uploads/2016/01/SI-Ocean-WaveTidal-Strategic-Technology-Agenda.pdf

Soukissian, T., Papadopoulos, A., Skrimizeas, P., Karathanasi, F., Axaopoulos, P., Avgoustoglou, E., Kyriakidou, H., Tsalis, C., Voudouri, A., Gofa, F., Katsafados, P., 2017a, “Assessment of offshore wind power potential in the Aegean and Ionian Seas based on high-resolution hindcast model results”, AIMS Energy, Vol. 5, No. 2, pp. 268-289. http://dx.doi.org/10.3934/energy.2017.2.268

Soukissian, T., Karathanasi, F., Axaopoulos, P., 2017b, “Satellite-Based Offshore Wind Resource Assessment in the Mediterranean Sea”, IEEE Journal of Oceanic Engineering, vol. 42, no. 1, pp.73–86.

Soukissian, T.H., Denaxa, D., Karathanasi, F., Prospathopoulos, A., Sarantakos, K., Iona, A., Georgantas, K., Mavrakos, S., 2017c, “Marine Renewable Energy in the Mediterranean Sea: Status and Perspectives”, Energies, Vol. 10, No. 1512

Soukissian T., Karathanasi F., Mikulčić H., Vujanović M., Čehil M., Novosel T., Duić N., Struglia M.V., Carillo A., Ballester R., Moyano C., Ruel C., Damasiotis M. (2017). Diagnostic study of the Mediterranean marine energy resources potential. PELAGOS deliverable: pelagos.interreg-med.eu/what-we-achieve/deliverable-database/

Struglia M.V., Carillo A., Pisacane G., Sannino G., Baleta J., Ballester Nortes R., Duić N., Mikulčić H., Moyano Martin C., Pukšec T., Ruel C., Soukissian T., (2017) EU Blue Energy Technologies Portfolio. PELAGOS deliverable: pelagos.interreg-med.eu/what-we-achieve/deliverable-database/

SET-plan, Ocean Energy Implementation Plan, 2018, available at: https://setis.ec.europa.eu/system/files/setplan_wind_implementationplan_0.pdf

SET-plan, Offshore Wind Implementation Plan, 2018, available at https://setis.ec.europa.eu/system/files/set_plan_ocean_implementation_plan.pdf

SI Ocean (2012), Ocean Energy: State of the Art. EU project Report, p.79. Available at: http://siocean.eu/en/upload/docs/WP3/Technology Status Report_FV.pdf

Strategic research and innovation agenda 2016, ETIP Wind, etipwind.eu

Strategic Research and Innovation Agenda 2018, ETIP Wind, etipwind.eu

Strategic Research Agenda for Ocean Energy 2016 ETIP Ocean Energy

The European offshore wind industry - Key trends and statistics 1st half 2016", WindEurope, July 2016. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-mid-year-offshore-statistics-2016.pdf

Uihlein, A. and Magagna, D. (2016).Wave and tidal current energy – A review of the current state of research beyond technology, Renewable and Sustainable Energy Reviews, 58, 1070-1081, https://doi.org/10.1016/j.rser.2015.12.284

Van Koningsveld M., 2017. Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore wind farms. Towards an implementation guide and experimental set-up. Available at: https://www.researchgate.net/publication/315589657_Eco

WindEurope position paper – "Wind Energy: backbone of the EU global leadership in renewables", September 2016. https://windeurope.org/wp-content/uploads/files/policy/position-papers/WindEurope-Global-leadership-in-wind.pdf

WindEurope press release – "Offshore can reduce costs to below €80/MWh by 2025", June 2016. https://windeurope.org/wp-content/uploads/files/policy/topics/offshore/Offshore-wind-cost-reduction-statement.pdf

Wind in power, 2015 European statistics. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/EWEA-Annual-Statistics-2015.pdf

Witt, M.J., Sheehan, E.V., Bearhop, S., Broderick, A.C., Conley, D.C., Cotterell, S.P., Crow, E., Grecian, W.J., Halsband, C., Hodgson, D.J., Hosegood, P., Inger, R., Miller, P.I., Sims, D.W., Thompson, R.C., Vanstaen, K., Votier, S.C., Attrill, M.J., Godley, B.J. (2012). Assessing wave energy effects on biodiversity: The Wave Hub experience, Philosophical Transaction of the Royal Society A, 370, 502–529, doi:10.1098/rsta.2011.0265, http://rsta.royalsocietypublishing.org/content/roypta/370/1959/502.full.pdf

Wind energy scenarios for 2030, European Wind Energy Association Report – August 2015 https://www.ewea.org/fileadmin/files/library/publications/reports/EWEA-Wind-energy-scenarios-2030.pdfWorld Energy Council (2016). World Energy Resources https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report-2016.10.03.pdf

Zaucha J., 2017. MUSES Stakeholder Workshop Report: "Multi-use for Sustainable Blue Growth". MUSES project. Available at: https://muses-project.eu/muses/wp-content/uploads/sites/70/2017/07/MUSES-StakeholderWorkshop-Report.pdf

Zodiatis, G., Galanis, G., Nikolaidis, A., Kalogeri, C., Hayes, D., Georgiou, G.C., Chu, P.C., Kallos G. (2014). Wave energy potential in the Eastern Mediterranean Levantine Basin. An integrated 10-year study, Renewable Energy, 69, 311-323, http://dx.doi.org/10.1016/j.renene.2014.03.051

ENEA - Promotion and Communication Service

enea.it

ISBN: 978-88-8286-379-1

Copy editing: Giuliano Ghisu

Cover design: Cristina Lanari

Printed in May 2019 at ENEA Frascati Research Centre

ISBN 978-88-8286-379-1

enea.it