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

EU Blue Energy Technologies Portfolio

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

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1. Purpose of this document

The present document is a preliminary study aimed to review, describe and analyze characteristics, degree of maturity and actual diffusion of Blue Energy technologies suitable to exploit the potential of Mediterranean Sea for the production of clean marine renewable energy.

Information coming from the results of past relevant projects will be included and presented in a synthetic and schematic manner.

This study has the scope of summarizing important information useful to meet the overall project objectives, mainly those concerning the acceleration of the development of Blue energy sector in Mediterranean regions, and the deployment of targeted solutions and products tailored to Mediterranean profile (fine-tuning study).

2. General introduction

The purpose of this document is to review the technologies in the Marine Renewable Energy sector, both those currently used and those under development.
According to the EU Communication on Blue Energy [1], Marine Renewable Energy (MRE) broadly refers to both **ocean energy** (energy from the oceans and the seas derived from waves, tides, salinity gradients and thermal gradients) and **offshore wind energy**, while Blue energy (BE) strictly refers to the exploitation of the sea or oceans resources for the production of energy.
Currently, five different marine resources have been identified which are liable for ocean energy exploitation:

- **Tidal current**, extracts kinetic energy from tidal flow;
- **Tidal range**, captures the potential energy created by the difference in sea level between high and low tides;
- **Wave**, converts kinetic energy transmitted by the wind to the upper surface of the ocean;
- **Ocean Thermal Energy Conversion**, exploits the temperature difference between deep and surface ocean layers;
- **Salinity gradients,** exploits the chemical potential due to salinity gradients in water bodies.

The exploitation of each one of these resources fostered the development of different technical solutions, in some cases adapting existing technology, otherwise leading to the design of new devices. Beyond that, technological innovations devoted to enhance the efficiency in energy conversion and/or in storage and distribution are equally important, and affect transversally all the energy technologies.
Although In this document we will not review marine energy technologies applied to buildings heating and cooling, as they are not strictly devoted to electricity production, we must recall here that this sector is in any case functional to energy harvesting and explicitly considered in National Renewable Energy Action Plans.
Moreover, integration of different technologies on offshore platforms is a way to boost blue growth and make renewable energy (especially wave energy) environmentally and socio-economically sustainable. Multi-use offshore platforms combine renewable energy from the sea, aquaculture and transportation facilities and allow sharing the financial and other market/non-market costs of installation and management, locally using the produced energy for different functionalities and optimizing marine spatial planning.
A particular focus will be devoted to those technologies more promising for the Mediterranean context, in line with the previous projects financed by the Interreg Med program, BLUENE and ENERCOAST.
Among all the MREs technologies, offshore wind energy, stream (in the Straits), waves (mainly for sites such as small islands) and Sea Water Air Cooling Conditioning – SWAC are the more interesting for the Mediterranean, although they are at different maturity stages according to technologies. Among the many studies focusing on the degree of maturity of REs, the table in Fig.1 classifies this maturity including the MREs. Offshore wind energy is by far, the major energy for the supply of electricity injected into the Mediterranean networks.

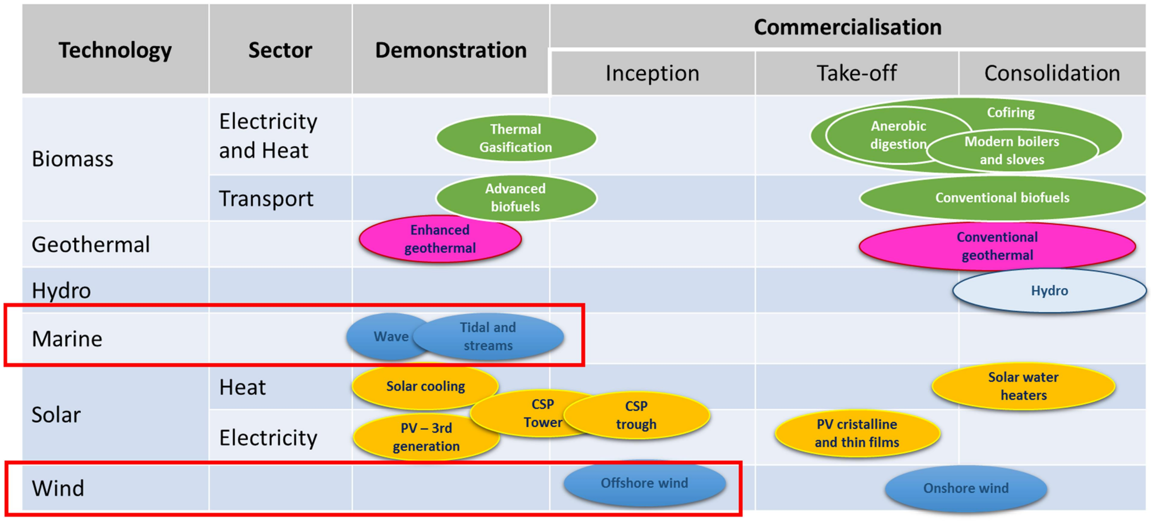


Fig 1 - Degree of Maturity of Marine Renewable Energy

There are very few MRE projects in the Mediterranean Sea, compared to northern Europe: there are no operational fields regardless of the different types of MRE, some demonstrators have been recently realized, while other R&D projects are on-going.

National legislation is also important for the diffusion and application of such technologies at the power plant scale. As an example, at this point there is not a single, either prototypal or commercial, offshore renewable energy power plant available in the Croatian part of the Adriatic Sea. As all the building and construction work in Croatia needs to be in accordance with existing legislation and spatial plans, and currently none of the spatial plans includes maritime demesne area designated for blue energy projects, there are no maritime installations on the Croatian maritime demesne that are used for generating power from offshore wind, wave energy, tidal potential or kinetic energy, nor from other types of blue energy installations.

In Croatia regarding blue energy projects, only sea thermal energy is utilized. Heat pumps are used to convert available sea thermal energy for heating and cooling applications. These applications ranged from private households, apartment building, and touristic buildings.

A similar situation holds in Italy. According to the 2013 National Energy Strategy [2] the Italian government pointed out the sustainable development of renewable energies as one of its key priorities, estimating the effect of renewable energies up to 19-20% of the total consumption for the 2020. However, at 2015, none of the sixteen projects presented for offshore wind farms was in the implementation phase, mainly due to adverse decision of local administrations [3]. In Greece, the majority of the offshore wind projects are at the planning phase while for some of them, a production license has been issued by the Regulatory Authority for Energy. Some candidate locations for potential development of offshore wind farms have been identified based on a preliminary spatial planning; detailed feasibility studies, taking into account a variety of technical socio-economic and environmental parameters, are also in progress.

In this panorama, France is the only Mediterranean country who has already defined 3 pilot areas, in the Lion's Gulf, for floating offshore wind energy farms. Each of these areas will include 3 wind turbines of 5 MW, which is very significant because 5 MW is an industrial level.

Moreover, among the Mediterranean countries, France has decided to build stream electric fields of industrial power. These fields are obviously in the Channel but the experience and the industry is ready to adapt the technologies to the Mediterranean context (Straits of Gibraltar, Sicily)
Finally, important industrial installations were carried out on the Mediterranean façade of French coast for SWAC (Monaco, Marseille, etc.).
Beyond technological development and environmental and administrative issues, the diffusion of MREs and the exploitation of marine resources must face the bottleneck of finance and markets.
However, it is premature to give the investment cost and operational cost of such MREs (CAPEX and OPEX), as many ocean technologies are yet to become commercially viable.
It should be added that even in Northern Europe, the feedback on wind energy (particularly Floating offshore wind energy) is still insufficient to give reliable figures.
And obviously, the other types of MREs (stream, tidal, waves, etc.) are still in the R&D stage and for the more advanced, at a prototype stage, so, it does not allow to predict reliable costs.
The only significant figures are estimates of the prospective costs of electrical delivery (€/MWh) of the systems (wind, stream, etc.) until they are introduced into the network. Of course, it will be necessary to add also the cost related to the adaptation of the infrastructural networks.
Since international comparisons are based on these costs of electrical delivery it is necessary to give some explanations on these costs which are only one component of the prices paid by the consumers.
The price paid by consumers is the sum of several costs:

- The cost of production by power plants (fossil, nuclear, wind, hydro, etc.). This is the cost that is generally used to compare different production types. This cost includes amortization of investments and operations (CAPEX + OPEX)
- The cost of routing, that is to say essentially networks (CAPEX + OPEX)
- Taxes including the cost of compensation for the costs of the RE: "Contribution to the Public Electricity Service (CSPE) in France and VAT.

In France the "Contribution to the Public Electricity Service (CSPE)" is around 25 €/MWh. In Germany this is around 100 €/MWh.
Obviously these prices evolve and are different according to the countries because the natural and political contexts are different.

3. Assessments delivered by past INTERREG and EU Projects

In the last decade, many programs have been financing projects dealing with the exploitation of MRE resources in the EU, both at transnational and national scale, and in different areas.

Various territorial and research projects have demonstrated that the MRE sector represents a great potential in MED, in particular with regard to the exploitation of offshore wind, waves, tides-currents, and thermal gradients. However, the various types of technologies involved and devices realizations are quite different: wind turbine technology is at a very advanced stage of development, taking advantage of the onshore wind sector experience, current and tidal turbines are at a good degree of maturity although new solutions are currently at a demonstration phase. Wave energy devices are at very different stages of development, in the context of a fragmented landscape of small companies, each developing its own device.

Reviewing state of the art existing technologies was an essential objective of several past EU projects. Table 1 synthesizes, for the relevant projects, their area of interest and application, as well as the technologies considered.

The BLUENE and ENERCOAST were both co-financed under the Interreg-MED Program, which is part of the European Territorial Cooperation (ETC) objective, and addressed blue energy in the Mediterranean.

The two projects covered the studying phase of an ETC project, and their deliverables correspond mainly to processes of gathering information and elaborating data necessary to implement further and complementary actions. An analysis and inter-comparison of the results of the two projects is given in [4].

Programme and period	Project Acronym	Application area	MRE Technologies
MED 2007-2013	BLUENE	Italy, Spain, Greece, Croatia	Offshore Wind, Tidal, Wave
MED 2007-2013	ENERCOAST	Adriatic-Ionian region	Offshore Wind, Tidal, Wave
EU FP7	COCONET	Mediterranean, Black Sea	Offshore wind
EU FP7 2011 - 2015	MARINET	Europe	Wave, Tidal, Offshore wind
EU FP7 2011 - 2014	TROPOS, H2OCEAN, MERMAID	Europe	Multi-platforms
EU FP7 2010 - 2011	ORECCA	Europe	Wave, Tidal, Offshore wind

Table 1: Past projects dealing with MREs technologies

The main outputs of the BLUENE projects were:

- Study on ongoing and future initiative and available funds.
- Study on relevant territorial actors.
- Value chain scheme for cooperation.
- Guidelines for future cooperation projects on blue energy

The BLUENE project [5] pointed out notable differences in development of “blue energy” sector in the Mediterranean Sea respect to Atlantic Ocean and northern Europe, where first ocean energy projects were implemented. Existing “Blue energy” projects in Mediterranean at the time of the project analysis were on initial level of development. BLUENE dealt with different sectors.
Regarding the **wind energy** sector, R&D is primarily focused on maximizing its value and on taking the technology offshore where wind speeds are higher and less turbulent, leading to more wind energy generation. The effort to take wind technology offshore drove the main technological development towards the construction of larger wind turbines, and required increased technological focus on foundations and materials adapted to the marine environment. The further deployment of wind farms will also need to be accompanied by developments in storage technologies and increased grid flexibility in order to be able to accommodate increasing levels of wind energy in the electricity network.
The BLUENE project took into account also other forms of OCEAN ENERGY such waves, tides, marine currents, salinity gradient and temperature gradient, being wave and tidal energy the most mature technologies. However, it must be taken in consideration that the power level of wave energy in Mediterranean decreases drastically comparing to Atlantic Ocean, therefore a different technological approach is needed.
An internal report containing a survey of up to date technologies in the sectors of offshore wind, wave energy, tidal energy and thermal energy has been prepared in the context of BLUENE Med project under the responsibility of HCMR and contributions from the partners.
The main outputs of the ENERCOAST project were:

- Report on Renewable Energy Sources (RES) availability, the existing installations and the national and local legislation in each country involved.
- Report on four detailed analyses of technologies under investigation.
- Report on proposals for future projects for the exploitation of renewable energy

The project focused on elaboration of the state of art of the renewable energy sector through a deep analysis of the available data and technologies for the exploitation of renewable energy sources in marine-coastal areas, development of technical and non-technical solutions to increase the use of such technologies, in order to contribute to the Blue Growth through a transnational cooperation in the Adriatic-Ionian sub-region, with emphasis on technical and economic activities such as: solar radiation, wind power, wave and tidal current power and sea water thermal energy to be used in heat pumps. The technologies apt to exploit energy from each one of the above resources were discussed in their general principles, together with their main advantages and disadvantages and a technology data sheet was compiled.
The results from the ENERCOAST were in preparation of the case studies under Action 3: “*Case studies*” of the same project.
According to their findings, a lack of data for small and medium size installation of blue energy technologies in Adriatic-Ionian region was pointed out. Furthermore, the blue energy technologies analyzed in the project had very low penetration level, which could be explained by the high investment costs and maturity of analyzed blue energy technology, at the time of the project.
However, it was expected that penetration level of these technologies would have increased. In the case of cooling and heating, focus was on seawater heat pumps and solar cooling technologies while in the case of electricity production wind energy had the main role. The ocean energy at that moment had very low penetration level mainly because of high investment costs, which are very technology specific.

Beyond Cooperation Programs, the EU has in the last decade supported MRE also in the EU FP7 program, "Ocean of Tomorrow". The EU-FP7 Project MaRINET (Marine Renewables Infrastructure NETwork) has contributed to the development of these energies creating a network among testing facilities and research centers.

MARINET, the Marine Renewables Infrastructure Network, was a network of research centers and organizations that were working together to accelerate the development of marine renewable energy technologies - wave, tidal & offshore-wind. It was co-financed by the European Commission specifically to enhance integration and utilization of European marine renewable energy research infrastructures and expertise. MARINET offered periods of free-of-charge access to world-class R&D facilities & expertise and conducted joint activities in parallel to standardize testing, improve testing capabilities and enhance training & networking. MaRINET ran for four and a half years and ended in September 2015.

The COCONET project also reviewed Offshore Wind Farm (OWF) technologies, and their distribution among nations. In particular general information about all the components of OWF was given, and a review of technologies was given, both commercial and at development stage [6]. Other projects that were financed under the Ocean of Tomorrow call of FP7 and devoted to the development of multi-purpose platforms were TROPOS, H2OCEAN and MERMAID.

The TROPOS project contributed to advances to the EU Wind Offshore development by studying how the TROPOS platform could be installed in water depths beyond 50m, adding an innovative component to the substructure concepts, and by enabling turbines to be mounted on the platforms. Synergies, limitations and economic viability of the integration of the different technologies developed have been analyzed regarding offshore wind, ocean thermal and wave energies exploitation.

H2OCEAN is a project aimed at developing an innovative design for an economically and environmentally sustainable multi-use open-sea platform. Wind and wave power will be harvested and part of the energy will be used for multiple applications on-site, including the conversion of energy into hydrogen that can be stored and shipped to shore as green energy carrier and a multi-trophic aquaculture farm.

MERMAID was aimed to develop concepts for the next generation of offshore platforms that can be used for multiple purposes, including energy extraction, aquaculture and platform related transport. The project does not envisage building new platforms, but will theoretically examine new concepts, such as combining structures and building new structures on representative sites under different conditions.

4. Offshore Wind Energy

Among the technologies available in the renewable energy sector, wind energy is by far the most relevant one in Europe, with a long-standing experience especially in Northern European countries.

The European wind industry also plays a crucial role in the development of wind energy in non-European markets, and due to both domestic and international activity, the wind energy industry is emerging as a strategic sector for the European economy.

4.1 Degree of maturity

According to the last position paper [7] of 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 [8]. The reduction of costs of offshore wind energy seems to be among the key priorities of wind industry.

The 2015 European Statistics of the sector [9], published during February 2016, gives a total of 142 GW of installed wind power capacity in the EU, 131 GW onshore and 11 GW offshore. During 2015, 12,800 MW were installed and grid-connected, with an increase of 6.3% on 2014 installations, the share among on shore and offshore of the new installations being respectively 9,766 MW and 3,034 MW. Offshore wind accounted for 24% of total EU wind power installations in 2015, double the share of annual additions in 2014. This confirms the growing relevance of the offshore wind industry in the development of wind energy in the EU, with investments in this sector doubled compared to the previous year.

A focus on the offshore wind industry in 2015 is given in [10]:

- 3,019 MW of net installed, grid-connected capacity was added in 2015, 108% more than in 2014. A net addition of 754 new offshore wind turbines in 15 wind farms was grid-connected from 1 January to 31 December 2015.
- 419 new turbines were erected in 2015. Seven turbines were decommissioned in the UK and Sweden, resulting in a net addition of 412 turbines.
- 53 of these turbines equivalent to 277 MW are awaiting grid connection.
- 14 projects were completed in 2015. Work is ongoing on six projects in Germany, the Netherlands and the UK.

Of the total 3,018.5 MW connected in European waters, 86.1% were in the North Sea, 9.2% in the Baltic Sea, and 4.7% in the Irish Sea.

Globally, 3,230 turbines are now installed and grid-connected, making a cumulative total of 11,027 MW, mainly installed in the North Sea (7,656.4 MW, 69.4%) The UK has the largest amount of installed offshore wind capacity in Europe (5,060.5 MW) representing 45.9% of all installations. Germany follows with 3,294.6 MW (29.9%). With 1,271.3 MW (11.5% of total European installations), Denmark is third, followed by Belgium (712.2 MW, 6.5%), the Netherlands (426.5 MW, 3.9%), Sweden (201.7 MW, 1.8%), Finland (26 MW), Ireland (25.2 MW), Spain (5 MW), Norway (2 MW) and Portugal (2 MW). Including sites under construction, there are 84 offshore wind farms in 11 European countries.

In the first six months of 2016 [11], Europe fully grid connected 114 commercial offshore wind turbines with a combined capacity totaling 511 MW. Overall 13 commercial wind farms were under construction which once completed will have a total capacity of over 4.2 GW.

According to WindEurope, the dominance of Northern European countries in the wind energy market is mainly due to the stability of the regulatory frameworks in these countries.

In the medium term, an analysis of consented wind farms confirms that the North Sea will remain the main region for offshore deployment (78% of total consented capacity) with significant developments also foreseen in the Irish Sea (8.6% of consented capacity) and in the Baltic Sea (12.4%). Whilst consented projects exist in the Mediterranean, there is no immediate outlook for deployment.

4.2 Mid-term perspectives

Three different possible development scenarios have been proposed in the European wind energy association analysis [12]. The perspective for the next 15 years of wind energy power is, according to the new Central Scenario, 320 GW of wind energy capacity to be installed in the EU in 2030, 254 GW of onshore wind and 66 GW of offshore wind. That would be more than twice as much as the installed capacity in 2014 (129 GW) and an increase of two thirds from the expected capacity installed in 2020 (192 GW).

However, the repartition among different European basins forecasts the majority of offshore wind installations in the North Sea with 45 GW at 2030. The Atlantic Ocean and the Baltic Sea follow at well maintained distance with 13 GW and 8 GW respectively. 23 MW are going to be installed in the Mediterranean Sea in 2030.

The EU is also the first region where offshore wind has been deployed, reaching 11,5 GW of installed capacity by mid-2016 at commercial scale. As the undisputed leader with 92% of global installations and technical expertise now in European waters, the EU has a clear opportunity to spearhead the technology uptake in other parts of the world.

R&I efforts in offshore should capitalize on the progressive turbine size optimization and the positive cost reduction path of the industry. The average size of offshore wind turbines installed in 2015 was 4.2MW, up from 3.7MW in 2014. 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 (€100/MWh by 2020) and is working to make offshore wind cost-competitive by 2025.

A dedicated R&I strategy for wind energy, alongside a visible and reliable post-2020 project pipeline, would be key prerequisite for driving the industry towards full market maturity. To maintain offshore wind's first-mover advantage, the European Commission's Strategic Energy Technologies Plan (SET-Plan) identified it as a priority technology. The European wind industry recommends that further R&I efforts envisage the roll-out of an integrated offshore grid also in the framework of enhanced regional cooperation efforts between EU Member States for the delivery of the 2030 EU-wide binding target.

4.3 Technologies

The available offshore wind energy technologies can be first 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 their specific design.

Beyond the usual requirement of being heavy enough to create sufficient momentum and holding force to withstand the movements and bending movements of the wind acting on the turbines, the choice of the most adequate type of offshore fixed foundation depends on water depth, wave load and ground conditions as well as on turbine induced frequencies (interaction with wave load may give higher loads to the foundation). Table 2 summarizes the main characteristics of the different types of fixed foundation, according to the site-dependent requirements listed above. The most common foundations used for current offshore wind projects are the Mono-pile and Gravity based structures, followed by space frame structures, more adequate for intermediate and deep water depths (figure 2).

Fixed foundation Types					
	Type	Foundation	Seabed	W. Depth	Dimension
Gravity	Concrete	Standing	Semihard,uniform	Low	15-25 m
Monopile	Steel tube	Driven	Hard/semihard	5 -20 m	4-8 m
Jacket	Steel struc	Driven		Deep	Huge
Tripod	Steel struc	Driven		25-50 m	Huge
Tripile	Steel struc	Driven			Huge
Suction bucket		Pushed by pressure	Soft clays/ low strength sediments	Deep	Huge

Table 2 Main characteristics of offshore platforms fixed foundations

As the industry evolves, offshore wind farms are built further from the coast and in deeper waters, mainly based on floating platform designs. Currently, offshore wind farms have been using four main types of deep offshore foundations:
Ballast stabilized: a very large cylindrical buoy stabilizes the wind turbine using ballast. The center of gravity is much lower in the water than the center of buoyancy. Whereas the lower parts of the structure are heavy, the upper parts are usually empty elements near the surface, raising the center of buoyancy.
Mooring line stabilized: a very buoyant structure is semi submerged. Tensioned mooring lines are attached to it and anchored on the seabed to add buoyancy and stability.
Semi-submersible: combining the main principles of the two previous designs, a semi-submerged structure is added to reach the necessary stability.
Buoyancy stabilized.

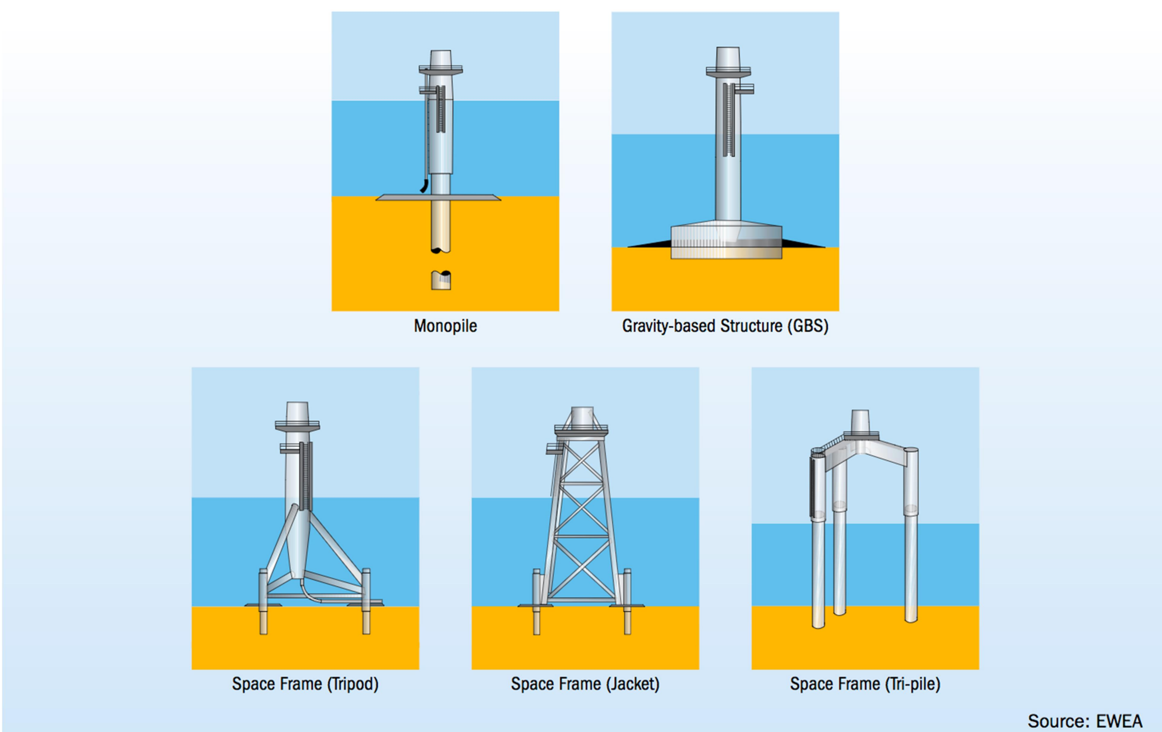
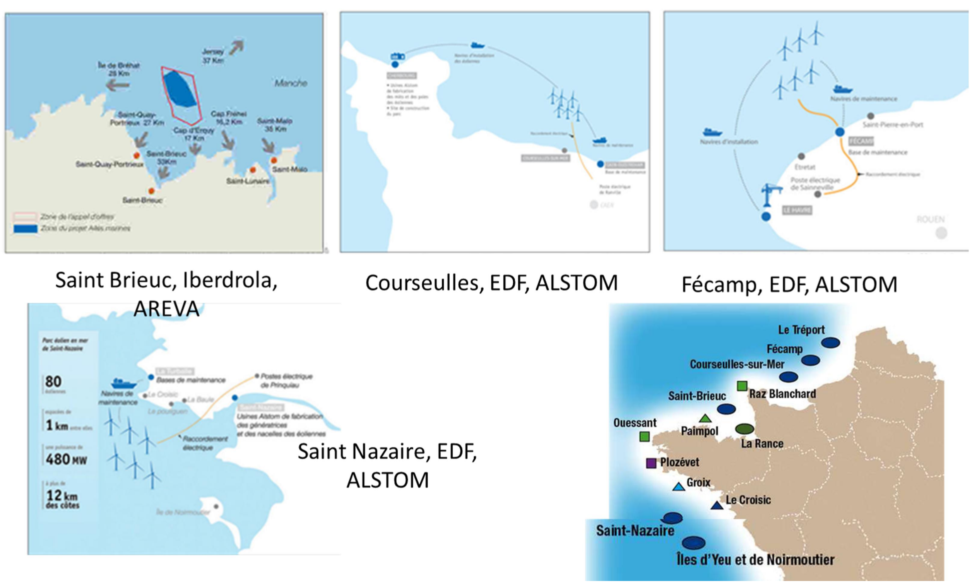


Figure 2: Schematic view of different types of fixed foundations

The main components of a wind turbine are the rotor, the nacelle or the generator house, and the tower. Different devices are characterized by the rotor diameter, by the rotor shaft that can be either vertically or horizontally oriented, by the regulation (stall regulated or pitch regulated) and by the tower height. The rated power output range of commercial devices is 0.011MW – 15MW, the rotor diameter spans from 18m to 140m, while the tower height can exceed 100m.
Considering both commercial devices and prototypes, more than one hundred different wind turbines can be considered, so an exhaustive description is not feasible.
In the following, we will describe some examples of either most recent applications or those particularly interesting for the Mediterranean context, where they are used in current projects or are under study.
In the Atlantic Ocean, offshore wind energy with fixed platforms is being installed in France (6X500 MW). In Germany, Denmark and in the United Kingdom, this technology is widespread. The connection to the electric network in France is plan by 2020 for the first ones. The delivery of electricity costs represent in France around € 200/MW (remember that for the terrestrial wind the costs are of 80- € 100/MWh).
Four wind farms with fixed foundations have been decided in 2011 as presented in fig 3 below.



Saint Brieuc, Iberdrola, AREVA

Courseulles, EDF, ALSTOM

Fécamp, EDF, ALSTOM

Saint Nazaire, EDF, ALSTOM

Figure 3 Wind farms with fixed foundations in France

Two additional offshore areas in the Atlantic Sea were chosen in 2013:

- Le Treport: 62 wind turbines ADWEN (AREVA) of 8 MW (i.e. a power of approximately 500 MW) Société Les Eoliennes en Mer of Dieppe - Le Tréport (LEMDT), whose shareholders are ENGIE (formerly GDF SUEZ), EDP Renewables and Neoen Marine
- Noirmoutier: 62 wind turbines ADWEN (AREVA) of 8 MW (ie a power of approximately 500 MW. ENGIE associated with EDP Renewables and Neoen

The investment per area (500 MW) is estimated about 2 to € 2.5 billion.
The main technologies used in these installations are described in the following, and shown in Figure 4. ALSTOM HALIADE, with its Direct-driven permanent magnet generator, provided 240 wind turbines for EDF EN areas (Courseulles-sur-Mer, Fecamp and Saint Nazaire). “Direct drive”

systems have no mechanical gearbox coupled to the generator. Their low number of rotating parts increases reliability, to maximize turbine availability and reduce maintenance costs. The use of a "permanent magnet" generator leads to better generation efficiencies and even greater overall mechanical reliability, which is critical in offshore wind where reliability is fundamental.
Germany, 45 km from the coast, on an area of 56 km^2, has 40 wind turbines (200 MW) installed with the GAMESA (ADWEN) technology. At the end of 2014, there were 120 wind turbines in Germany, i.e. 1/3 of the German offshore capacity.

© ALSTOM

© GAMESA

Figure 4 Wind turbines used in offshore projects in France

In the Mediterranean there are no realizations on such large scale and given the important depth seabed there is little prospect of installation with this technology.

4.4 The Mediterranean context

There are some prototype experiments using the floating offshore technology. In France, 4 experimental areas for pilot farms were chosen in 2016, equipped with 3 to 4 turbines of about 5 MW each. Three pilots out of the four were decided in the Gulf of Lion in the Mediterranean Sea (Fig. 5). The implementation plan shows that the objective is to implement them by 2020. Then depending on the results, the industrial farms would be launched after. These industrials farms could be achieved 500 MW each.
As said before, one of the main points is the adaptation of the electrical network to these prospective offshore wind energies. Taking into account the important delay to build such network (around 10 years), it is necessary to plan the work not so late.
The 3 pilot projects selected are the following with the ambitious objective to be fully operational in 2020:

- EOLMED project in Gruissan led by QUADRAN (partners: Ideol, Bouygues TP, Senvion) 4 wind turbines of 6,15 MW;
- EFGL project "Les Eoliennes Flottantes du Golfe du Lion" in Leucate area led by Engie (Partners: Caisse des dépôts, Principle Power, Eiffage and General Electric) 4 wind turbines of 6MW;
- PGL project "Provence Grand Large" in Faraman area led by EDF EN (partners: Siemens, SBM and IFP EN)

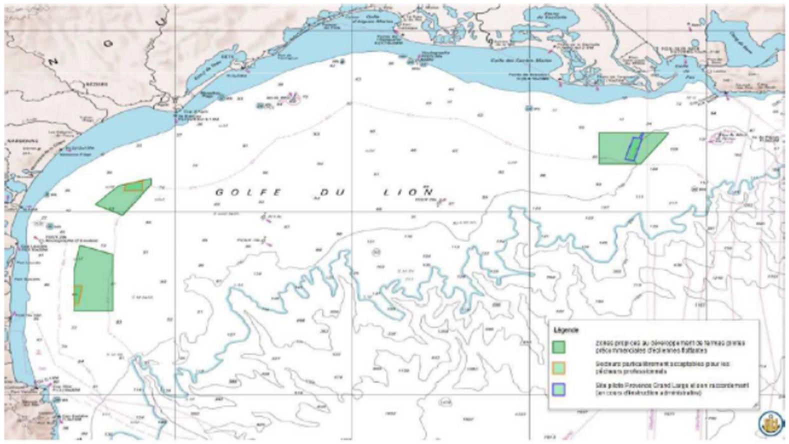


Figure 5 - offshore wind farms demonstrators

In the current situation, it is difficult to estimate the costs of supplying electricity. Probably between 200 and € 300/MWh for the first prototypes. The prospective costs for industrials plant could be around € 150 /MWh.

Innovative devices suitable for the Mediterranean conditions are described in the following. **Vertiwind** (fig. 6), an innovative concept of floating vertical axis wind turbines, which represent a technological breakthrough in the landscape of offshore wind farms, which are almost all designed on a traditional horizontal axis. Perfectly adapted to the marine environment, the concept has several advantages.

- Fitted with lower masts, these turbines have a lower center of gravity, which reduces the cost of the floating structure and the impact on the landscape.
- Robust and simple (neither gearbox nor steering system for the mast or the blades), these turbines are more reliable and therefore more suitable for the marine environment.
- Smaller sizes than conventional wind turbines will facilitate safer industrial deployment by avoiding the main problems in the offshore wind sector (e.g. maritime resources, organization of the construction phase).

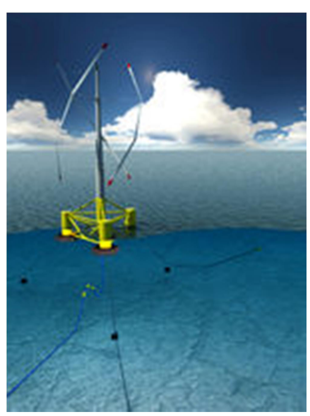


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Figure 6 - The Vertiwind turbine

This new floating concept eliminates the current limit of 35 meters depths for offshore wind farm foundations. Therefore, the location of the projects will not be constrained by the seabed (e.g.

underwater shelves, raised seabed areas) but maintain a balance between use, environmental sensitivity and the stated objective of competitive energy costs.
In the EOLMED project (pilot offshore wind farm in the Mediterranean Sea), an innovative foundation concept for floating wind turbines by IDEOL has been used (Figure 7).
This foundation, a ring-shaped platform developed and patented by the company's engineers, is a breakthrough technological development in the floating wind turbine market. Made from steel or concrete and designed to support 2–8 MW turbines, Damping Pool® foundations are square structures with a typical side length of 35 to 55m.

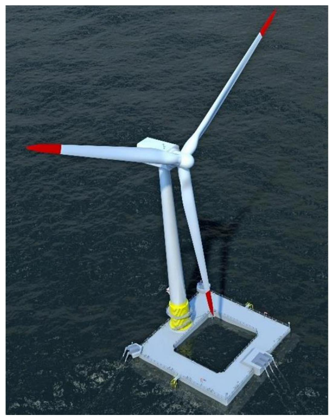

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Figure 7 – Floating wind turbine used in EOLMED project

Floating offshore wind farm experiments in the Mediterranean Sea are currently carried out also off the Spanish coasts [13].
ZEFIR Floating Med Wind Plant (figure 8) was part of the second phase of the experimental station project and proceeded to the installation of five floating wind turbines of 5 MW each off the coast of Tarragona.
During the course of the first phase of the ZEFIR project, the five 5 MW floating turbines were installed on different floating structures in a perimeter between 3 and 45 km off the Spanish coasts on depths that went from 40 to 100 meters.
It was planned to add, in a second stage, three additional wind turbines (their capacity that has not been specified yet) in order to obtain an experimental park of 8 offshore wind turbines, with a minimum total of 5 MW. This initiative has received the highest rating and appreciation in the category "innovative experimental projects for the exploitation of renewable energies".
The Spanish project searched in 2012 for funding for the second phase of the ZEFIR station for an amount of € 30 million. A decision was expected to be taken by the end of 2012. Construction of the second phase was planned for 2015.

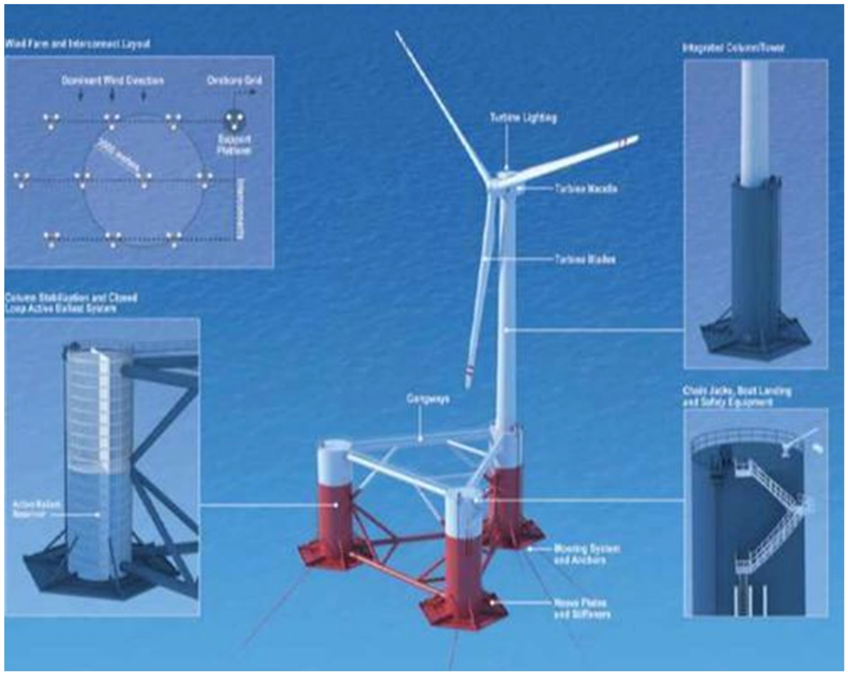

Figure 8. ZEFIR Floating Med Wind Plant

Taking into account the characteristics of the Mediterranean continental platform, the expansion of offshore wind energy should be deployed in deep waters using innovative technological solutions. The ZEFIR pilot project aimed to demonstrate the viability of this type of floating structures. Its priority objective was to set new limits on the understanding of the technology involved, drawing the attention of Spanish companies in the market and facilitating the implementation of training programs.

With regards to the offshore sector, Spanish companies seem to be boosting offshore projects with floating wind efforts. Floating turbines will allow the expansion of the country's optimal windfarm areas to places with depths up to 200 m and harder seabed substrates, although commercial conventional development of floating turbines remains in the midterm, most of them in an experimental phase (EWEA, 2013)[14]

5. Tidal Energy (tidal range and tidal current)

Tidal energy technologies can be divided into tidal range technologies and tidal currents technologies. In the first category a barrage harvests energy from the height difference between high and low tide, converting the potential energy into electricity. Devices based on this technology have been operating since 1960s. Tidal barrages represent a mature technology with some plants in operational for decades like the 240 MW La Rance, located in France.

Tidal currents technologies are applied to water currents generated by tidal motions; the energy is exploited by means of horizontal or vertical axis turbines. Tidal current converters have not yet reached the same level of maturity as tidal barrages, however an intense research activity is actually carried out. Many large industrial companies are deploying pre-commercial arrays and new technical solutions are under study.

Turbines based on the technology developed for wind energy and designed to be mounted on the seabed represented a first generation of tidal current devices. The second generation of tidal energy converters consists of floating devices that allow to reduce the installation costs and to extract energy from the surface most energetic layer.

Tidal movement generates streams that may surpass an intensity of 9 meters per second. The International Energy Agency estimated that tides could generate about 1.2 million MWh annually, in other words, 7.5% of all the energy worldwide.

Up to now, average costs of this technology can be hardly estimated, as few tidal range plants are operational in the world, the costs are very site specific, and in some cases already existing structures have been used. Tidal current technologies are still in the demonstration stage, so cost estimates are projected to decrease with deployment. Estimates from across a number of European studies for 2020 for current tidal technologies are between EUR 0.17/kWh and EUR 0.23/kWh, although current demonstration projects suggest LCOE to be in the range of EUR 0.25-0.47/kWh. Moreover, It is important to note that costs for these technologies can heavily fall when combined and integrated in the design and construction of existing or new infrastructures [15].

In the following we describe most recent and innovative technologies, which are currently under investigation at prototypal stage in several projects.

5.1 Technologies

5.1.1 Spain

The Magallanes Project [16] was launched in 2007, in Redondela (Galicia, Spain), aimed to develop a technology capable of extracting energy from tidal streams. In 2012, the project was in the final stage of assembly and construction of a real scale prototype with 350 tons of weight. Sea trials began late 2015, early 2016.

The Magallanes Project was the only Spanish research initiative with an advanced level of development focused on tidal energy. The project was based on a floating technology with no type of dam, without the need of pillars in the marine bottom. Its upsides were: low maintenance and installation cost, and a higher efficiency. As floating devices, they are adaptable to all sea locations and have a low environmental impact.With regards to the project itself, the floating system was based on building a steel-built trimaran, with an attached submerged part where the hydro-generators were fitted. This platform was anchored to the sea bottom by two mooring lines, to the bow and stern. Due to its floating nature, it did not involve any construction on the sea bottom.

The Magallanes Project was developed in Galicia to benefit from the tidal harnessing power based on patents, expert teams and shipbuilding industries. This project was supported by the Regional Government of Galicia (Xunta de Galicia). Forty researchers from universities and technological centres took part in developing the technological model, based on the latest third generation machineries. It also required industrial development backed by know-how of R&D&I, technology and components that already existed in Vigo's industries. An experienced multidisciplinary team took part in developing all stages of execution: from university research to specialized workers in the shipyard.

5.1.2 France

The Sabella project (SABELLA D10) is carried out by Hydrohélix (Figure 9). These turbines placed on the seabed, without surface grip, are stabilized by gravity and anchored according to the nature of the bottom. A first prototype was launched in 2008 in the estuary of Benodet, a second project was selected at the end of 2010 under the first AMI Marine Energies launched by ADEME and the "Commissariat General aux Investissements d'Avenir". In June 2012, an agreement was signed between Eole Génération, a subsidiary of the GDF-Suez group, and Sabella. "La Sabella D10", Hydrohélix's second hydroelectric, will in principle be launched in 2013, as a demonstration project near Ouessant (Passage du Fromveur).

© SABELLA

Figure 9 - the Sabella turbine

Open Hydro: In 2008, EDF has selected Open Hydro (Irish company) for the supply of 4 hydro-turbines for its Paimpol-Bréhat pilot area (Figure 10). Combined with the development of the turbine by Open Hydro, DCNS has built the support structure for the hydro-turbine and its composite materials, and the assembly of the various assemblies, and has just increased to 60% of the capital of this Company. In addition, EDF-EN has also planned to equip a pilot plant at Raz Blanchard with the Open Hydro technology. This project is called "Normandie Hydro", makes use of 16 meters second generation diameter. Commissioning in summer 2015, series production from 2016 for pre-trade farms.

The turbines, based on the technology developed by OpenHydro (subsidiary of DCNS), will have a unit power of 2 MW and will be connected to the grid around 2018-2020.

OCEADE: Engie is the operator of the installation of four Oceade 18 hydrojets developed by Alstom (GE) and with a power of 1.4 MW (Figure 10).

ENGIE develops a proven hydroelectric technology with a particular focus on operation and maintenance. Thanks to the success of the test programs of its 500 KW and 1 MW turbines (which injected more than 1 GWh into the Scottish network), Alstom improved the design of its hydro-turbine by offering the OCEADETM 18-1.4MW, in order to make it even more efficient, to optimize the costs and to facilitate its maintenance. With a rotor diameter of 18 meters, the OCEADE, with a nominal power of 1.4 MW, is equipped with three variable pitch blades, "plug-and-play" modules on rails and a floating platform. ALSTOM was selected with ENGIE in December 2014 to equip the Raz Blanchard (France) hydro pilot project with four OCEADETM 18-1.4MW and an ALSTOM submarine interconnection system as part of the call for expressions of interest launched by the French government.

© Alstom © DCNS

Figure 10 - Oceade and OpenHydro turbines

5.1.3 Italy

In order to extract energy from marine currents, the KOBOLD turbine (Figure 11) has been designed and patented [17]. The Kobold turbine is a rotor mounted on a vertical shaft, which produces mechanical energy by exploiting marine currents. A platform equipped with a Kobold turbine of the diameter of 6 m with three blades with a span of 5 m, designed by the Ponte di Archimede Company, has been installed in the Strait of Messina in the year 2000 and is still in operation. The nominal power output is 30kW, the device is connected to the grid.

Figure 11 - The Kobold installation

GEM, the Ocean's Kite (Figure 12), is an ocean current energy conversion system that consists of a submerged body with two horizontal axis hydro turbines. It is tethered to the seabed and free to self-orienting to the current. The device is placed at the desired depth thanks to its self-towing winch and is easily recovered to the surface for maintenance. Patented in 2005 GEM, after the experimental phase in towing tank, a first full-scale prototype has been deployed in Venice lagoon.

The nominal power of the device is 100kW with 5 knots of current speed, in the real condition of about 3 knots the power that can be produced is about 20kW.

Figure 12 - The GEM device

6. 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 Europe the most energetic areas are found along the coastline facing the Atlantic Ocean. The Mediterranean Sea offers a lower level of waves energy but presents a potential for future development. It is interesting to note in fact that while the initial research in the sector was principally on large-scale devices operating in high-energy environments, the actual research focuses on small-scale devices and to the exploitation of lower energy sites. This choice has many economical advantages, as in the design of large-scale devices the survivability to the most intense wave extremes has to be taken into account increasing significantly the costs. Moreover small-scale devices are designed to operate in farms so the maintenance activities can be done without a total stop of the production. Also the testing phase of small-scale prototype can be easier and less expensive.

Estimates of LCOE based on demonstration projects are in the range between EUR 0.33/kWh and EUR 0.63/kWh. However if considerable deployment levels will be achieved, the projected LCOE in 2030 for wave energy is estimated between EUR 0.11/kWh and EUR 0.23/kWh [18].

Actually, there is a variety of devices based on different technologies but none of them has taken a leading role. Many different methods have been used to classify wave energy converters, basing on the distance from the coast, the size of the device or the working principle [19, 20, 21]. Here we follow the classification proposed by Falcao [20], based on the principle of operation.

The main classes can be considered:

- Oscillating Water Column (OWC) devices are among the first wave converters developed. They are located on the shoreline or near shore and are constituted by a submerged structure that contains a chamber with air that is alternatively compressed and uncompressed following the entering waves. The pressure of the air is then converted into energy by a turbine. Some floating devices have been developed on the same principle.
- Oscillating body systems are offshore devices constituted by oscillating bodies, either floating or submerged. They use the incident wave motion to induce an oscillatory motion between two bodies that drives the power take-off system. Their main disadvantage is the distance from the coast that requests to solve mooring problems and needs long underwater electrical cables.
- Overtopping converters are based on the use of a reservoir of water at a level higher than the free surface of the sea; the potential energy of the water is converted in energy through low-head hydraulic turbines. Overtopping converters can be floating structures or incorporated into breakwaters.

Power take-off systems are used to convert the water motion into electricity. In the case in which the motion is alternative, as in oscillating body and OWC devices, it is necessary the use of self-rectifying turbines, that rotate in the same direction independently of the direction of the inflow. Most of the oscillating-body devices and OWC provide the best production in resonant conditions, this requires a specific design of the geometry of the structure to fit local wave conditions.

In the following we describe most recent and innovative technologies, which are currently under investigation at prototypal stage in different countries.

6.1 Technologies

6.1.1 France

The Pelamis snake (developed by Ocean Power Delivery Ltd, now Pelamis Wave Power Ltd) is a "attenuator" type float, consisting of an articulated steel tube of 140 meters long, 3.5 meters Diameter, weighing 350 tons before ballasting, generating a power of 750 kW (Figure 13). This system is now in the pre-commercial stage. Demonstration trials were conducted in Portugal and in Scotland. There is a project of 5 machines 3.75 MW, in the Island of Reunion.

SeaRev (Ecole Centrale de Nantes)[22], a wave energy converter with a floating device enclosing a heavy horizontal axis wheel serving as an internal gravity reference (see Fig.13). The center of gravity of the wheel being off-centered, this component behaves mechanically like a pendulum. The rotational motion of this pendular wheel relative to the hull activates a hydraulic Power Take Off (PTO), which, in turn, set an electric generator into motion. Two major advantages of this arrangement are that, first: all the moving parts (mechanic, hydraulic, electric, components) are sheltered from the action of the sea inside a closed, waterproof shell; and secondly that the choice of a wheel working as a pendulum involve neither endstop nor any security system limiting the stroke.

An application of the SeaRev technology for a wave farm located offshore the island of Yeu (5 000 inhabitants) consists of:

- 40 SeaRev of 250 kW = 10 MW.
- Energy storage and liaison with the mainland.

CETO is a submerged subsurface system with 3 projects in Australia, La Réunion and Ireland.

The CETO system (Figure 14) is different from other wave energy devices as it operates under water where it is safer from large storms and invisible from the shore.

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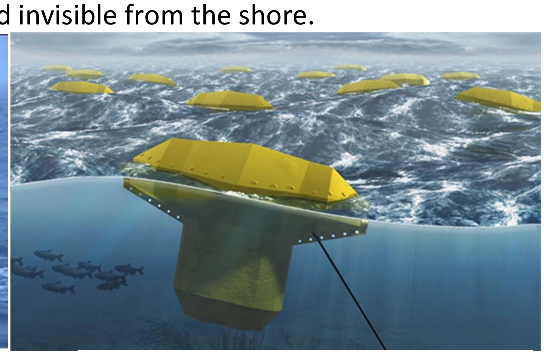

© Ecole Centrale de Nantes

Figure 13 The Pelamis and SeaRev devices

The fully submerged buoys drive pumps and generators that are contained offshore, within the buoy itself, with power delivered back to shore through subsea cables to power desalination plants as well as for export into the grid.

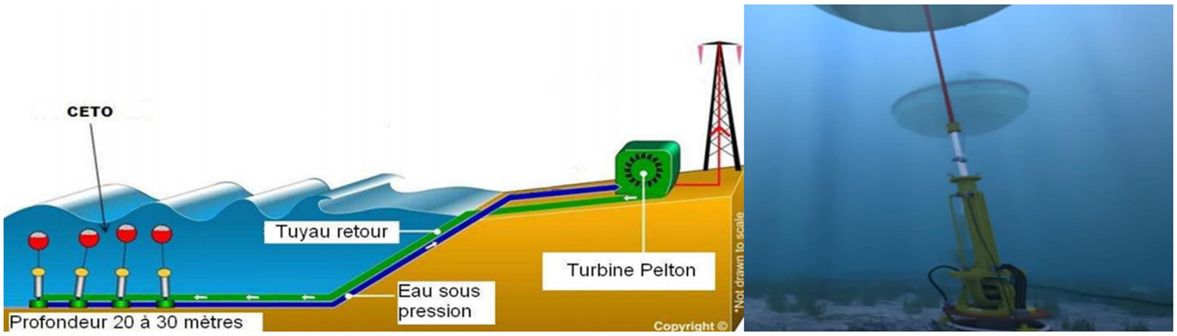

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Figure 14 - Scheme of the CETO system and a detail of the device

6.1.2 Spain

The propagation of waves from deep waters to the shore supposes an overall reduction of the available energy resources in an area [23]. However, due to the refraction process [24], wave energy is concentrated at particular places, being of highest interest for wave energy exploitation [25].

In this manner, wave patterns along the coast of N Galicia have been previously assessed, and more specifically in Cape Estaca de Bares [26]. This area was shown to boast an average wave power up to 40 kWm^{-1}, becoming a favorable area for wave energy exploitation[25]. The SIMAR-44 dataset, based on hindcast data spanning 44 years (1958-2001), was used alongside wave buoy data to carefully evaluate this significant energy resource [26].

In [26] a numerical model of that area was performed and various conditions analyzed, including average, growing, extreme and decaying wave energy conditions. On the basis of the numerical results, different coastal points were identified as sites where significant energy concentration exists, based on the bathymetry configuration. These results, led to define several locations of potential interest for the installation of a wave farm [26,27].

Two of these sites, one near shore (at 20 m depth) (located close to the Port of San Ciprián) and another offshore (at 70 m depth) were considered in [25] to analyze the intra-annual performance of different WECs. These sites were defined on the basis of the power available considering a few wave conditions.

In April 2016 an innovative wave farm has been placed near Gibraltar (Figure 15). The initial power plant was of 100kW and should be expanded to reach 5 MW in the next years.

The project utilizes wave converters of the Eco Wave Power Ltd. The wave energy converters use floaters attached to a fixed structure.

The floaters move up and down with the movements of the waves; the motion is then transmitted to a power station located on land that converts the energy into a pressure, used to spin a generator producing electricity. The floaters and pistons are located in the water, whereas all the technical equipment operates on land, thereby improving reliability and providing easy access for maintenance and repair.

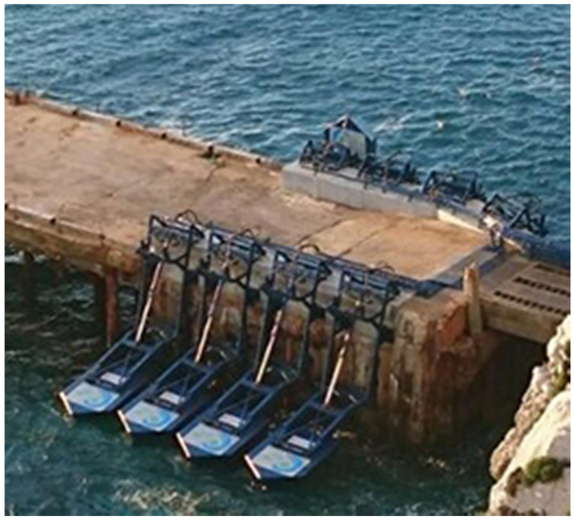


Figure 15 - Gibraltar Power Plant from http://www.ecowavepower.com/gibraltar-project/

In 2015 a research device was installed in the Mediterranean sea (Butterfly device), north of Valencia, by Rotary Wave, a Valencia (Spain) start-up, financed with FEDER funds (European Union). The device was working for more than three months, producing energy in the device, not sending energy to land and not connected to grid. A qualifying aspect of this new technology is its design for low energy wave potential seas, as it can absorb energy of waves from 0,5 to 5 m. Information about the tests is shown in the web-site: www.rotarywave.com.

6.1.3 Greece

Sigma Hellas owns a patented technology for harnessing sea wave energy. The device, called Wave2Water, can be used for desalination or for producing electricity or both. In Figure 16 its functioning scheme is shown.

Further information about the device are provided at the website [28]. Wave2Water device is modular (thus more units can be assembled in the basic configuration), it is simple and user-friendly, it has low construction, maintenance and operation cost, it is designed for harsh environmental conditions, capable of producing energy even at low sea states, it is a low-profile installation in order to avoid visual disturbance and operates at very low noise levels.

The principle of operation relies on the oscillating motion due to the propagation of surface sea waves. This motion increases the water pressure, and the water mass (with a higher flow speed) is then transported through a pipeline to a pressure tank which is located on shore. The tank regulates the pressure and the water flow. For desalination purposes, the pressurized seawater is transported to an array of reverse osmosis membranes. For producing electricity, the pressurized seawater is directed to a water turbine. The Wave2Water device has been tested in real sea states, however no performance results are available.

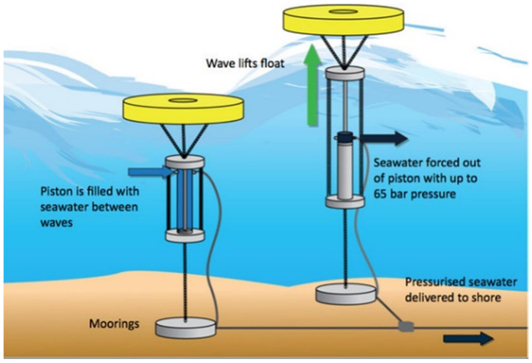


Figure 16: The Wave2Water wave energy converter (design principle, left panel) and in real sea states (right panel). Both pictures from sigmahellas website:
http://www.sigmahellas.gr/index.php?lang=1&thecatid=3&thesubcatid=439

Triton II is an onshore wave energy converter (Fig 17). It has been designed by Constantinos A. Hatzilakos. At the initial stage of development (2002-2004), the TRITON converter had been tested in the context of two projects (one national and the other European). The Greek Ministry of Development funded the first project; three full-scale devices have been produced and tested in real sea states. The second project was funded by the EU; five 1/10-scale devices had been produced and tested at the wave tank laboratory of the National Technical University of Athens (NTUA), with the collaboration of Queen's University of Belfast (UK) and University College Cork (Ireland).

The main features of the Triton II device are the following:

- Simple design with low construction and O&M costs;
- Long service life;
- The foundation is based on land, and it can be used in combination with a breakwater, pier or harbour;
- Utilization of the wave reflection on the wall of the pier;
- Innovating power transmission system, high conversion efficiency, high output power quality.

The converter is composed of two main parts:

i) the float, moving up/down following the vertical movements of the sea surface and
ii) the mechanism, which converts the vertical movements to horizontal and/or to rotational depending on the type of electrical generator used.

There is also the possibility to place many units side by side forming thus a group of units producing electricity of many MW. A shoreline of 100 m length and 5 m width is enough for a group of 40 converters with floats of 2 m diameter and raising forces more than 3600 kg each. Consequently, although the float is moving to two directions (upwards and downwards), the shaft of the generator rotates always to one direction.

All units except floats are housed and firmly protected. For more detailed information see also http://www.toswet.com/. The productivity of the unit is dependent on the size of the float. For example, for a float of 2.65 m^3 the forces on the float half emerged are 1325 kg and for 28.26 m^3 the forces become 14130 kg.

The technology for this design is protected by the World International Property Organization - Patent Cooperation Treaty (PCT) International Publication Nr. WO 2007/129126 A 1.

There are also 22 patents awarded already from South Africa, U.S.A., Canada, Chile, Israel, Greece, Japan, South Korea, Australia, and 3 Patents pending from Brazil, U. A. Emirates and India. Moreover, the European Patent Office announced recently the decision to award the Patent. This Patent is giving protection to all 20 European coastal countries, all around the coastlines of Baltic Sea - North Sea - Atlantic Ocean - Mediterranean, Aegean and Black Sea.

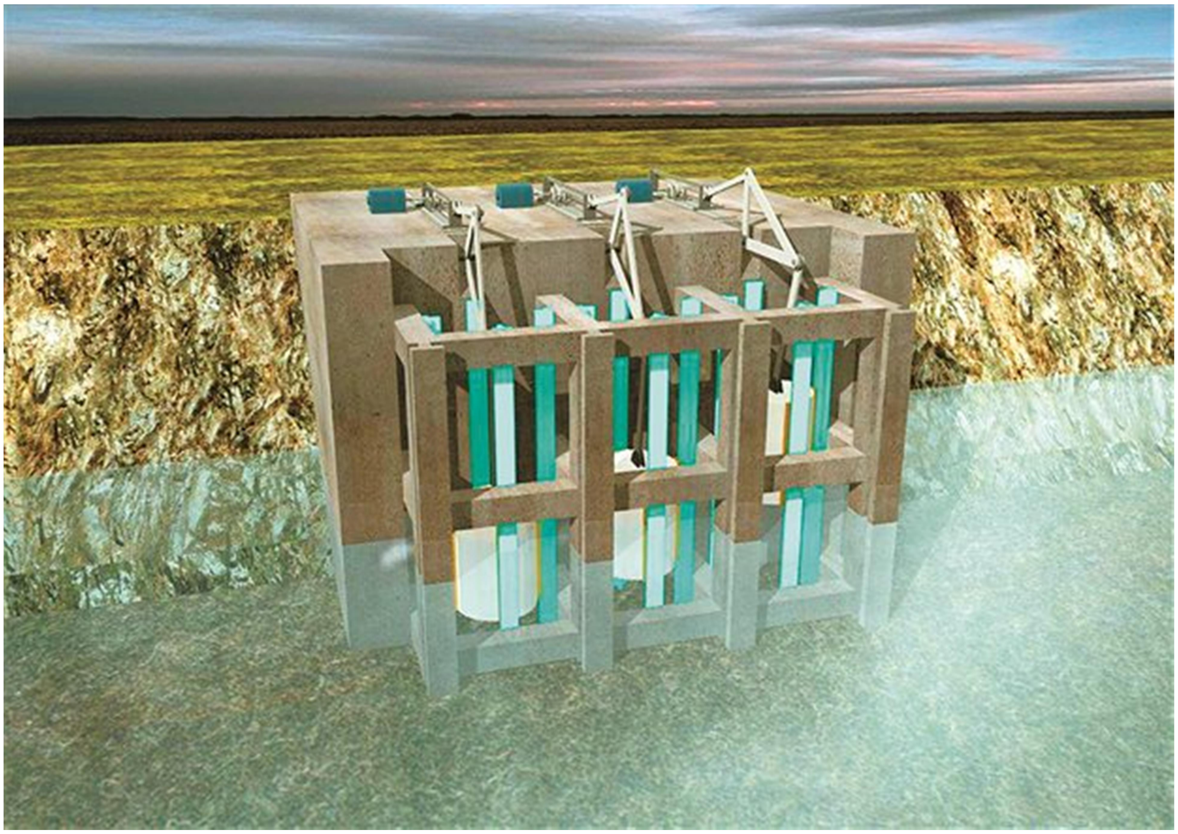


Figure 17 - The Triton II wave energy converter (picture downloaded from http://www.toswet.com/)

6.1.4 Italy

In Italy there is an increasing interest in the exploitation in the wave and tidal technology to produce renewable energy. Italian Government, according to the National Renewable Energy Action Plan (NREAP), expects to meet by 2020 the target of 3 MW of installed capacity. Some ocean energy converter technologies specifically designed for the Mediterranean Sea are actually under different stage of development.

Devices integrated into conventional breakwaters represent an interesting category of wave converters. Such a solution has the advantage of a limited increasing of the cost of the breakwater and of the easiness of maintenance.

Two different kinds of devices have actually been developed: the first is an OWC (Oscillating Water Column) composed by a structure including a chamber of water oscillating under the action of waves. The other is an Overtopping device that captures incident waves into a reservoir above the sea level.

The Resonant Wave Energy Converter (REWEC3) is a particular type of OWC based on the idea proposed by Boccotti [29, 30] and patented by wavenergy.it srl. The device is a modification of the classical submerged breakwater (Figure 18). It consists of a vertical chamber connected to the open wave field by a U-duct. The wave pressure at the U-duct opening induces water column oscillations, the oscillations act on the air pocket that is alternatively compressed and expanded moving a self-rectifying Wells turbine. The dimensions of the device are studied to reach resonance under the most frequent sea wave conditions present in the site. A small-scale device has been installed at the natural laboratory of the Mediterranean University of Reggio Calabria in 2005. The first full-scale prototype is under construction in the port of Civitavecchia (Rome, Italy). Theoretical and experimental analyses of the device are reported in [31] and in [32 , 33].

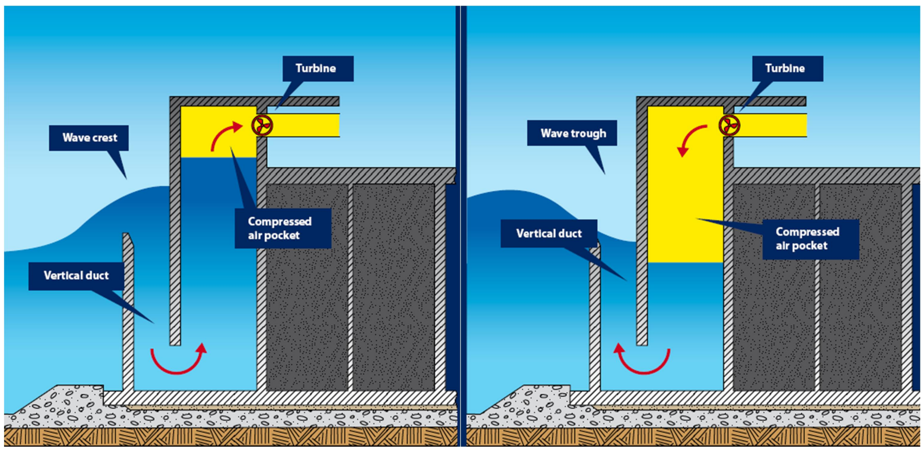


Figure 18 - Scheme of a Rewec3. Left panel: plant behavior during a wave crest, right panel: plant behavior during a wave through. (From [27])

A device denominated OBREC (Overtopping BReakwater for Energy Conversion) embedded into a breakwater and based on the wave overtopping process has also been developed [34, 35]. The device consists of a rubble mound breakwater with a frontal reservoir designed to capture the wave overtopping from a sloping ramp in order to convert wave energy into potential energy. Water stored in the reservoir produces energy by flowing through low head hydraulic turbines, using the difference in water level between the reservoir and the main sea water level. A small-scale (1:30) of the OBREC was tested at Aalborg University (Denmark) in 2012 and 2014 to study the geometrical parameters of the device in order to verify the hydraulic performances and loadings. Tests have shown that the integration of an OBREC into a breakwater improves its overall performances. A full-scale prototype has been installed in the port of Naples in 2015.

ISWEC is a point-absorber wave converter developed for mild climate seas such as the Mediterranean, by the Politecnico di Torino (Figure 19). It is based on the gyroscopic technology already used in marine applications for roll stabilization. The principle used is the same but the direction of the energy is opposite with the gyroscopic torque induced by the incoming waves and exploited by the electrical PTO [36, 37]. The system is enclosed in a sealed hull and consists of a flywheel that rotates generating a gyroscopic torque, the PTO converts such torque in electrical power. The main characteristic of the ISWEC is the possibility of controlling the flywheel spinning velocity to match the sea state increasing the productivity. An advantage of ISWEC is the absence of parts in relative motion immersed the water, as the whole conversion group is allocated inside the hull. Furthermore, the device does not require fixed constraints on the seabed, but only a slack mooring, guaranteeing an extremely reduced environmental impact. Research activities started 10 years ago and led to the development of the technology industrialized by Wave for Energy, spin-off of the University of Turin. On August 2016, the first full-scale ISWEC prototype, with a nominal power of 100kW, has been moored 800 m from the coast of Pantelleria, Italy.

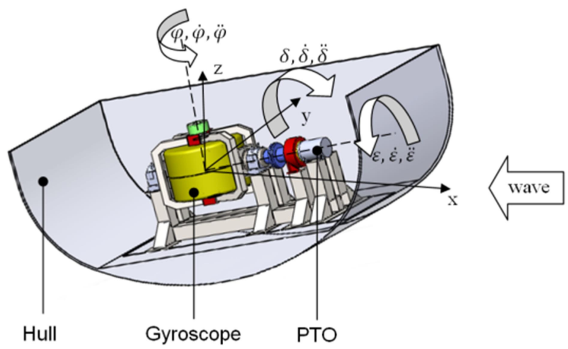


Figure 19 - The layout of ISWEC (from: [30])

PEWEC (PEndulum Wave Energy Converter) is another point-absorber converter developed by the Politecnico di Torino together with ENEA. PEWEC is a passive system based on a pendulum positioned inside a hull, whose oscillation is converted in electrical energy by the power take-off. A 1:12 PEWEC has been tested in the INSEAN's towing tank in Rome.
40SouthEnergy is developing wave energy converters since 2007. The devices are constituted by two parts, the upper one is kept at shallower depth with respect to the other (see Fig. 20). The waves affect the upper and lower parts differently and the relative motion energy is extracted using electrical generators. A family of devices has been designed with different sizes. A prototype named 55/150 has been installed during March 2014 in Punta Righini test site in Tuscany. Next generation of machines will reach 500kW and 2MW.

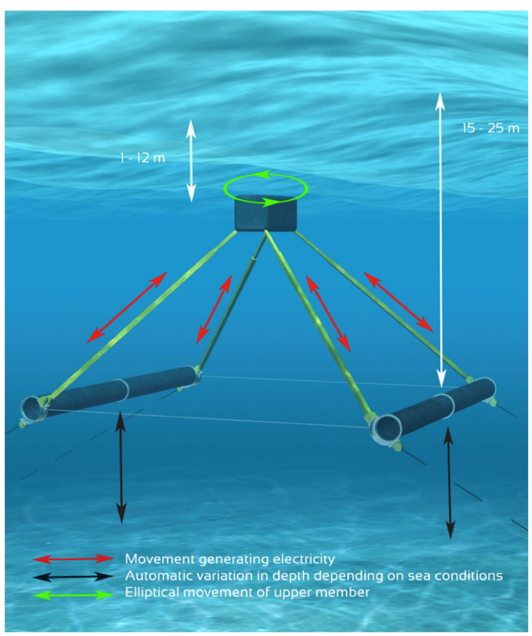


Figure 20 - Sketch of R115 from http://www.40southenergy.com/2012/02/brochure-r38-r115-wave-energy-converters/

WAVESAX is an innovative wave converter of OWC type [38], developed by RSE (Ricerca sul Sistema Elettrico). This device (Fig. 21) has been conceived to be installed in coastal structures, such as harbours. It consists of a vertical pipe, in which water moves upward and downward following wave movements. Inside the pipe is positioned a hydraulic turbine that transforms the energy of the water in electricity. The turbine is of bi-directional type that is the rotor rotates in the same direction during both the ascending and descending phases of water. The main characteristics of the device are the low cost and the modularity as it can be installed individually and in batteries of several elements. Laboratory test studies have been performed on a scale model (1:20) in the ocean wave basin of the HMRC - Hydraulic Marine Research Centre (Cork, Ireland).

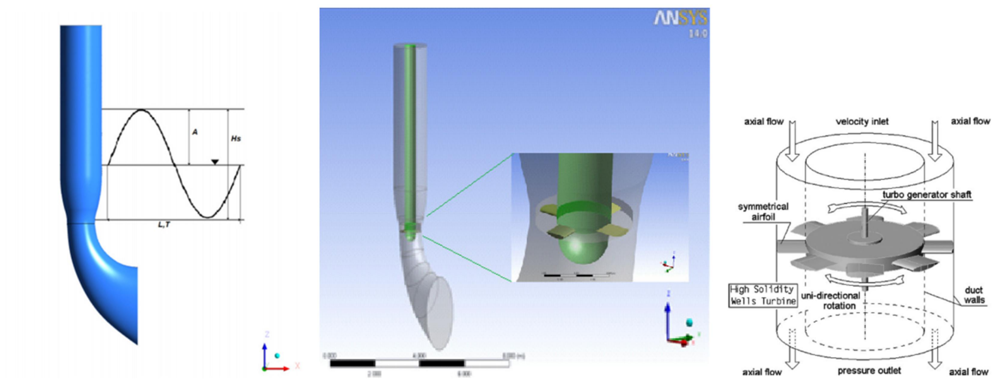


Figure 21 - WAVESAX scheme: Fixed body (left), rotational body (centre) and type of turbine (right) [38]

Another wave energy converter designed to be installed on the coast or in low depth water is the GEL system. The device, developed by Seapower scrl in collaboration with Umbra Group, consists of a floating body linked to a fixed frame free to oscillate around a horizontal axis under the action of waves.

A floating body of about 5 m width can produce power of around 60 kW out of a wave of heights of 1.5 meters. A full-scale scale prototype of the system has been tested in the towing tank of Department of Industrial Engineering (DII) of University of Naples “Federico II”. After the optimization of the floating body geometry, a full-scale prototype of 60 kW will be produced [39].

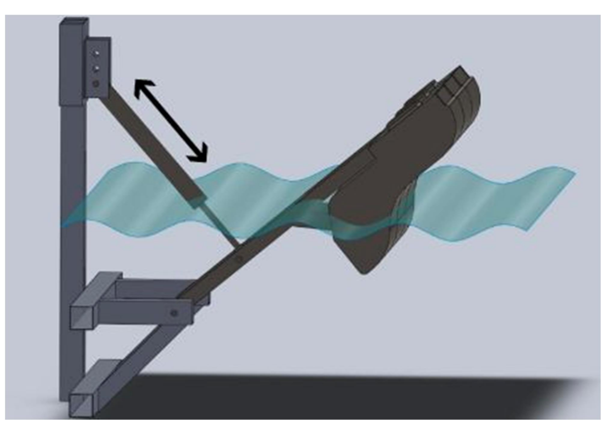


Figure 22 – CAD drawing of the GEL prototype [39]

7. Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) for electricity production can be considered an emerging technology, with just a couple plants in operation worldwide during 2014 [40], and a new 100 kW OTEC plant, believed to be the world's largest, connected at Hawaii's electric grid during 2015 [41] and operated by Makai Ocean Engineering (United States).

The OTEC idea is to capture the temperature difference between cooler deep and warmer shallow ocean water to produce electricity.

OTEC needs a temperature difference of about 20°C or more, thus limiting its application mainly in tropical latitudes. Hence, the technology offers little potential in European continental waters, but can be interesting in islands like La Réunion, Tahiti, etc.

The OTEC energy is based on the principle of Carnot whose efficiency is equal to delta temperatures between surface and bottom divided by the absolute temperature. Three main types of OTEC can be differentiated: open-cycle, closed-cycle and hybrid systems. In the open cycle system warm surface water is flash evaporated and drives a turbine (Figure 23). Cool water is used to condense the vapor again. The condensed desalinated water can be used for various purposes. The cold water that has been pumped from the sea can feed air-conditioning systems after it has been used in the condenser. In addition, the cold seawater can also
be used in aquaculture, since it is rich in nutrients.

Instead, closed-cycle OTEC plants use a working fluid with a low boiling point. The vapor drives a turbine and is condensed using cold seawater. In general, refrigerants or ammonia can be used as the working fluid, but water–ammonia mixtures are also used (Kalina cycle). Closed-cycle plants are more efficient compared to open-cycle plants. Makai's research and evaluation OTEC plant uses the temperature difference between deep ocean water (at 670 meters) and surface water to generate electricity, where a closed-cycle working fluid of ammonia drives a turbine for power generation

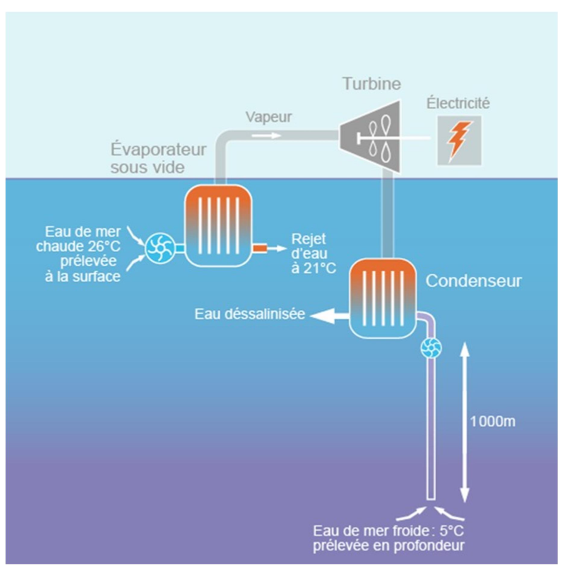


Figure 23 - OTEC open cycle scheme

In the Mediterranean Sea, the temperature of the deep sea is of the order of 10-12 °C. It is therefore unthinkable to use this difference of temperature (surface-bottom) to produce electricity.

Consequently, this technology can be applied in the Mediterranean only for SWAC - Sea Water Air Cooling Conditioning purposes. It can be used either on large scale, with plants planned to be connected to district heating and cooling network, or on smaller scale for the heating and cooling of single buildings, in a sort of distributed energy system for local use, feasible to meet energy efficiency objectives.

8. Salinity gradients

Salinity gradient energy (SGE) is a renewable energy source that can be harnessed from the controlled mixing of two different salt concentration water masses. The mixing of seawater and freshwater is a natural process in river mouths that could be use for power production. As major cities and industrial areas are often sited at the mouths of major rivers, salinity gradient power plants could be constructed in those areas. However, since salinity gradient energy is still a concept under development, further research is needed for this technology to uptake.

There are two concepts that are relatively already well researched, and these are the Reversed electro dialysis (RED) and the Pressure-retarded osmosis (PRO) concept. These two concepts of energy conversion are often called osmotic power. The RED process harnesses the difference in chemical potential between two solutions. Figure 24 shows the RED system concept. Concentrated salt solution and freshwater are brought into contact through an alternating series of anion and cation exchange membranes (AEM and CEM). The chemical potential difference generates a voltage across each membrane, where the overall potential of the system is the sum of the potential differences over the sum of the membranes [21].

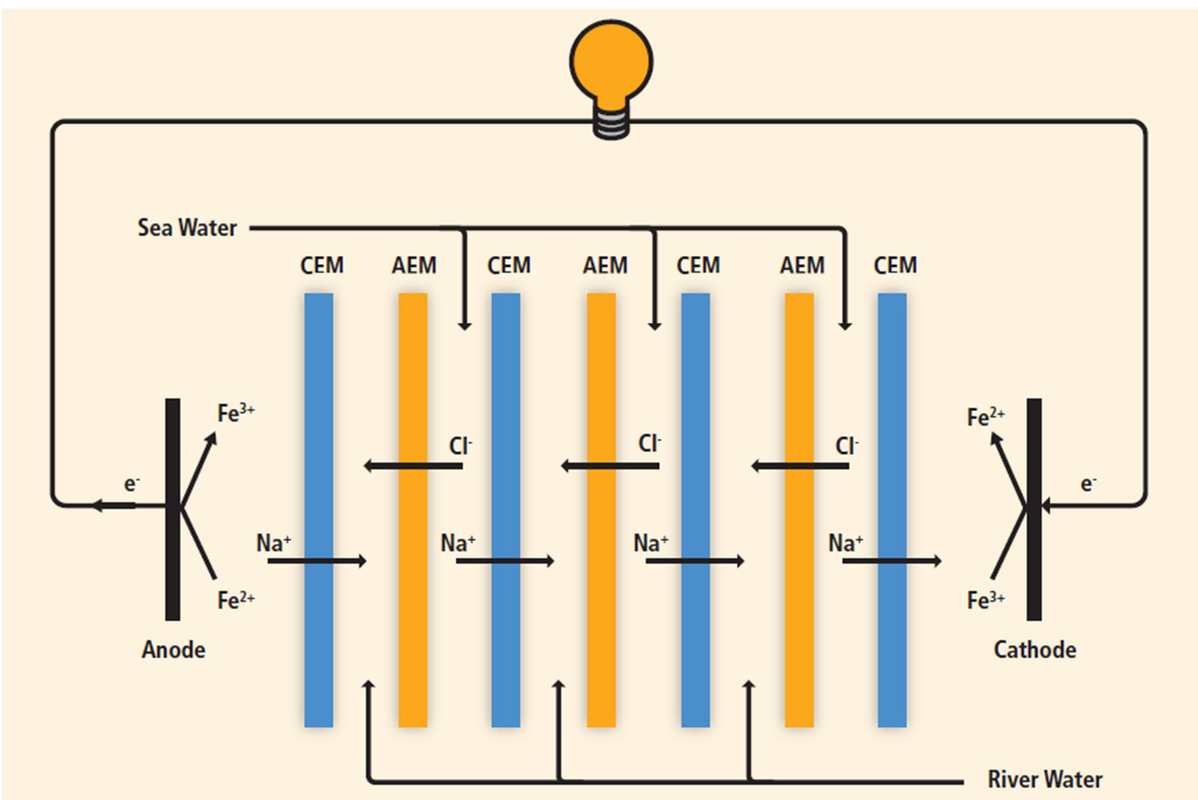


Fig.24: Reversed electro dialysis (RED) system [21].

Pressure-retarded osmosis (PRO), also known as osmotic power, is a process where the chemical potential is exploited as pressure. The PRO process utilizes naturally occurring osmosis caused by the difference in salt concentration between two liquids (for example, seawater and freshwater). Seawater and freshwater have a strong tendency to mix and this will occur as long as the pressure difference between the liquids is less than the osmotic pressure difference. In the membrane

module, freshwater migrates through the membrane and into pressurized seawater. The resulting brackish water is then split into two streams. One-third is used for power generation (corresponding to approximately the volume of freshwater passing through the membrane) in a hydropower turbine, whilst the remainder passes through a pressure exchanger in order to pressurize the incoming seawater (Figure 25). The brackish water can be fed back to the river or into the sea, where the two original sources would have eventually mixed. The first 5 kW PRO pilot power plant was commissioned in Norway in 2009 [21].
Recently, a new series of techniques has been invented, called "capacitive mixing", for salinity gradient energy recovery. Three different types of "capacitive mixing" processes have been studied, including capacitive double layer expansion (CDLE) devices, which store ions in the electric double-layer on the porous electrode surface when an external voltage is applied, devices based on capacitive Donnan potential (CDP), which employ ion-selective membranes to separate cations and anions, and mixing entropy batteries (MEB), which use battery electrodes that store and release specific ions [42].

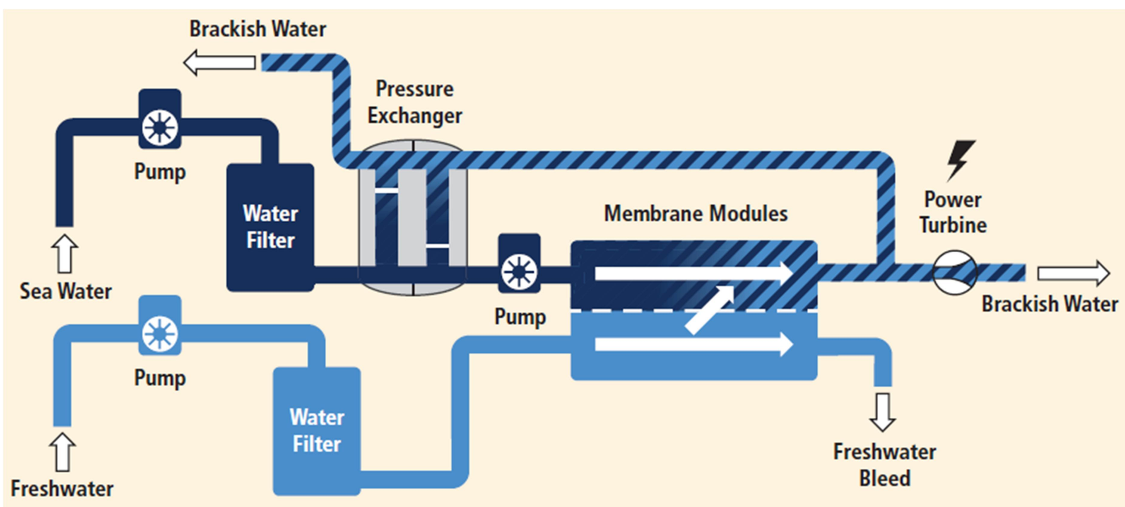


Fig.25: Pressure-retarded osmosis (PRO) process [35].

The MEB is a promising technology since it uses battery electrodes with relatively high specific capacity and low self-discharge. The study by Ye et al. [42], reported a 74% efficiency of energy extraction for this technology, making it a promising technology for salinity gradient energy recovery.

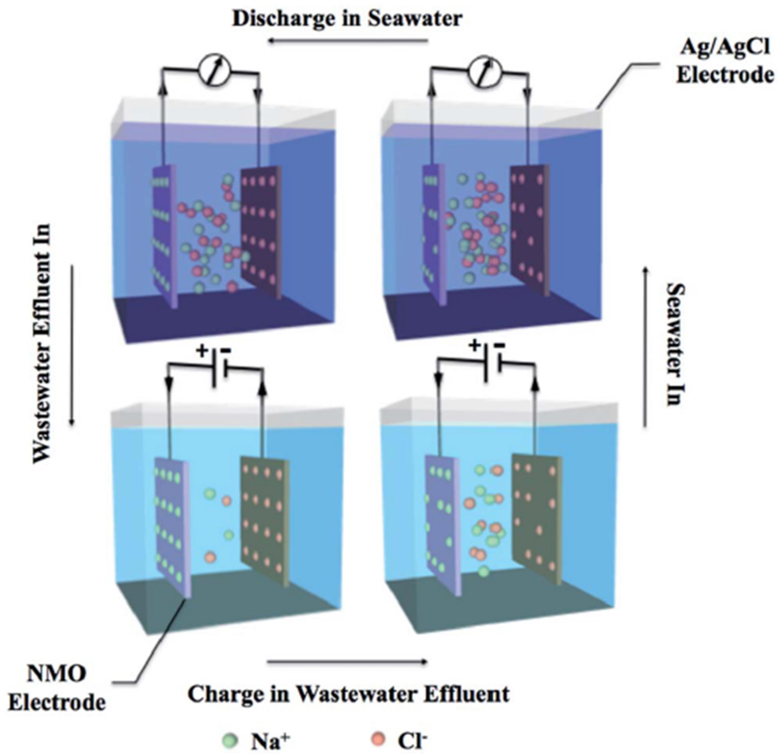


Fig.26: Work cycle of a mixing entropy battery [36].

Figure 26 illustrates the work cycle of a mixing entropy battery. The technology works in a way that first water stream of lower salinity flushes the cell, and ions in the electrodes are released into solution, after that seawater flushes the cell, and ions in the seawater enter the electrodes.

Membranes represent the critical part of the technology. Research is devoted to increase the net power density, actually of the order of 2-3 Watt per square meter, but reaching up to 20 Watt in particular test experiments. The cost of membranes is actually the main economic barrier for this technology.

A pilot plant, based on RED technology, has been developed in the Netherlands and produces energy from the difference in salinity between the surface water on the two sides of the Afsluitdijk dam. The 50kW pilot plant has been opened in 2013, the installation should reach a power of 200 MW.

An interesting future application is related to hybrid plants that use brine from desalination plants. A small RED pilot plant of this kind was operating in Trapani, on the west coast of Sicily. The RED unit was equipped with 50 square meters of ion exchange membranes and was tested with solutions of brackish water and saturated brine. The plant production was monitored for five months reaching a power of about 2.7 W/m^2 for cell pair.

The energy company Statkraft developed the first prototype of PRO plant in 2009. The plant is located at Tofte, Norway, in the premises of a cellulose factory. The plant uses 2000 square meters of membranes and could produce 10 kW, it powered a kettle for demonstration.

Actually investments by Statkraft in osmotic power have been stopped. Other initiatives testing PRO technology are in course in Canada, Singapore and South Korea.

The power available at a global scale in the form of salinity difference is very large, the energy released from 1m^3 of fresh water is estimated comparable to the energy released by one m^3 falling over a 260 m height. Moreover the availability and predictability of this form of energy are much higher than most of the other renewable sources. RED and PRO technologies are still at a demonstration phase, efforts are done to develop different methodologies [43].
The FP7 project Capmix has been devoted to study a different approach based on Double Layer Expansion (CDLE) technique [44], which allows more design flexibility respect to RED and PRO. A power density of about 300 W/m^3 has been reached in laboratory conditions.

9. Integration of different technologies on multi-functional platforms

A particular effort has been done at EU level in the sector of multi-functional platforms, with several projects financed under the FP7 program.

The degree of maturity of the different MREs is very different, the wave sector is at an earlier stage of development than the offshore wind sector, and only full-scale prototypes of wave converters have been tested. A way to boost the development of wave energy installation may be to promote the use of resource diversity to develop promising technical synergies, reduce the variability of renewable power and lower the system integration costs.

Moreover, beyond the cost reduction due to common foundation, common grid connection, power take off technologies and infrastructures for operability and maintenance, it is mostly desirable to foster the development of synergies with other activities such as gas platforms, aquaculture, fish farms and transportation.

Within this context, the MERMAID project, funded by the European Commission under the call FP7-OCEAN2011-1, is developing design concepts for a next generation of offshore platforms for multi-use of ocean space for energy extraction, aquaculture and platform related transport. Other recently ended FP 7 projects, TROPOS and H2Ocean also investigated similar concepts.

In [45] a new methodology for the design of a MUP based on technical, environmental, social and economic criteria is given. The methodology consists of four steps: a pre-screening phase, to assess the feasibility of different maritime uses at the site; a preliminary design of the alternative schemes based on the identified maritime uses; a ranking phase, where the performance of the MUPs is scored by means of expert judgment of the selected criteria; a preliminary design of the selected MUP selected. An example application of this procedure to a site offshore the Western Sardinia coast, Mediterranean Sea, Italy, is provided. In this site the deployment of a MUP consisting of wave energy converters, offshore wind turbines and aquaculture is specifically investigated.

Among the multi-platform projects in the Mediterranean Sea there is the ORECCA project Off - shore Renewable Energy Conversion platforms - Coordination Action (www.orecca.eu), and the YDRIADA floating platform that uses wind and solar energy to desalinate seawater to potable water.

ORECCA has analyzed the state of the art of current offshore RE converters and platform technologies they are being used in the sectors: oil and gas, offshore wind and ocean energy. The analysis has covered structural requirements and designs of the different technical solutions and described realized systems, including demo and pilot projects. The technical information provided has been processed so as to devise the possible scenarios of development and penetration of RE platforms in each area. Existing and demonstrated structural solutions are analyzed, synergies on both technical level (installation and operation) and non - technical level (cost, permits and other) have been identified.

"Ydriada" (fig.27) is an offshore floating construction designed mainly for desalination purposes. The platform is equipped with a wind turbine and solar panels capable to produce the energy required for the desalination process.

Due to the wind turbine installation, the platform is kept stable even for harsh meteorological or sea state conditions. For more information see the websites [46, 47].

The desalination unit is theoretically capable to produce 70000 lt of fresh water per day. The project has been co-financed by the Greek State (through the General Secretariat of Research and Technology) and EU. The project consortium consisted in several public and private partners including among others the University of Aegean, LAMDA SHIPYARDS SA, TECHNAVA SA, etc. The project has excelled at both national and European levels. The platform had been installed and operated off the shore in Iraklia Isl. (Cyclades complex in central Aegean Sea) for a period of 2.5 years, but then it was considered that is not capable to meet the fresh water needs for the island and its operation stopped. For a more detailed description see also [48].

Figure 27 - Ydriada desalination unit [46]

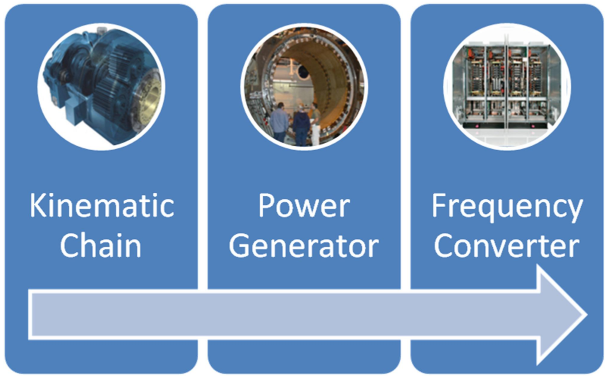
10. Supporting new technologies

Beyond the design of new devices for the exploitation of MREs, technological innovations in their classical components should be considered, leading to an increased efficiency of the device. Moreover, these kinds of innovation are transverse to all technologies so far discussed. In particular, a couple of important developments in the sector of Power Take Off (PTO), deserve some attention: a new patented technology named PYTHEAS, and the development of new materials, such Dielectric Elastomers. The objective of these new technologies is to solve an important obstacle to the development of MRE: a solution to convert slow motion into exploitable electric power in an effective way. PYTHEAS Technology is developing an innovative and patented Power Take Off (PTO) dedicated to renewable energy (Fig.28). The PYTHEAS Technology solution has the following characteristics:

- **Constant performance at low speed and partial load**, increasing the annual electricity production on a given site, for a same prime mover
- An **electrical torque not depending on rotational speed**, reducing the stress on the mechanical structures
- An **electronically controllable electrical torque** with millisecond precision, optimizing the dynamic behavior of the prime mover without costly and fragile mechanical control
- PYTHEAS Technology's PTO is a synchronous generator producing DC. Therefore, it requires **only one power conversion stage** for the production of grid code compliant electric power

WECs are generally based on traditional mechanical components, such as turbines. These represent often a bottleneck in the productivity of the device both for their cost and their efficiency. New materials are under study for the use in wave converters, in particular the Dielectric Elastomer Transducer (DET) technology seems to offer great potentialities in the wave energy sector.

Dielectric Elastomers (DEs) are highly deformable rubber-like solids, which are mechanically incompressible and electrically non-conductive. Deformable capacity transducers, capable of converting electricity into mechanical energy and vice-versa, can be realized by alternating DE and electrode layers. Materials used as DE are typically natural rubbers and silicone elastomers and can be very cheap. DE-based power take-off can help the development of wave energy converters for their characteristics; that include low cost, easiness of manufacturing and installation and tolerance to the salty/aggressive marine environment [49].



Power Take Off Scheme

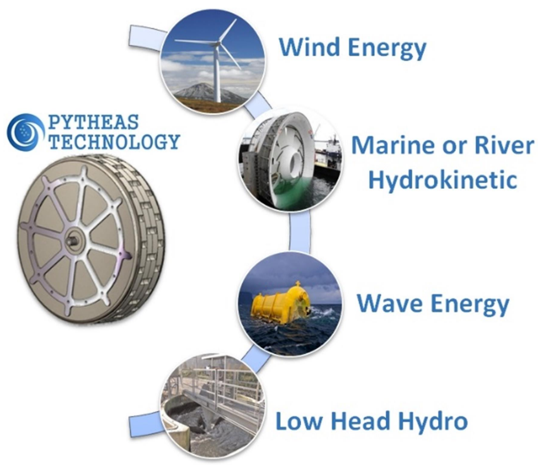


Figure 28 - Pytheas Power Take Off scheme

11. Conclusions

Relying upon results of previous projects such ENERCOAST and BLUENE, to which outputs in any case we refer, mainly for most mature technologies, the present document reviews the technologies most recently developed in the MREs sector.

Although we consider the European scale, a special focus on the technologies suitable for the application in the Mediterranean Sea has been maintained.

The wave energy sector is by far the most rich of innovations, mainly due to the variety of different solutions proposed, even though this situation is due to a lack of convergence in the proposed technologies, each one still being at a prototypal stage of development.

This analysis also pointed out that, in the case of already commercial technologies such offshore wind energy, the main obstacles to its large-scale diffusion in the Mediterranean Sea are the different policies and regulatory frameworks in these countries.

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13. Glossary

CAPEX: **CAP**ital **EX**penditure
LCOE: **L**evelized **C**ost **o**f **E**nergy
OPEX: **OP**erating **Ex**penditure
PTO: **P**ower **T**ake **O**ff