
WaveRoller wave energy device
developed by AW-Energy.

**243.4 MW**

*Capacity of ocean energy officially registered in the EU at the end of 2018*

# OCEAN ENERGY BAROMETER

*A study carried out by EurObserv'ER*

**The ocean energy sector has been a beehive of activity over the last three years with many prototypes being submerged off the British, Brittany, North Sea and Mediterranean coastlines. Tidal stream energy leads wave energy conversion and the other technologies in this ocean race. This is the first time that the sector has been specifically monitored for a regular EurObserv'ER theme-based barometer**

**3 678.5 kW**

*Capacity of tidal stream projects and prototypes deployed in the EU in 2018*

**444.2 kW**

*Capacity of projects and wave prototypes deployed in the EU in 2018*


La Rance tidal range power plant located between the municipalities of La Richardais and Saint-Malo, Ille-et-Villaine (Brittany)

The European Union Member States' exclusive economic zones, including the UK, offer a combined maritime area of more than 25 million km², which is the largest zone in the world and so offers huge energy recovery potential. The European ocean energies industry reckons that by 2050, 100 GW of wave energy and tidal stream energy capacities could be deployed in Europe. This capacity could meet 10% of Europe's current electricity needs. Some of the ocean technologies such as tidal stream energy and tidal range energy (see below) offer the advantage of the predictability that their forthcoming outputs will exceed those of wind energy. As for wave energy, its advantage is that it is more abundant in winter, which coincides with peak electricity demand. Ocean energy capacity, according to the International Energy Agency publication, Energy Technology Perspectives 2012, could be as much as 337 GW of global installed capacity by 2050 with about 30% (101 GW) provided by marine currents and 70% (236 GW) by waves. This figure might seem low compared to those of photovoltaic, which passed the 500 GW mark for on-grid capacity in 2018, and wind energy which had passed the 600 GW mark at the start of 2019 (591 GW at the end of 2018 according to the GWEC). Nonetheless, at the scale of certain countries with coastlines or islands like the British Isles, ocean energies have the potential to make a significant contribution to the total decarbonisation of their electricity mix and thus warrant the developers' current efforts.

### *A SET OF FIVE FAMILIES*

Ocean energy covers 5 distinct families that each has its own technologies.

Historically, **TIDAL RANGE ENERGY,** is the first ocean energy to have been deployed in Europe. It represents the energy potential created by tidal movement, more specifically the difference in level (the tidal range) between high water and low water. It is harnessed by constructing a barrage in a bay or across an estuary equipped with turbines (the same as those used in hydropower dams). It is the flow and ebb of the tide that in turn fills and drains the reservoir driving the turbines to generate electricity. Tidal range plants, like hydroelectricity dams, can also be fitted with pumped storage systems to increase the head of stored water to boost production when the tide ebbs. This system operates at the European Union's only tidal range power plant in service, across the La Rance estuary, Brittany. It has 240 MW of installed capacity, including about 20 MW dedicated to pumped storage. Other projects using this technology are currently in the pipeline, such as the UK's Swansea Bay Tidal Lagoon project (320 MW), which is based on a new design – that of an artificial lagoon that will fill up with water at high tide and drain out through sluices fitted with turbines as the tide ebbs.

**TIDAL STREAM ENERGY** harnesses the kinetic energy of tidal and ocean currents. It is generally drawn through marine turbines (akin to underwater wind turbines) anchored to the seabed or moored (often in pairs) under a barge or floater. According to Ocean Energy Europe, the European industry association, 18 projects were up and running in 2018 including 6 new machines that were immersed last year off France, the UK and Belgium with 3 678.5 kW of combined capacity **(see table 5).**

**WAVE ENERGY** is produced by wave movement. Many technologies convert wave energy into electricity by using point or



## Tabl. n° 1

**Ocean energy capacity installed** in the European Union at the end of 2017 (MW)

| | 2017 | | | | |
|---|---|---|---|---|---|
| | Wave energy | Tidal stream | Tidal range | Others | Total |
| France* | 0.0 | 0.0 | 218.9 | 0.0 | 218.9 |
| United Kingdom** | 5.7 | 12.7 | 0.0 | 0.0 | 18.4 |
| Spain | 0.5 | 0.0 | 0.0 | 4.5 | 5.0 |
| Portugal*** | 0.4 | 0.0 | 0.0 | 0.0 | 0.4 |
| **Total EU 28** | **6.6** | **12.7** | **218.9** | **4.5** | **242.7** |

**Ocean energy capacity installed** in the European Union at the end of 2018 (MW)

| | 2018 | | | | |
|---|---|---|---|---|---|
| | Wave energy | Tidal stream | Tidal range | Others | Total |
| France* | 0.0 | 0.0 | 218.0 | 0.0 | 218.0 |
| United Kingdom** | 5.7 | 14.7 | 0.0 | 0.0 | 20.4 |
| Spain | 0.5 | 0.0 | 0.0 | 4.5 | 5.0 |
| Portugal*** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total EU 28** | **6.2** | **14.7** | **218.0** | **4.5** | **243.4** |

** In France,in the UK, in Portugal, only the capacity of La Rance tidal power plant is taken into account in official statistics. The total power of this plant is 240 MW but includes a pumped storage device. Only renewable capacity part is taken into account in this table.*
*** In UK. devices are not permanently deployed at test sites and therefore operational project does not mean the devices are in the water permanently.*
**** In Portugal. the Pico Wavec plant (0.4 MW), located in the Azores was disconnected on 17th April 2018.*
***Source: EurObserv'ER 2019 based on national official statistics (some pilot projects may be missing).***

## Tabl. n° 2

**Ocean energy yearly installed capacity** in the European Union since 2010 (MW)

| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| France | 216.0 | 214.7 | 215.9 | 218.5 | 220.0 | 218.3 | 220.2 | 218.9 | 218.0 |
| United Kingdom | 4.000 | 4.0 | 9.0 | 8.0 | 9.0 | 9.000 | 13.0 | 18.4 | 20.4 |
| Spain | | | | | | | 5.0 | 5.0 | 5.0 |
| Portugal | | | | | 1.0 | | | 0.4 | 0.0 |
| **Total EU 28** | **220.0** | **218.7** | **224.9** | **226.5** | **230.0** | **227.3** | **238.2** | **242.7** | **243.4** |

***Source: EurObserv'ER 2019 based on national official statistics (some pilot projects may be missing).***

linear floaters, swell systems and even oscillating columns of water. In 2018, Ocean Energy Europe data identified 24 wave energy converter projects operating along the coasts of 9 European Union countries. No fewer than 8 machines (spread over 7 projects) were submerged in 2018, off Italy, the UK, France, Denmark and Greece **(table 4),** for 444.2 kW of combined capacity.

**OCEAN THERMAL ENERGY CONVERSION** (OTEC) exploits the temperature difference in a classic thermodynamic cycle, between the warm surface water available in some of the world's oceans (at 25–30°C) and the cold deep seawater (at about 4°C from a depth of 800 m and below). This technology is still at the low-capacity demonstrator stage and its commercial development lags far behind that of marine turbines and wave energy converters. For some years, current OTEC projects have been concentrated on ons-

Launch of the tidal turbine Sabella D10

Nathalie Wernimont-Donfut/Balao/Sabella

hore rather than on floating installations that are technically more complex. In 2012, Naval Energies installed a 15 kW OTEC prototype on land on Reunion Island and another test bench was installed in 2017 in Martinique as part of the Marlin project (led by Ademe).

The sea's thermal energy can also be recovered by other processes. Spain's gas supplier, Enagas, has hit on the idea of using its liquified natural gas (LNG) methane offloading terminal regasification plant in the port of Huelva in Southern Spain. It operates a 4.5 MW plant on its son site that uses the temperature difference between the seawater (which acts as the hot spot) and the liquified natural gas (which acts as the cold spot) to generate electricity. Another recovery method uses this temperature difference to produce heat or cooling. Commercially viable SWAC seawater air-conditioning projects are already operating in Europe. This process exploits the temperature difference between the warm surface water and the cold deep water pumped through pipes to buildings heat them or cool them. On the coast, heat exchangers and heat pumps can produce heat or cooling as needed. This process is used by the Engie Centrale Thalassia plant inaugurated in 2016 in the port of Marseille (France). It supplies heat and cooling to all the buildings connected to it via a 3 km pipeline network. Eventually this network should supply 500 000 m² of offices in the Euroméditerranée ecodistrict.

The fifth ocean energy to be identified is **SALINITY GRADIENT ENERGY** which uses the energy that can be exploited from the difference in salinity between seawater and freshwater. The natural phenomenon of osmosis is characterized by the transfer, through a semi-permeable membrane (water permeable only), of the water from the environment with the lowest salt concentration (freshwater) to where it is the most concentrated (seawater), to the point where concentration equilibrium is reached either side of the membrane. The difference in salinity makes the water move, which exerts pressure in the saltwater compartment. The resulting water pressure drives a power generating turbine. Like OTEC, this technology is still in the development phase. The first 4 kW prototype was tested in Norway in 2009 by the public company Statkraft, on the Tofte site south-west of Oslo. A technical variant called Reversed Electro Dialysis has also been successfully tested in the Netherlands on the Afsluitdijk dike, with the sea on one side and freshwater on the other side. RedStack has operated the 50 kW Dutch demonstrator since 2014. It uses 1 m³/s of freshwater and the same amount of seawater. The company intends to use its process to produce hydrogen directly and increase capacity to 1 MW.

### AT LEAST 263 MW IN SERVICE AT THE END OF 2018

Statistics on the very varied ocean energy sectors can be somewhat hit and miss. So far, the official statistics bodies have not monitored the on-grid prototypes, while the constant turnover (immersion, improvement and decommissioning phases) of the prototypes tested over relatively short time spans (in the region of 1–2 years) does nothing to clarify the active projects' details. The findings of the survey of official statistical bodies conducted by EurObserv'ER are presented in **tables 1 and 2.** They are consistent with the follow-up of the Eurostat database indicators on a long series. Thus, the official estimate of the European Union's renewable on-grid ocean energy capacity (excluding pumped storage, for the specific case of the La Rance tidal range power plant) is put at 243.4 MW in 2018 (242.7 MW in 2017). Electricity output (excluding pumped storage) has slipped slightly from 526.2 to 489.3 GWh **(table 3).**





EurObserv'ER has chosen to publish another ocean energy capacity follow-up indicator in this barometer that includes all the pre-commercial prototypes and demonstrators that were operating in 2018 **(table 4).** This is based on the list of active projects reported by Ocean Energy Europe, on the tidal stream and wave energy technologies. EurObserv'ER has supplemented the list with a few active projects that use other ocean energies such as tidal range, OTEC and salinity gradient systems. This indicator differs slightly because it puts the capacity in service during 2018 at 263.4 MW, including the 4.1 MW of projects that went on grid that year. The few statistical differences between countries are explained in the following paragraphs. As stated above, the capacity of active ocean sites does not represent all the machines that have been tested over the past decade. In its annual publication, Ocean Energy Key trends and statistics 2018, published by the Ocean Energy Europe association monitored tidal stream and wave energy converter projects. It claims that 3.7 MW of projects using marine currents were submerged during 2018, which is more than double the amount in 2017 **(table 5).** Furthermore, 26.8 MW of projects using tidal stream energy have been deployed since 2010, and of that total, 11.9 MW are currently operational, which means that 14.9 MW have been taken out of service since they completed their test programme. As for wave energy converter technology, Ocean Energy Europe identified 7 new projects for a combined capacity of 444 kW in 2018 **(table 6).** Since 2010, 11.3 MW of projects have been deployed, but only 2.9 MW were operating in 2018, which means that 8.4 MW were taken out of service on completion of their test programmes.

## *10 EU COUNTRIES ARE WAITING ON THE SLIPWAY*

### BRITTANY TAKES ON THE TIDAL STREAM CHALLENGE FOR FRANCE

The ocean energy capacity and production figures released by the French Ministry of Ecological and Inclusive Transition's Monitoring and Statistics Directorate (SDES), only refer to the La Rance tidal range power plant. Its capacity is 240 MW, but it includes a pumped storage device. The plant's renewable capacity excluding pumping varies very slightly from year to year. It was recorded at 218 MW in 2018 compared to 218.9 MW in 2017. The plant's electricity output dropped between 2017 and 2018. If we include output from pumping, it slipped from 565 GWh in 2017 to 522 GWh in 2018, and without the pumped output, from 522 GWh in 2017 to 480 GWh in 2018. Therefore, the official data does not cover the pre-industrial Sabella D10 marine turbine demonstrator that was immersed in the Fromveur Passage off Ushant Island. This 1 MW project (rotor diameter 10 metres) was connected to the ERDF grid for the first time in 2015 and tested for a year. The marine turbine was raised in 2016 to improve its system. In October 2018, the modified marine turbine was re-immersed in the same place, taken out of the water again in April 2019 to correct a fault detected in the engine cooling system and finally submerged in the Iroise Sea on 5 October 2019. It is planned to operate the marine turbine until 2021 pending commissioning of the Phares project led by Akuo Energy. Phares provides a hybrid insular energy model combining three renewable energy sources and plans to install two Sabella D12-500 marine turbines (rotor diameter 12 meters and 500 kW per unit), a 0.9 MW wind turbine, a 500 kW solar photovoltaic farm and a 2 MWh energy storage system provided by EDF SEI. This multi-energy project, which is backed by public finance through PIA 3 (Strategic Investment Programme) and the Brittany Region, combined with existing energy projects, will enable renewable energy to cover 70% of Ushant Island's needs in 2023. A second marine turbine, called "Hydroquest Ocean" developed by the Isère manufacturer Hydroquest and its partner Constructions Mécaniques de Normandie (CMN), was connected to the French national grid at the end of May 2019 and has been injecting electricity since the middle of June. This 1 MW marine turbine is 25 metres wide and 11 metres high and was submerged for a year on the test site of Brehat Island (Côtes d'Armor) developed by EDF. The manufacturer puts the tidal stream potential at 3 GW in France and 10 GW in Europe.

### PROJECTS ABOUND IN THE UK

The UK's interest in ocean energies is based on their potential. A BEIS (Department for Business, Energy and Industrial Strategy) memorandum published in 2013, states that wave energy and tidal stream energy have the theoretical potential to meet 20% of the UK's electricity demand with 30–50 GW of installed capacity. The UK's "tidal stream" and "wave energy" sectors are particularly active, with the political and strategic resolve to get their industries underway as fast as possible. The official BEIS count identified 18 active projects in 2018 for 20.4 MW of combined capacity (2 MW up on 2017). The output of only three of these 18 projects, is monitored (i.e. a total of 9.3 GWh). The Ocean Energy Europe association's figures are slightly lower coming in at 13.3 MW of capacity at the end of 2018. The difference between the lists arises from Ocean Energy Europe's decision to remove certain projects that they consider have been permanently mothballed.

The UK has the distinction of having the first and biggest commercial marine turbine array on the MeyGen project site in Pentland Firth, Scotland. The first phase of this project (MeyGen Phase A1) entailed installing 4 No. 1.5 MW turbines in October 2016. The first three hydroelectricity turbines were built by Andritz Hydro Hammerfest (AH1000 MK1) and the fourth by Simec Atlantis Energy (AR 1500). The BEIS reported its electricity output at 7.2 GWh in 2018. Since March 2017, the project has been accredited by OFGEM which manages the ROCs (Renewable obligation certificates) system and it was formally commissioned in April 2018 with plans to run for 25 years. The site is now in its second development phase (Phase 1B) to set up a hub to connect several turbines to a single power export cable and connect two new 2 MW marine turbines (Atlantis AR 2000) in 2019 or 2020, which will be the most powerful ever constructed. This phase will be carried out as part of the Stroma project which has European funding through the NER300 programme. A third phase (Phase 1C) plans to add an additional 49 turbines (73.5 MW). The Crown Estate operating licence awarded for the site is for 398 MW, which augurs well for new development phases if the previous phases are successful.

In one of the latest large projects, the Spanish developer, Magallanes Renovables, towed its ATIR tidal platform (2 MW) from the port of Vigo to its Scottish test site. The prototype was installed on the

Boarding of the tidal turbine "Hydroquest Ocean".

PHILIPPE GOSSELIN/AVOTRIMAGE/HYDROQUEST

Fall of Warness tidal test site, one of the European Marine Energy Centre's five major test sites in Orkney (see note 1). The specific site offers current technology developers various locations with a grid connection in depths ranging from 12–50 meters. This 45 metre long tidal platform has two immersed rotors 19 metres in diameter and was commissioned and went on-grid in 2019. The demonstrator has been developed and received 1.9 million euros of funding under the European Ocean_2G project (second-generation ocean energy technologies) from the European Commission's Horizon 2020 research and innovation programme. On the same site, the Scottish developer Orbital Marine Power (formerly Scotrenewables Tidal Power Limited) recently removed (in September 2018) its SR-2000 tidal turbine installed since 2016. It is now concentrating on developing the 2 MW Orbital O2 commercial scale demonstrator, comprising a 73 metre long floating superstructure, supporting two No. 1 MW rotors with rotor diameters of 20 metres. The demonstrator will be installed on the same site in 2020. It has been developed as part of the FloTEC (Floating Tidal Energy Commercialisation) project and benefited from 10 million euros (7.74 million pounds) of Horizon 2020 funding.

## THE OTHER EUROPEAN COUNTRIES SHOWING INTEREST

Behind the UK and France, eight other European Union coastal countries are developing innovative prototypes and demonstrators. It has to be said that some manufacturers do not test their prototypes in their own territorial waters as a matter of routine but opt to test and connect their demonstrators in dedicated test centres, in Scotland for instance, as in the example of Spain's Magallanes Renovables mentioned above.
Officially, Spain officially claims to have 5 MW of capacity including the innovative concept of recovering the thermal energy of the seas through the Enagas plant in Andalusia and the wave energy converter plant run by the Basque Energy Agency in Mutriku harbour in the Bay of Biscay (296 kW). This plant is a one-off as it is the world's first breakwater plant to harness wave energy using several turbines. The concept is special because the plant, sheltered by a dike, produces electricity through the force of the waves that crash against it. Spanish statistical data protection legislation prevents the release of electricity output statistics for these two plants as the number of projects and their capacity is too low. However, the 2013 Enagas Annual Report indicates that in normal operating mode the ocean thermal energy plant in the port of Huelva produces about 24 GWh per annum, while according to Basque Energy Agency, the Mutriku harbour plant produces about 1.3 GWh per annum.
As for Portugal, it no longer has any active plants. Its only working wave energy plant (Pico project) in the Azores was decommissioned for good after an accident in April 2018. In the other countries where projects and manufacturers are registered, such as Italy, Sweden, Denmark, Belgium, the Netherlands and Greece, the dearth of official statistical sector monitoring can be put down to the status of the prototype, demonstration plant used for R&D purposes or the low level of connected capacities. Yet we would mention the latest devices to be submerged... the Danish Crestwing wave energy converter project with a 300 kW attenuator type machine installed in Frederikshaven port

*1) The European Marine Energy Centre (EMEC) located in the Orkneys to the far north of Scotland is a test and research centre primarily devoted to ocean energies. It offers developers the possibility of testing their prototypes and connecting them to the grid across the various specialist test sites that offer excellent marine current and wave conditions.*

## Tabl. n° 3

Electricity production from ocean energy in the European Union in 2017 (GWh)

| 2017 | Wave energy | Tidal stream | Tidal range | Others | Total |
|---|---|---|---|---|---|
| France* | 0.0 | 0.0 | 522.0 | 0.0 | 522.0 |
| United Kingdom | 0.0 | 4.2 | 0.0 | 0.0 | 4.2 |
| Portugal | 0.006 | 0.0 | 0.0 | 0.0 | 0.006 |
| Spain | n.a | n.a | n.a | n.a. | n.a. |
| Total EU 28 | 0.006 | 4.2 | 522.0 | 0.0 | 526.2 |

Electricity production from ocean energy in the European Union in 2018 (GWh)

| 2018 | Wave energy | Tidal stream | Tidal range | Others | Total |
|---|---|---|---|---|---|
| France* | 0.0 | 0.0 | 480.0 | 0.0 | 480.0 |
| United Kingdom | 0.0 | 9.3 | 0.0 | 0.0 | 9.3 |
| Portugal | 0.000 | 0.0 | 0.0 | 0.0 | 0.0 |
| Spain | n.a. | n.a. | n.a. | n.a. | n.a. |
| Total EU 28 | 0.0 | 9.3 | 480.0 | 0.0 | 489.3 |

** The electricity production of La Rance tidal power plant, taking into account pumped storage. was 565 GWh in 2017 and 522 GWh in 2018.*
**Source: EurObserv'ER 2019.**

### Substantial support from the European Commission

The issue of production costs is vital to safeguard the commercial development of ocean technologies. Developers have various support mechanisms to reduce costs, via regional funds, national and European programmes. The European Commission is particularly involved in developing ocean energies. Thus, the developers benefit from funding under the European Commission's Horizon 2020 research and innovation programme through dedicated projects (e.g.: the Ocean_2G and FloTEC projects) or via the NER 300 programme (e.g.: the STROMA project).
They can also take up inter-regional project funding via the European Interreg programme. It aims to finance economic development or environmental management cooperation projects between European regions. A particularly ambitious Interreg project, the Tiger (Tidal Stream Industry Energiser) project, directly involving the marine turbine sector was announced on 16 October 2019. It is part of the Interreg France (Channel) England Programme to develop submerged turbines off the coasts to harness tidal stream energy. It thus aims to foster growth in the area of marine energy turbines by developing machines of capacities up to 8 MW. This programme will serve to demonstrate the economic profitability of marine turbine energy so that it can enter England's and France's energy mix, by using economies of scale through mass production. The project preamble states that the total theoretical tidal energy capacity in the Channel region is nearly 4 GW – enough to power up to three million homes.
The project budget is 46.8 millions euros, making it the biggest ever of the 75 Interreg programmes to be financed in the 2014-2020 programming period. Carolyn Reid, Programme Manager for the Interreg France (Channel) England Programme said: "The long-term aim is to support the industry to reduce generating costs of tidal stream energy from the existing € 300 MW/h to € 150 MW/h by 2025 and increase uptake. There is an EU target to reach € 100/MWh by 2030". The funding will particularly help the machine manufacturers (such as Hydroquest, Orbital Marine Power, CMN, Minesto AB, etc.), university research programmes, the EMEC centre and other French and British tidal stream players.

## Tabl. n° 4

List of projects using ocean energies in operation in 2018 having been active during the year 2018

| Summary | Device Developer | Technology | Location | Year | Total capacity (MW) |
|---|---|---|---|---|---|
| **France** | | | | | |
| Estuary of La Rance* | EDF | Tidal Range | Richardais – Saint-Malo | 1966 | 240.000 |
| EEL at Brest | EEL | Tidal Stream | Port of Brest | 2017 | 0.010 |
| Ouessant | Sabella | Tidal Stream | Brittany – Fromveur | 2018 | 1.000 |
| Test in La Rochelle | HACE | Wave energy | Port of la Rochelle | 2018 | 0.050 |
| Test in Seeneoh | DesignPro Renewables and Mitsubishi Electric | Tidal Stream | Seeneoh | 2018 | 0.025 |
| Test p66 | Guinard Energies | Tidal Stream | Port of Brest | 2018 | 0.004 |
| Total France | | | | | 241.089 |
| **United Kingdom** | | | | | |
| Open Hydro scale demonstration | Naval Energies | Tidal Stream | EMEC (Scotland) | 2006 | 0.250 |
| Eco Wave Power - Gibraltar | Eco Wave Power | Wave energy | Gibraltar (England) | 2016 | 0.100 |
| MeyGen phase 1A | Andritz | Tidal Stream | Pentland Firth (Scotland) | 2016 | 4.500 |
| Scotrenewables Tidal Power Ltd | Orbital Marine Power | Tidal Stream | EMEC (Scotland) | 2016 | 2.000 |
| MeyGen phase 1A | SIMEC Atlantis Energy | Tidal Stream | Pentland Firth (Scotland) | 2016 | 1.500 |
| Shetland tidal array | Nova Innovation | Tidal Stream | Bluemull Sound. Shetland (Scotland) | 2016 | 0.300 |
| Mingary Bay | Albatern | Wave energy | Mingary Bay (Scotland) | 2016 | 0.045 |
| EMEC | Wello Oy | Wave energy | EMEC (Scotland) | 2017 | 1.000 |
| Nautricity demonstration EMEC | Nautricity | Tidal Stream | EMEC (Scotland) | 2017 | 0.500 |
| Sustainable Marine Energy Plat-I | Schottel Hydro | Tidal Stream | Connell Sound (Scotland) | 2017 | 0.280 |
| InToTidal | Tocardo | Tidal Stream | EMEC (Scotland) | 2017 | 0.250 |
| HiWave | CorPower Ocean | Wave energy | EMEC (Scotland) | 2017 | 0.025 |
| Marine Power Systems | Marine Power Systems | Wave energy | Ramsey Sound. Pembrokeshire (Wales) | 2017 | 0.010 |
| Magallanes Renovables EMEC demonstration | Magallanes Renovables | Tidal Stream | EMEC (Scotland) | 2018 | 2.000 |
| Fish farm shetland | Aqua Power Technologies | Wave energy | Shetland (Scotland) | 2018 | 0.005 |
| Holyhead Deep | Minesto | Tidal Stream | Anglesey (Wales) | 2018 | 0.500 |
| Total United Kingdom*** | | | | | 13.265 |
| **Spain** | | | | | |
| Voith Hydro. Ente Vasco de la Energia (EVE) Project | Voith Hydro | Wave energy | Pais Vasco | 2011 | 0.296 |
| Planta de Huelva. OTEC (between ocean and Liquified natural gas) | Enagas | OTEC | Huelva. Andalousia | 2013 | 4.500 |
| Wedge | Wedge | Wave energy | Plocan. Gran Canaria | 2014 | 0.200 |
| Oceantec - oscilating water column prototype | Oceantec | Wave energy | Biscay Marine Energy Platform | 2016 | 0.030 |
| Total Spain | | | | | 5.026 |
| **Netherlands** | | | | | |
| IHC Merwede | IHC Merwede | Wave energy | Western schelde | 2009 | 0.030 |
| Afsluitdijk project (reverse electrodialysis techno) | Redstack | Salinity gradient | Afsluitdijk | 2014 | 0.005 |
| Oosterscheldedam | Tocardo | Tidal Stream | Oosterscheldedam | 2015 | 1.250 |
| Tocardo Afsluitdijk | Tocardo | Tidal Stream | Afsluitdijk | 2015 | 0.300 |
| Total Netherlands | | | | | 1.585 |
| **Sweden** | | | | | |
| Seabased - Sotenas Phase 1A** | Seabased | Wave energy | Sotenäs | 2016 | 1.080 |
| Total Sweden | | | | | 1.080 |
| **Portugal** | | | | | |
| Wavec | | Wave energy | Azores | 1999 | 0.400 |
| Total Portugal | | | | | 0.400 |
| **Italy** | | | | | |
| Messina Strait | ADAG | Tidal Stream | Strait of Messina | 2000 | 0.050 |
| Wave for Energy | Wave for Energy | Wave energy | n.a. | 2015 | 0.200 |
| Port of Naples | University of Campania | Wave energy | Port of Naples | 2015 | 0.003 |
| Wavenergy | Wavenergy | Wave energy | Civittavecchia | 2016 | 0.020 |
| 40South Marina di Pisa | 40South energy | Wave energy | Marina di Pisa | 2018 | 0.050 |
| Adriatic | OPT | Wave energy | Adriatic | 2018 | 0.003 |
| Total Italy | | | | | 0.326 |
| **Denmark** | | | | | |
| Wavepiston at DanWEC prototype project | Wavepiston | Wave energy | Danish Wave Energy Centre. Hanstholm | 2017 | 0.012 |
| Test in Denmark | Crestwing | Wave energy | Port of Fredrikshaven | 2018 | 0.300 |
| Wavepiston at DanWEC prototype project | Wavepiston | Wave energy | Danish Wave Energy Centre. Hanstholm | 2018 | 0.012 |
| Total Denmark | | | | | 0.324 |
| **Belgium** | | | | | |
| Demo Antwerp | Water2Energy | Tidal Stream | Port of Antwerp | 2018 | 0.150 |
| Total Belgium | | | | | 0.150 |
| **Greece** | | | | | |
| Port of Heraklion | SINN Power | Wave energy | Heraklion | 2016 | 0.024 |
| Port of Heraklion | SINN Power | Wave energy | Heraklion | 2017 | 0.048 |
| Port of Heraklion | SINN Power | Wave energy | Heraklion | 2018 | 0.048 |
| Total Greece | | | | | 0.120 |
| **Total EU 28** | | | | | **263.365** |

** The 240 MW La Rance Tidal range power station includes some pumped storage capacity. ** Because of the increased efficiency of the new generators, the 36 WECs of the Seabased Sotenas project suggest an installed capability up to 3 MW instead of 1 MW. *** There is a discrepancy between the BEIS official data on the total capacity of marine energy installed in the United Kingdom and those from the Ocean Energy Europe database, which has withdrawn some projects, considering that they are no longer operational.*

***Source: Ocean Energy Europe 2019 (for wave and tidal stream projects), EurObserv'ER 2019 (for tidal range projects, salinity gradient and ocean thermal energy projects)***

and the new pressure differential version (50 kW) of the wave energy converter developed by 40South Energy, which is being tested on the Marina di Pisa test site off the Tuscan coast. Other active projects of note are the Sotenäs (Phase 1) demonstration project of the wave energy converter array in Sweden, connected at the end of 2015 in the North Sea at a depth of 50 metres off the towns of Sotenäs and Smögen. The project, developed by Seabased and financed by the Fortum energy company and the Swedish Energy Agency has installed 36 No. 30 kW wave energy converters, i.e. just over 1 MW. Ireland also has strategic goals to develop a wave energy sector. The grid manager ESB Network has already signed contracts for

## Tabl. n° 5

**European tidal stream deployments** by country in 2018

| Country | Location | Device Developer | Type | Capacity (kW) | Number of Turbines |
|---|---|---|---|---|---|
| France | Seeneoh | DesignPro Renewables and Mitsubishi Electric | Vertical axis | 25.0 | 1 |
| | Port of Brest | Guinard Energies | Horizontal axis | 3.5 | 1 |
| | Brittany - Fromveur | Sabella | Vertical axis | 1 000.0 | 1 |
| UK (Scotland) | EMEC | Magallanes Renovables | Vertical axis | 2 000.0 | 1 |
| UK (Wales) | Anglesey | Minesto | Kite | 500.0 | 1 |
| Belgium | Port of Antwerp | Water2Energy | Vertical axis | 150.0 | 1 |
| Total | | | | 3 678.5 | 6 |

*Source: Ocean Energy Europe 2019*

## Tabl. n° 6

**European wave energy deployments** by country in 2018

| Country | Location | Device Developer | Type | Capacity (kW) | Number of Devices |
|---|---|---|---|---|---|
| Italy | Marina di Pisa | 40South energy | Submerged pressure differential | 50 | 1 |
| | Adriatic | OPT | Point absorber | 3 | 1 |
| UK (Scotland) | Shetland | Aqua Power Technologies | Point absorber | 5.2 | 1 |
| Denmark | Port of Fredrikshaven | Crestwing | Attenuator | 300 | 1 |
| | Danish Wave Energy Centre, Hanstholm | Wavepiston | Attenuator | 12 | 1 |
| France | Port of la Rochelle | HACE | Oscillating water column | 50 | 1 |
| Greece | Heraklion | SINN Power | Point absorber | 24 | 2 |
| Total | | | | 444.2 | 8 |

*Source: Ocean Energy Europe 2019*

two wave energy connection project sites. The first will connect the Atlantic Marine Energy Test Site (AMETS) intended to take 10 MW of capacity and the second is the 5.4 MW WestWave project off Killard, County Clare.

### A SHARP REDUCTION IN COSTS IS EXPECTED AND MEASURED

Like offshore wind energy, current ocean energy costs vary wildly from project to project (site, depth, capacity, etc) and it is still too early to come up with standard tidal stream or wave energy converter reference costs. If we accept the precedent of offshore wind energy, LCoE projects costs should come costs rapidly as arrays are commissioned. In May 2018, ORE Catapult, one of the UK's main offshore energy research centres, provided the first elements on the cost reduction trajectory in its publication “Tidal stream and wave energy cost reduction and industrial benefit”. It claimed that the mean tidal stream cost for pilot projects that are already operating is £ 300/MWh (34.7 ct€/kWh). They forecast that permanent reductions will be made on a relatively low deployment volume, based on their analyses and the industry's commitments. Thus, they aim for a LCoE of £ 150/MWh (17.39 ct€/kWh) from 100 MW installed, £ 130 MWh from 200 MW installed (15.07 ct€/kWh) and £ 90/MWh (10.43 ct€/kWh) from 1 GW installed. As for wave energy converter technology, the mean cost of operating pilot projects is more than £ 300/MWh – a figure that should be considered with caution because it is hard to talk about LCoE for a technology that is still at the prototype stage. The European Commission's Joint Research Centre (JRC) calculations of the LCoE of technologies that use marine currents, based on some twelve MW of active projects at the end of 2018 came out at 34–38 ct€/kWh in 2018. The same indicator produced in 2015 put the LCoE at 60 ct€/





The fourth tidal turbine of the Meygen project in Scotland.

SIMEC Atlantis Energy

kWh... a reduction of over 40% observed in three years. Incidentally, the JRC notes that this reduction is bigger than was expected in 2015 as the 2015 trend forecast a LCoE of 40 ct€/kWh for a 12 MW deployment level. These sharp reduction costs stem from the increased reliability of the apparatus deployed in demonstration projects. On-going demonstration projects show that electricity can be continuously generated and that load factors of 37%, and even more are feasible.
In March 2018, the European Commission published an implementation plan for ocean energy as part of the Strategic Energy Technology Plan (SET Plan). The document describes the necessary stages, timescale and estimated financing needs to take ocean energy technologies to commercial deployment in Europe by 2025 and 2030. Tidal stream and wave energy converter LCoE cost targets were quantified and set to reduce to at least 15 ct€/kWh in 2025 and 10 ct€/kWh in 2030, as the capacity of the installed projects rises. For wave energy technology, it forecasts a similar pathway through convergence in development and reach at least the same cost targets a maximum of 5 years later, i.e. 20 ct€/kWh in 2025, 15 ct€/kWh in 2030 and 10 ct€/kWh in 2035. According to Ocean Energy Europe, these targets are in line with those set by the sector in 2016 – namely 20 ct€/kWh by 2030 for tidal stream for 10 GW of installed capacity and 10 ct€/kWh by the 2035 timeline for wave energy for the same installed capacity.

### ENTERING THE COMMERCIALISATION PHASE

If we exclude tidal range energy, which is technically very close to that of hydroelectricity dams, ocean energy technologies have not yet reached the commercial phase where machines will be mass-produced with the appropriate durability and reliability to operate over the long term. The most advanced sector in this respect is the tidal stream sector, which is gathering feedback on full-scale prototypes, namely “commercial” size turbines at the scale of one MW. During this phase, turbines are still evolving and perfectible and will be tested over a fairly short period, typically one or two years, to validate the technology choices. Ocean Energy Europe predicts that by 2020 tidal stream will enter a new project phase with more rugged machines that will pave the way for commercial operation with higher-capacity arrays. This stage will call for guaranteed remuneration systems to be set up, such as Feed-in Tariffs. One positive indication is the growing interest shown by the major global industrial concerns like General Electric. The American company's Power's GE Conversion business branch announced in May 2019 that it had entered into a technology partnership agreement with the Turbine and Engineering services division (ATES) of the British company Simec Atlantis Resources. This partnership is part of the high capacity marine turbine development on tidal currents called Atlantis AR2000. This type of marine turbine will be the world's largest and most powerful single axis turbine. The system should be deployed during future phases of Atlantis' iconic MeyGen project in Scotland (see above).
OTEC and salinity gradient technologies, for their part, are promising but still require additional developments and public investment decisions to implement major projects. The NEMO project, the first offshore electricity plant to use ocean thermal energy conversion with a capacity of 10.7 MW in Martinique, developed by Akuo Energy and Naval Energy (a Naval Group subsidiary), was officially suspended in April 2018, as a result of technical difficulties developing a reliable water pumping system at great depth and the decision of local councillors to withdraw their support for the project. So, while tidal range energy projects have already proved themselves technically, they do not arouse overwhelming approval on the grounds of their environmental impacts in estuaries that are highly sensitive environmental areas.

### CROWDFUNDING ENLISTED

Ocean energies, like the more common renewable sectors, use crowdfunding campaigns to raise funds for their projects. It is never easy to mobilize capital for a new firm or project and this is even more applicable to ocean energy sectors whose procedural or regulatory time scales can be long, whose initial investments are often significant and whose

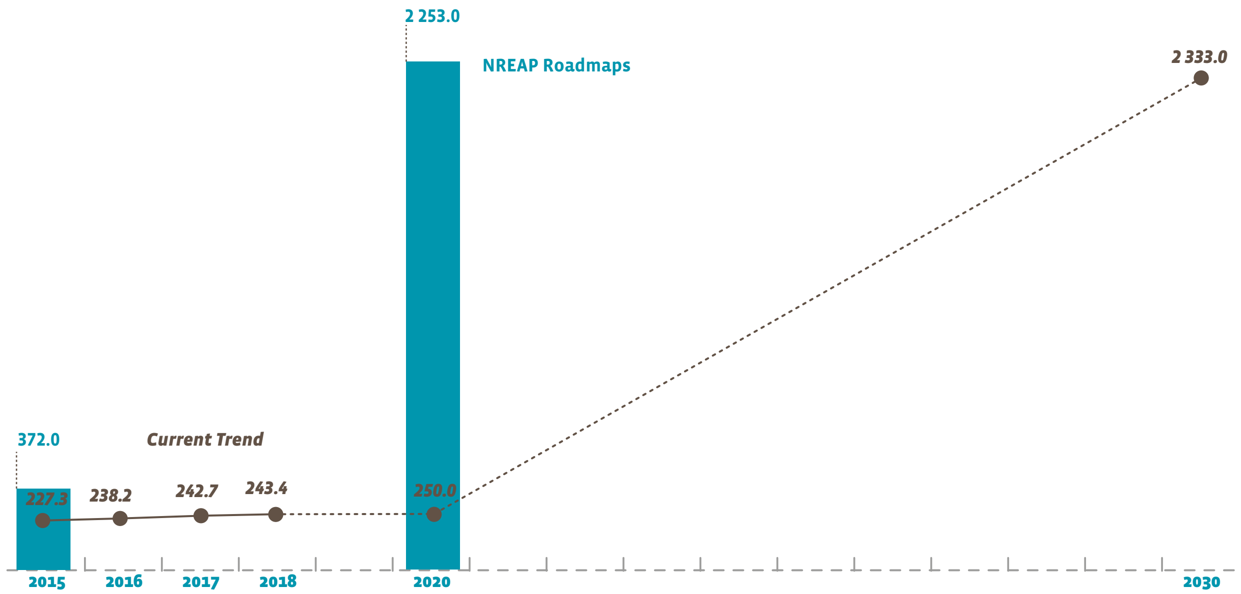
chances of failure are higher than with technologies with longer track records. In addition to providing them with another source of income, to top up traditional bank loans, crowdfunding is also a way of ensuring the backing and recognition of the section by the general public that identifies with the funded projects. The American publication, The Marine Executive, has identified fundraising for over 20.7 million euros over the 2012-2018 period for projects mainly sited in Europe. When broken down by technology, wave energy projects attracted 6.2 million euros compared to more than double, i.e. 13.9 million euros for tidal range technologies. The main beneficiaries include the British with Simec Atlantis Energy (formerly Atlantis Resources) and WITT Energy as well as the Finns Wello Oy and the Scots with Orbital Marine Power.
In 2018, Swedish firm Seabased launched a crowdfunding campaign to contribute to its R&D work. It initially pitched for a € 550 000 target, but the firm decided to extend its campaign given the speed at which it reached its first target. In the end, the campaign raised 1.5 million euros. Another example is, Orbital Marine Power, which in January 2019 completed its campaign to finance its project for the first commercial floating tidal turbine with a capacity of 2 MW. Funds to the tune of 8.1 million euros were thus raised involving 2 300 individuals. Average investment was £ 3 000 (3 475 euros) which entitled individuals to a tax credit. Orbital Marine Power has committed to repay each lender within 2.5 years and with an annual interest rate of 12%.

## CONSERVATIVE GOALS FOR THE 2030 TIMELINE

Admittedly, the ocean energy deployment targets to the 2020 timeline (excluding offshore wind energy), defined in 2010 by the National Renewable Energy Action Plans under the previous Renewable Energy Directive of 2009, were over-optimistic about the timing of capacity build-up. These plans effectively aspired to targets of 1 300 MW in the UK, 380 MW in France, 250 MW in Portugal, 135 MW in the Netherlands, 100 MW in Spain, 75 MW in Ireland and 3 MW in Italy **(graph 1).** Over the current decade, the quicker industrial and "commercial" maturing of the wind energy (onshore and offshore), photovoltaic and biomass sectors, certainly delayed the deployment of ocean energies. Furthermore, caution needs to be exercised on the deployment capacities of these sectors by the 2030 timeline. Even if the various pieces of the puzzle have started to fall into place, it is too soon to clearly establish the growth pace of the various ocean technologies in the next decade, if not propose different growth scenarios. Incidentally, the European Commission has submitted to this exercise by commissioning and publishing a market study in May 2018, entitled "Market study on ocean energy" conducted by WavEC (ocean engineering association) and COGEA (Construction Générale de l'Atlantique).
The work suggests three worldwide and Europe-wide growth scenarios for ocean energy sector capacities through to 2030. In the optimistic scenario, technologies using ocean currents (tidal stream) should reach 2.4 GW in 2030, with 93% concentrated in Europe (i.e. about 2.2 GW), as well as 0.5 GW of wave energy with 87.5% in Europe (i.e. about 0.44 GW). For its part, tidal range energy should reach 1 GW with 72% deployed in Europe (0.72 GW), which

## Graph. n° 1

Comparison of the current trend of ocean energy capacity installed against the NREAP (National Renewable Energy Action Plans) roadmap (in MW)




Source: EurObserv'ER 2019.




2 MW floating tidal turbine (Orbital Marine Power)

corresponds to commissioning two new sites in Europe including the key Swansea Bay Tidal Lagoon (320 MW) project off the Welsh coast. Ocean thermal energy should reach 28.5 MW, essentially deployed overseas. In the end, European ocean energy capacity would amount to 3.4 GW.
In the medium scenario and by the same timeline, tidal stream should reach, 1.6 GW (with 90% in Europe), wave energy 370 MW (with 85% in Europe), tidal range energy 840 MW (with 66.7% in Europe, i.e. 560 MW meaning that only the Swansea project would be added) and OTEC 18.5 MW overseas. The total for the medium scenario should just exceed 2.3 GW. Lastly, in the pessimistic scenario, tidal stream should only reach 700 MW (with 92% in Europe), wave energy 70 MW (58 MW in Europe), no new tidal range energy would emerge (520 MW globally including the 240 MW at La Rance) and OTEC, 17.5 MW overseas.
The conclusion of this first EurObserv'ER barometer dedicated to ocean energies is thus that these promising sectors have still a long way to go, especially in industrial terms to achieve their commercialisation targets and become integrated into the national electricity mix. However, we suggest that the significant backing made by the national and European research and development programmes will enable these sectors to emerge successfully, with the full blessing of the general public. □

*Sources : SDES (France), BEIS (United kingdom), CBS (Statistics Netherlands), IDAE (Spain), DGEG (Portugal), SEAI (Ireland Rep.), Swedish Energy Agency, ENS (Denmark), ETIPOCEAN, Observ'ER, Ocean Energy Europe.*

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