# Ocean energies, moving towards competitiveness: a market overview

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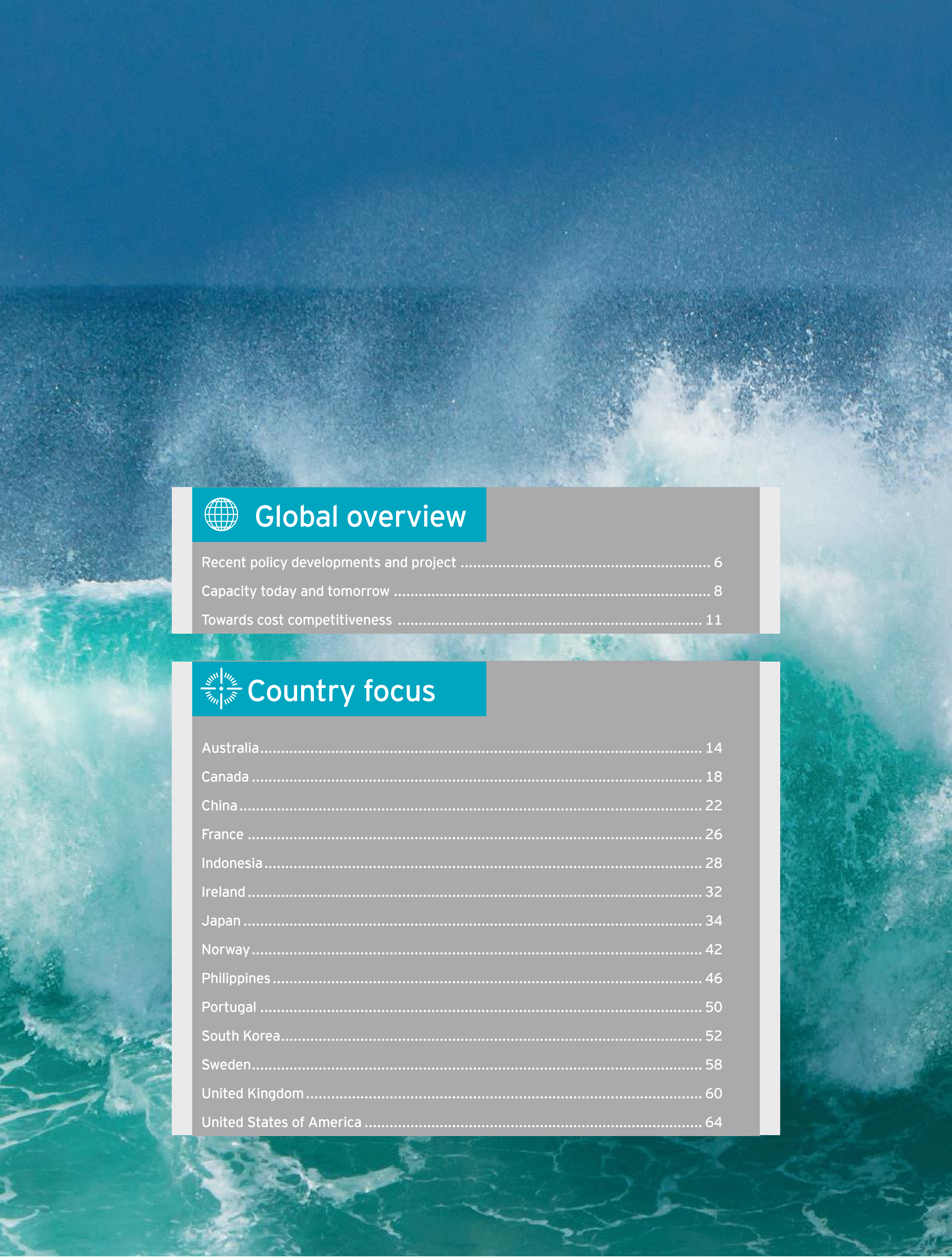
# Contents



## Global overview



## Country focus

# Global overview

## Introducing ocean energies

The transition to a clean energy future requires our societies to diversify their energy mix and include a growing share of renewable energies. While we have experienced tremendous growth and cost reductions of solar and wind power in the last decade, we need to continue exploring all forms of renewables to secure the overall reliability and availability of renewables and ensure that they will meet the growing demand for electricity.

The world's ocean have a sheer potential to provide for future energy needs. The kinetic, potential, chemical or thermal properties of seawater can be exploited by numerous technologies, producing energy from different phenomena occurring in the ocean : tidal range, tidal stream and ocean currents (referred to as tidal stream energy in this report), waves, thermal (OTEC) and salinity gradients. This report also includes floating offshore wind turbines (FOWT) in its analysis. Ocean energies produce electricity without emitting greenhouse gases and from local resources well distributed around the globe and available in coastal areas near densely populated areas with high energy demand. Subsequently, ocean energies have the potential to support the transition towards a cleaner energy mix and greater energy independence, in particular for island communities.

In addition to their potential to contribute to macro policy goals, ocean energies have a number of advantages for local development. While other forms of renewables struggle with the issue of competing land use and acceptability, ocean energies can be installed in locations less sensitive to such concerns. Most forms of ocean energies are also reasonably forecastable and constant enough to provide a base load of electricity.

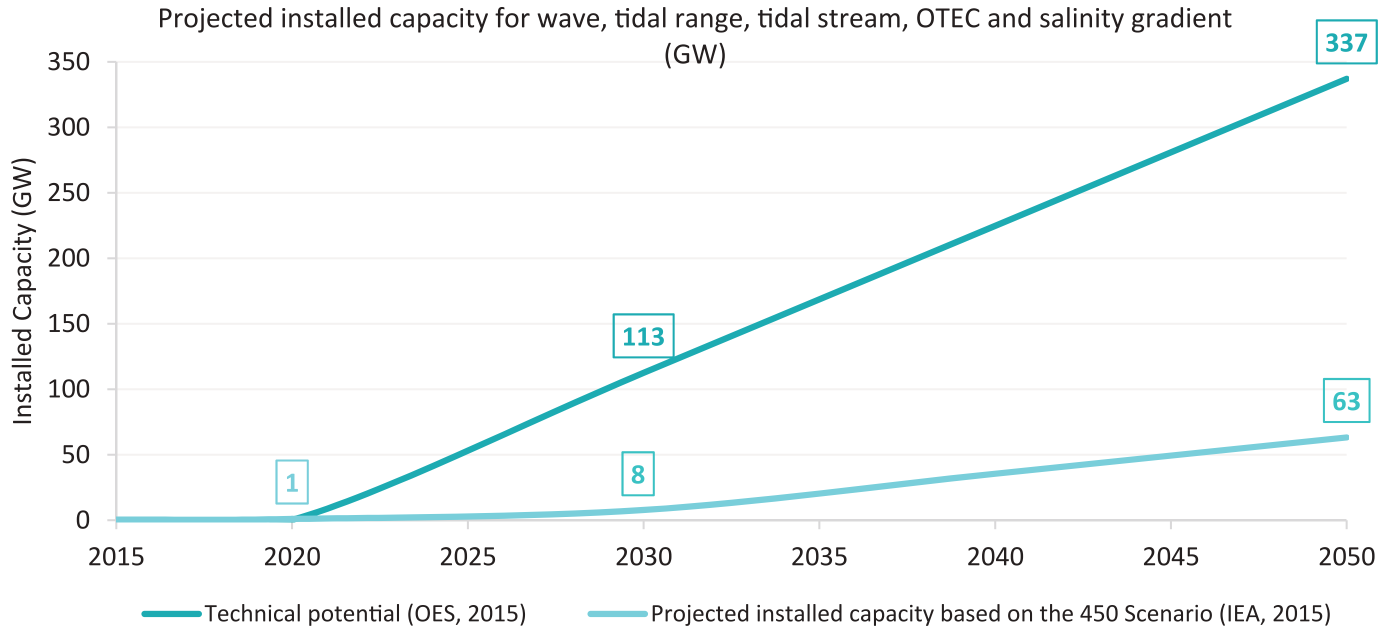
## Current market position and capacity forecast

Despite this tremendous potential, ocean energies represent only a small share of the global energy mix. In 2015 the global installed capacity of ocean energies reached 562 MW (including 15MW of floating offshore wind), an increase of 32 MW compared to 2014, mainly due to the installation of 19 MW in the UK (tidal stream and wave power)[1] and of a 7 MW floating offshore wind turbine for the Fukushima Forward II project in Japan. Ocean energies represent 0.03% of the global renewable energies installed capacity and South Korea, France, the UK and Canada together account for more than 90% of the world's installed ocean power. The contribution of ocean energies to the global electricity production therefore remains marginal.

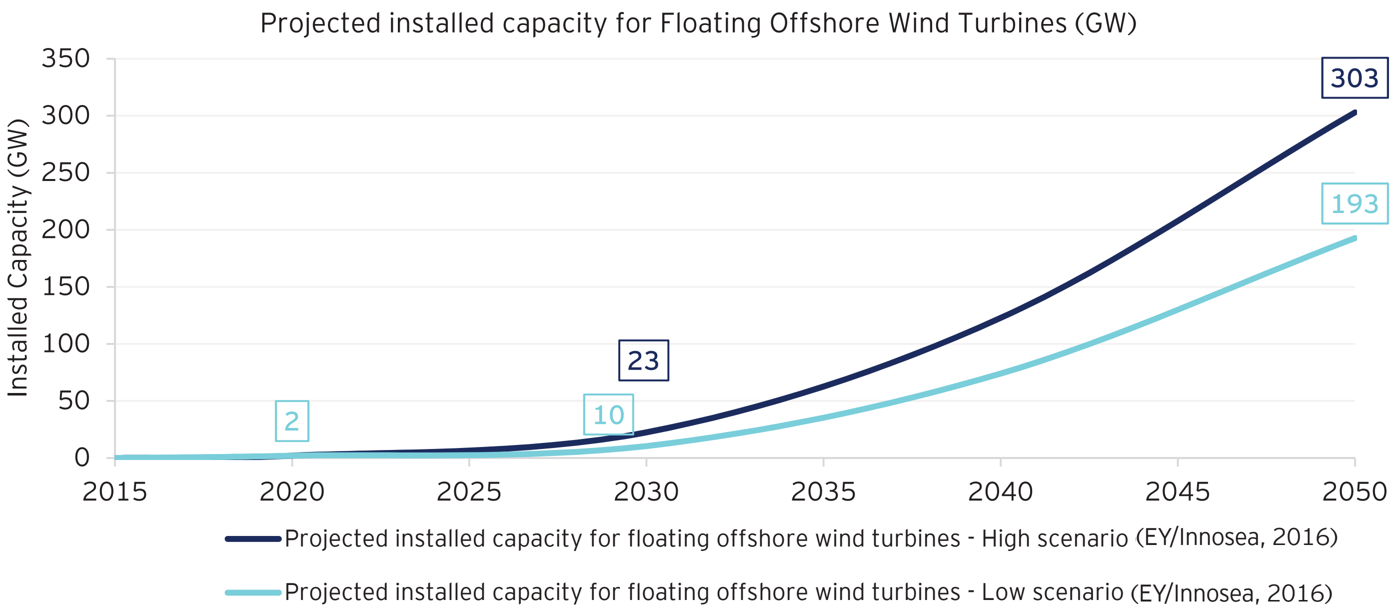
There is however a large potential to scale up ocean energies in the long run. The theoretical resource would be sufficient to meet present and projected global electricity demand, ranging from 20,000 TWh to 80,000 TWh per year, representing 100% to 400% of the current global demand[2].

For wave, tidal (range and stream), OTEC and salinity gradient, Ocean Energy Systems estimates a worldwide potential of 337 GW that could be developed by 2050, which would create nearly 300,000 direct jobs and allow reducing C02 emissions by 1 billion tons[3]. This estimate conveys a vision of the technical potential and does not take into account the current and expected policy framework. Such factors may well influence the development of ocean energies and are included in the projections issued by the IEA for the same ocean energies. In the 450 Scenario, which represents an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C, the IEA forecasts 36 GW installed by 2040[4]. The sharp difference between the technical potential and the 450 scenario predictions incites to consider the future development of ocean energies with regard to their enormous theoretical potential, bearing in mind the currently limited political ambitions to develop these energies and technical optimisation to be achieved. For the 2020 milestone, estimates range from a few hundred mega watts to 2 GW of installed capacity. Patent activity supports these estimates, showing a very strong interest of market and industry players in ocean energy technologies: between 2009 and 2013, there were 150 annual registrations for patents on average[5]. In Europe, Ocean Energy Europe identified a project pipeline of 302 MW to be installed by 2020[6].

1. *IRENA (2016), Renewable Capacity Statistics 2016*
2. *IEA (International Energy Agency) (2013), Energy Technology Initiatives 2013*
3. *Ocean Energy Systems (2016), Annual Report 2015*
4. *IEA (2015), World Energy Outlook database*
5. *Ocean Energy Systems (2016), Annual Report 2015*
6. *Ocean Energy Forum (2015), Draft Ocean Energy Strategic Roadmap*




*Sources: Ocean Energy Systems (2016), Annual Report 2015; EY (2016), Strategic assessment on floating offshore wind (confidential), Carbon trust (2015), Floating Offshore Wind: Market and Technology Review*




*Sources: Ocean Energy Systems (2016), Annual Report 2015; EY (2016), Strategic assessment on floating offshore wind (confidential), Carbon trust (2015), Floating Offshore Wind: Market and Technology Review*

Based on the announced projects to date, there should be 2 GW of floating offshore wind turbines installed by 2020. Estimates range from 10 GW to 25 GW in 2030 with a long term projection of 195 to 305 GW installed by 2050.

## Different deployment levels

Ocean energy is an emerging industry and most technologies are still at an early testing stage. Strong technical challenges resulting from the difficulty of working in an offshore environment have slowed down the expected pace of development over the past couple of years, raising uncertainties for commercial deployment in the medium term.

To date, only tidal range technologies are commercially mature, cumulating 0.5 GW of global installed capacity. This technology however faces strong opposition for its environmental and visual impacts as it consists of large dams installed across bays. Most of other ocean energies have smaller impact and are more modular; they are subsequently receiving growing interest. Apart from tidal range, tidal stream, wave energy and floating offshore wind turbines (FOWT) are the most advanced technologies available and have the highest potential for commercial development in the medium term. Several demonstration projects with a capacity of a few MW are being tested and they are expected to reach commercial maturity in the 2020s. While leading developers in tidal stream power are testing individual prototypes in offshore environments and converging to a dominant technology concept, there is more design divergence in wave energy and FOWT, for which demonstrators are being tested but no concept has emerged as dominant yet. Nonetheless, three FOWT concepts are ready to scale up to pre-commercial arrays. Several OTEC plants are currently being planned in tropical areas and should be installed by 2020 – the main impediment to a faster development of this technology remains the high capital investments it involves. To date salinity gradient technologies remain at the R&D stage.

*"In Ushant, where the cost of electricity production reaches EUR450/MWh, a project integrating conventional renewable energies with tidal stream energy and a storage facility with an energy monitoring system could be directly competitive."*

*Jean Ballandras, Akuo Energy*

### *Renewable electricity storage for a better integration in the grid and a greater energy independence*

The challenge of storage of the electricity produced by renewable energies is crucial to ensure that they can grow as a major share of the global energy mix. Renewable resources are generally irregular, steered by meteorological conditions or astronomic forecasts. Moreover, their integration into the grid is modifying the economic merit order due their limited OPEX. While gas power plants build most of the current back-up capacity, they are being pushed out of the market by renewable energy sources. With less gas plants operating to provide back-up energy during consumption peaks, the variability of renewables becomes more problematic. Energy storage could be an answer to this problem, as electricity produced by renewables during lower consumption time slots could be delivered during consumption peaks.

This challenge is gaining momentum in the sector, including amongst large utilities. After Total bought Saft, a leading French battery producer in June 2016, Engie took controlling interest of Green Charge networks, a Californian company specialised in battery storage.

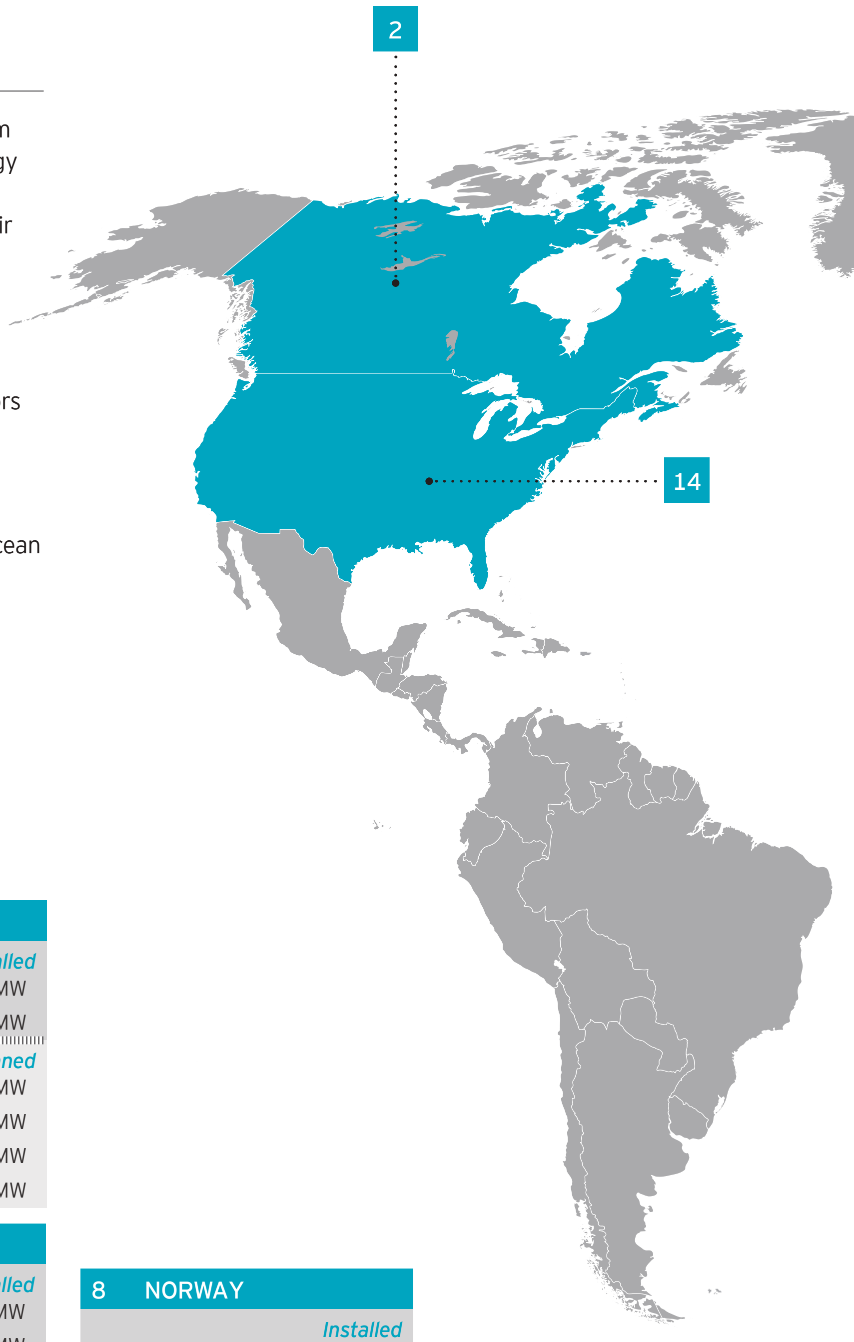
Although ocean energies are subject to this challenge, they are generally more predictable than most renewable energies. Ocean energies are subsequently highly relevant to experiment grid integration, even more in Island territories where electricity production costs are high. The successful implementation of a storage technology combined with various renewable energy sources would further increase the competitiveness of ocean energies and all other renewable energies, enabling them to cover a greater share of electricity needs.

## Recent policy developments supporting Ocean Energies

Policy support has been growing in several countries, in the form of market incentives, roadmapping, sectoral maritime and energy strategies, legislation improvements to facilitate licensing, and government funding. In the recent years, countries directed their efforts towards building a reliable and legible policy and legal framework for the development of ocean energies.

In terms of government funding, several States financially committed to supporting the emergence of a national industry while also implementing market incentives to encourage investors and energy providers getting involved alongside technology developers.

The Country Focus section of this report presents a detailed overview of policy developments and ongoing progress in the ocean energy sector for a selection of countries.




| 1 AUSTRALIA | |
|---|---|
| | *Installed* |
| Wave | 1.25 MW |
| | *Planned* |
| Wave | 3 MW |

| 2 CANADA | |
|---|---|
| | *Installed* |
| Wave | 0.759 MW |
| Tidal range | 20.5 MW |
| | *Planned* |
| Tidal stream | 22 MW |

| 3 CHINA | |
|---|---|
| | *Installed* |
| Wave | 0.5 MW |
| Tidal range | 4.1 MW |
| Tidal stream | 0.2 MW |
| OTEC | 0.015 MW |
| | *Planned* |
| Wave | 2.8 MW |
| Tidal range | 0.5 MW |
| Tidal stream | 4.8 MW |

| 4 DENMARK | |
|---|---|
| | *Planned* |
| Wave | 0.05 MW |

| 5 FRANCE | |
|---|---|
| | *Installed* |
| Tidal range | 240 MW |
| Tidal stream | 2.5 MW |
| | *Planned* |
| Wave | 1.5 MW |
| Tidal stream | 14 MW |
| OTEC | 10 MW |
| FOWT | 36 MW |

| 6 JAPAN | |
|---|---|
| | *Installed* |
| Wave | 0.15 MW |
| Tidal stream | 0.61 MW |
| FOWT | 11 MW |
| | *Planned* |
| Wave | 350 MW |
| FOWT | 116 MW |

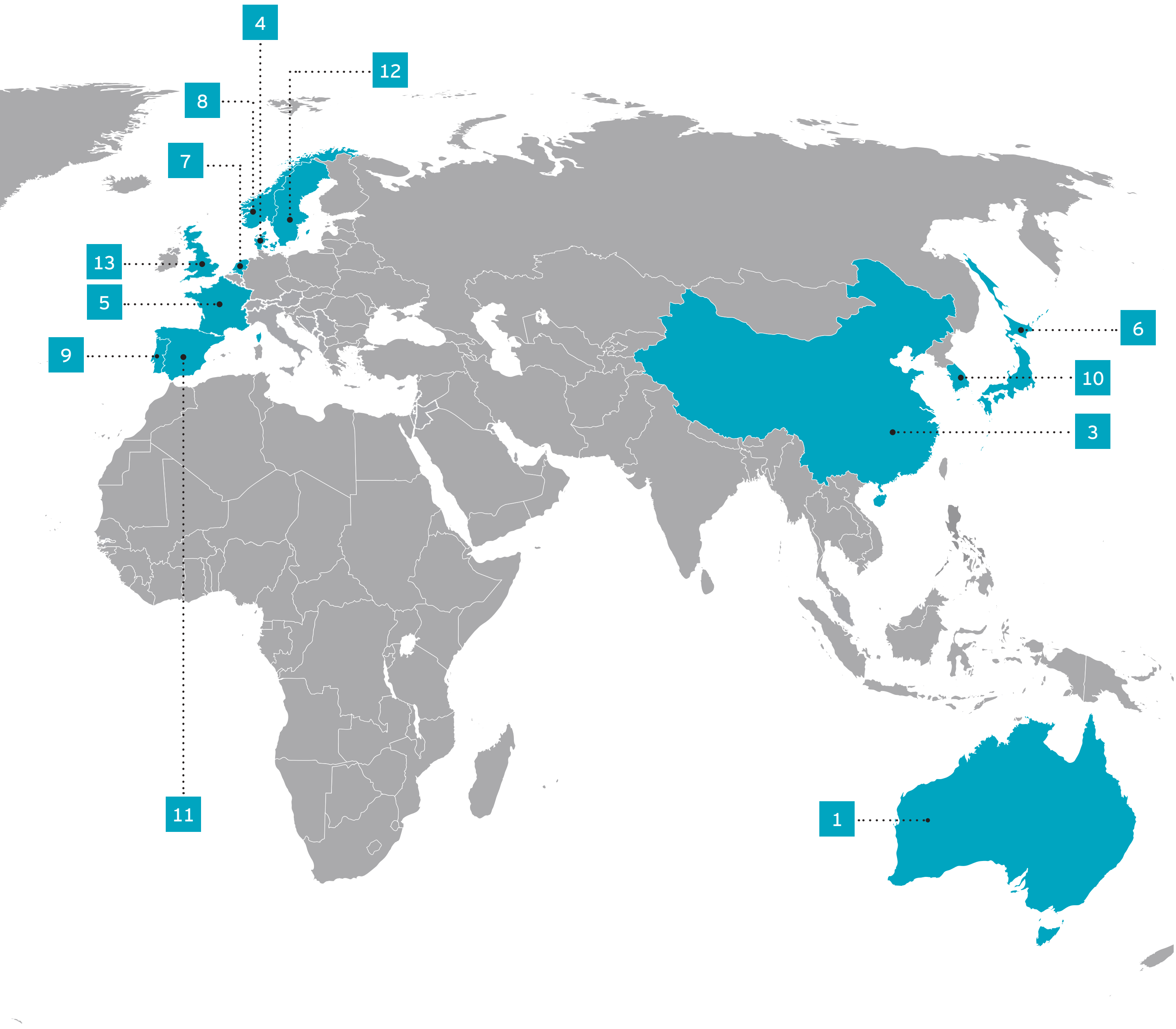
| 7 NETHERLANDS | |
|---|---|
| | *Installed* |
| Tidal stream | 1.3 MW |
| Salinity | 0.05 MW |
| | *Planned* |
| Tidal stream | 1.6 MW |
| Salinity | 100 MW |

| 8 NORWAY | |
|---|---|
| | *Installed* |
| Wave | 0.2 MW |
| FOWT | 2.3 MW |
| | *Planned* |
| Wave | 40 MW |
| Tidal stream | 9.8 MW |

| 9 PORTUGAL | |
|---|---|
| | *Installed* |
| Wave | 0.5 MW |
| FOWT | 4.35 MW |
| | *Planned* |
| Wave | 5 MW |
| FOWT | 150 MW |

| 10 SOUTH KOREA | |
|---|---|
| | *Installed* |
| Wave | 0.5 MW |
| Tidal range | 254 MW |
| Tidal stream | 1.5 MW |
| OTEC | 0.2 MW |
| | *Planned* |
| Wave | 0.3 MW |
| Tidal stream | 0.2 MW |
| OTEC | 1 MW |

*Source: EY/Innosea and press releases, 2016*




| 11 SPAIN | |
|---|---|
| | *Installed* |
| Wave | 0.3 MW |

| 12 SWEDEN | |
|---|---|
| | *Installed* |
| Wave | 0.2 MW |
| Tidal stream | 0.008 MW |
| | *Planned* |
| Tidal stream | 10.4 MW |

| 13 UNITED KINGDOM | |
|---|---|
| | *Installed* |
| Wave | 1 MW |
| Tidal stream | 2.1 MW |
| | *Planned* |
| Wave | 40 MW |
| Tidal stream | 96 MW |
| FOWT | 110 MW |

| 14 USA | |
|---|---|
| | *Installed* |
| FOWT | 0.06 MW |
| | *Planned* |
| Wave | 1.5 MW |
| Tidal range | 1.4 MW |
| FOWT | 1,658 MW |

# Capacity today and tomorrow

## WAVE POWER

Waves offer a large source of energy that can be converted into electricity by a wave energy converter (WEC). There are several principles for converting wave energy using either fixed onshore devices or mobile devices at sea.

More than 100 wave power pilot projects in the world have been launched over the past few years, including some deployed and tested at full scale[7]. Total installed capacity is about 4 MW, with 1 MW installed in the UK, about 0.76 MW in Canada and 0.4-0.5 MW in South Korea, China and Portugal.

Wave power energy plants' main challenge today is to drive down the LCOE, which remains higher than any other marine energy technologies, including tidal energy. However, over the past few years, large engineering firms (DCNS, Lockheed Martin, Mitsubishi Heavy Industries, Mitsui, etc.) and utilities (EDF, Iberdrola, Vattenfall, Fortum, etc.) have shown interest in wave power, and could accelerate cost reduction through volume effect and strong R&D support.

| WAVE POWER* | Installed capacity[8] | Planned |
|---|---|---|
| | 4 MW | 411 MW |

## TIDAL RANGE

Tidal turbines are designed to convert the kinetic energy of ocean and tidal currents into electricity or into a second pressurised fluid. Tidal range uses a dam to use the power from the height difference between low and high tide, through turbines located in the dam. The energy of tides is predictable but also localised, the most suitable sites being those where ocean currents are particularly strong.

The tidal range technology has been well established since the construction of the Rance dam in France (240 MW)[9]. Since that date, smaller-scale tidal range plants were built in Russia (0.4 MW, 1968), China (5 MW, 1980), Canada (20 MW, built in 1984), the UK (1.2 MW, 2008) and South Korea (1.5 MW, 2009). The latest (and largest) tidal range plant was built in 2012 in South Korea, with a total capacity of 254 MW. Further tidal range projects are planned for a total capacity of 1.9 MW, mainly in the USA and China.

| TIDAL RANGE* | Installed capacity | Planned |
|---|---|---|
| | 519 MW | 2 MW |

## TIDAL STREAM

Similarly to tidal range technology, tidal stream uses turbines to convert the kinetic energy of tidal currents into electricity. Tidal stream technologies are more recent and have been developed in dozens of different designs. The most frequent designs include horizontal-axis turbines (positioned in parallel to the flow of water), vertical-axis turbines (positioned perpendicular), and enclosed turbines (in order to concentrate currents going through the turbines).

Tidal stream technologies are at an early stage of development. Over the past few years, several prototypes have been developed in different countries, and some of them are being tested at full-scale in the UK (2.1 MW installed), France (2.5 MW), Korea (1 MW) and the Netherlands (1.3 MW).

Following this proof of concept, large engineering firms (General Electric, Siemens, Voith, Andritz, DCNS) have entered the market, and large utilities have started running demonstration projects (EDF, Engie, Iberdrola, Bord Gais Energy). Although several technologies exist (such as vertical axis and enclosed turbines), most of the projects ran by these actors tend to converge towards the use of horizontal axis turbines.

Similarly to other ocean energy technologies, tidal stream energy's high LCOE will need to be decreased for projects to become commercially mature. To decrease costs, financial support (in the form of capital investments, feed-in-tariffs etc.) may be critical. This financial support should allow the installation of larger scale arrays of turbines, hence taking the technology closer to a potential market deployment.

The first larger scale array of farms that could take the technology one step further towards commercialisation are expected in the UK, France and Canada between 2016 and 2020.

| TIDAL STREAM* | Installed capacity | Planned |
|---|---|---|
| | 8 MW | 139 MW |

7. *IRENA (2014), Wave energy, technology brief*
8. *Ocean Energy Systems (2016), Annual Report 2015*
9. *IRENA (2014), Tidal energy, technology brief*

* *Installed and planned capacities are based on the figures of the countries included in the scope of the current study.*

## FLOATING OFFSHORE WIND (FOWT)

Floating offshore wind turbines are mounted on a floating structure, they are consequently not constrained by the same depth limitations as bottom-fixed turbines. While bottom-fixed turbines can hardly be installed where depths are greater than 50m, floating wind turbines can be anchored in deep waters, 50-120m depth being optimal. Underwater cables are used to transfer the electricity onshore. These floating structures can be located further away from the shore, granting access to a greater resource of steadier and stronger winds. Their impact on landscapes and risks of conflicting land use with leisure activities are also reduced. In the future, they could become a growth driver for the wind power sector, allowing the offshore wind industry to reach a much higher resource than with the bottom-fixed technology.

More than 30 concepts for floating structures are under development, clustered in 3 main designs: spar buoys, semi-submersible and tension-leg platforms. These 3 concepts are suited to different site specificities and depth characteristics. The cylindrical ballast-stabilised structure of the spar buoy concept have heavy lower parts and light upper parts, which allows its center of gravity to be lower in the water than the center of buoyancy. Although this concept is easy to manufacture, logistical challenges can emerge from the large draft it requires to be installed. Semi-submersible platforms consist of a platform stabilised by buoyancy and anchored to the seabed with catenary mooring lines. Installation may be facilitated as this concept requires a lower draft, however the platform must be large and heavy to ensure stability. Tension-leg platforms are also buoyant structures anchored to the seabed for which the mooring lines are tensioned instead of catenary. This allows to have a lighter structure in shallow draft but implies greater stress on the anchor system. To date, none of these concepts has reached commercial stage. Many projects are under way to test technical innovations in an offshore environment.

Total installed capacity in 2015 is 17.7 MW, consisting in several pilot projects. The Hywind Demo project (2 MW), led by Statoil in Norway has been ongoing since 2009 and is planned to be scaled up to 6 MW in Scotland in 2017. In Portugal, another leader of the offshore wind market, Principle Power, is overseeing the Windfloat Atlantic project (2 MW), also planned to be scaled up in 2017. Japan is also active in the development of pilot projects, with 9 MW being installed under the Fukushima Forward Project and 2 MW installed by Hitachi in Kabashima.

An additional 2,070 MW are already planned to be installed in the next 5 years, mainly in Japan, the UK, the US (including three large capacity projects at a permitting phase in Hawaii and California) and France. Installed capacity could reach 250 GW in 2050, based on projected capacities for the offshore wind industry[10].

| FOWT* | Installed capacity | Planned |
|---|---|---|
| | 18 MW | 2,070 MW |

## OCEAN THERMAL ENERGY CONVERSION

Ocean thermal energy conversion (OTEC) technology relies on a temperature difference of at least 20°C between warm surface water and cold deep water. This means that only tropical waters have the right conditions for its deployment. OTEC has the advantage of producing renewable energy on a continuous (non-intermittent) basis. Implementing OTEC demands systems-engineering competencies and industrial capacities that limit the number of players that can be involved in its development.

After a first wave of construction of plants with a capacity of under 1 MW, larger scale projects have been developed since 2015. Several demonstration plants are being developed in the US, Japan, the Caribbean and South Korea. The most advanced project is being developed by Akuo Energy and DCNS in Martinique. This project, called NEMO, will be composed of an array of turbines for a total capacity of 10 MW.

The development of larger scale projects is an important step for OTEC, as several challenges remain to be raised. First, the technical applicability of larger plants (such as NEMO 10 MW project) remains to be demonstrated empirically (for instance regarding the size of water ducting systems in large plants). Second, potential adverse environmental impacts on marine biodiversity must be addressed. Finally, the high up-front capital requirements require appropriate financing solutions, as a complement to current funding from governments and technology developers.

Nevertheless, OTEC presents an interesting advantage in particular for islands in the Caribbean and Pacific Ocean. In addition to energy production, OTEC can be combined with a desalination device, thereby increasing its attractiveness in areas with limited access to freshwater.

| OTEC* | Installed capacity | Planned |
|---|---|---|
| | 0.2 MW | 11 MW |

*10. EY (2016), Strategic assessment on floating offshore wind (confidential), from Carbon trust (2015), Floating Offshore Wind : Market and Technology Review*

# SALINITY GRADIENT ENERGY

Osmotic energy technology uses the energy available from the difference in salt concentrations between seawater and freshwater. Such resources are found in large river estuaries and fjords. The system uses a semi-permeable membrane that allows the salt concentrations to equalise, thus increasing pressure in the seawater compartment.

This technology remains in the early research and development stages, and only a few pilot projects have been initiated.

REDStack launched in 2014 in the Netherlands the first pilot plant that uses reverse electrodialysis (called RED technology). The pilot plant is expected to produce 50 kWh, and to demonstrate the technical feasibility of the technology in real operation conditions. In addition to this installed capacity, permits for an additional capacity of 100 MW have already been granted in the Netherlands. Launched in 2009, the operation of the world's first salinity gradient power generation plant using pressure-related osmosis (called PRO technology), with a capacity of 10 kW, was stopped in 2014 by Statkraft[11].

A major challenge to be addressed in order for this technology to mature is the technical optimisation of membranes, which are used in both PRO and RED technologies. In addition, their cost, which represents 50% to 80% of total capital costs, must be reduced. According to IRENA[12], their price range needs to be reduced to EUR 2-5/m² (against EUR 10-30/m² today) to become competitive with other renewables. However, with new companies entering the market to produce membranes, the development of new pilot projects in the future could be facilitated.

| SALINITY* | Installed capacity | Planned |
|---|---|---|
| | 0.05 MW | 100 MW |

*11. Statkraft (2013) – Statkraft halts osmotic power investments*
*12. IRENA (2014) – Salinity gradient energy, technology brief*

# Towards cost competitiveness

## Technology testing and cost competitiveness are two essential prerequisites for market ramp-up

High investment costs and several technical difficulties such as grid connection and permitting for offshore systems remain substantial barriers to the development of ocean energies. Specific policy support as well as empirical technical and cost data from full scale demonstrators (capacity factor and technology design life span) will be necessary for ocean energies to reach commercial development.

Current cost estimates for ocean energies reveal significant cost reductions potential between the prototype and commercial phase :

- Operational and maintenance costs of wave power are expected to decrease by nearly 80%, with a subsequent decrease of the LCOE over the 2020 – 2050 period.
- OPEX for tidal stream are higher due to the fact that most tidal turbines are anchored on the sea bed and fully submerged. They are expected to decrease by approximately 50%.
- Relatively low OPEX - due to the possibility of towing away the turbines to undertake major repairs, are a significant advantage of FOWT[13]. In addition, the expected capacity factor for FOW is 50%[14]. Floating offshore wind is expected to be one of the most competitive ocean energy technologies on the long run.
- OTEC technologies require significant CAPEX investments, however thermal gradients are a rather constant resource, available year-round, and OTEC technologies have a capacity factor as high as 92% on average, which will be a strong advantage in reaching cost competitiveness.

| | | 1st Array | | Commercial | Capacity Factor | Annual availability |
|---|---|---|---|---|---|---|
| WAVE | CAPEX (kEUR/MW) | 6 750 | -46% | 3 675 | 25% - 40% | 80% - 95% |
| | OPEX (EUR/MW/yr) | 360 | -79% | 75 | | |
| TIDAL STREAM | CAPEX (kEUR/MW) | 7 050 | -51% | 3 450 | 30 - 40% | 85% - 95% |
| | OPEX (EUR/MW/yr) | 460 | -54% | 210 | | |
| FOWT | CAPEX (kEUR/MW) | 6 500 | -48% | 3 400 | 45 - 55% | 85 - 95% |
| | OPEX (EUR/MW/yr) | 260 | -54% | 120 | | |
| OTEC | CAPEX (kEUR/MW) | 26 250 | -71% | 7 500 | 85 - 95% | 85 - 95 % |
| | OPEX (EUR/MW/yr) | 1 290 | -71% | 370 | | |

Note: Data from OES (2015) and Carbon Trust (2015) is an average from aggregated values and projections provided by project developers, and is based on different technologies and prototypes. Consequently, both the duration of the transition period towards a commercial phase and the cost of the technologies can vary. These data could only be confirmed through empirical experimentation at sea.

13. *EY (2016), Strategic assessment on floating offshore wind (confidential), from Carbon trust (2015), Floating Offshore Wind : Market and Technology Review*
14. *Myrh et al. (2014), Levelised cost of energy for offshore floating wind turbines in a life cycle perspective*

Achieving economies of scale in developing pre-commercial and commercial project is critical for ocean energies to realise significant cost reductions. Progress on open sea testing is needed to advance research in offshore environments, thereby building capabilities in installation, operation, maintenance and decommissioning activities, as well as structuring the value chain and developing strategic partnerships to assist private actors on the path to commercialisation. In addition, opportunities for synergies amongst ocean energies exist, whether in technology development, infrastructure, supply chain and policy framework. Co-location of several ocean energies is also possible and will allow mutualising operation and maintenance costs. Mutual learning processes will surely contribute to accelerating the expansion of ocean energies and related value chain.

Subsequent efforts are needed to confirm the cost reduction potential of ocean energies, and enlarge their competitiveness potential. In particular, there could be a sheer opportunity for ocean energies to grow faster in island energy systems where costs of electricity production are generally significantly higher than on the mainland. Constrained real estate resource is another key driver for the development of ocean energies in Island communities, while most Island have access to substantial natural ocean resource – depending on their location and topography.

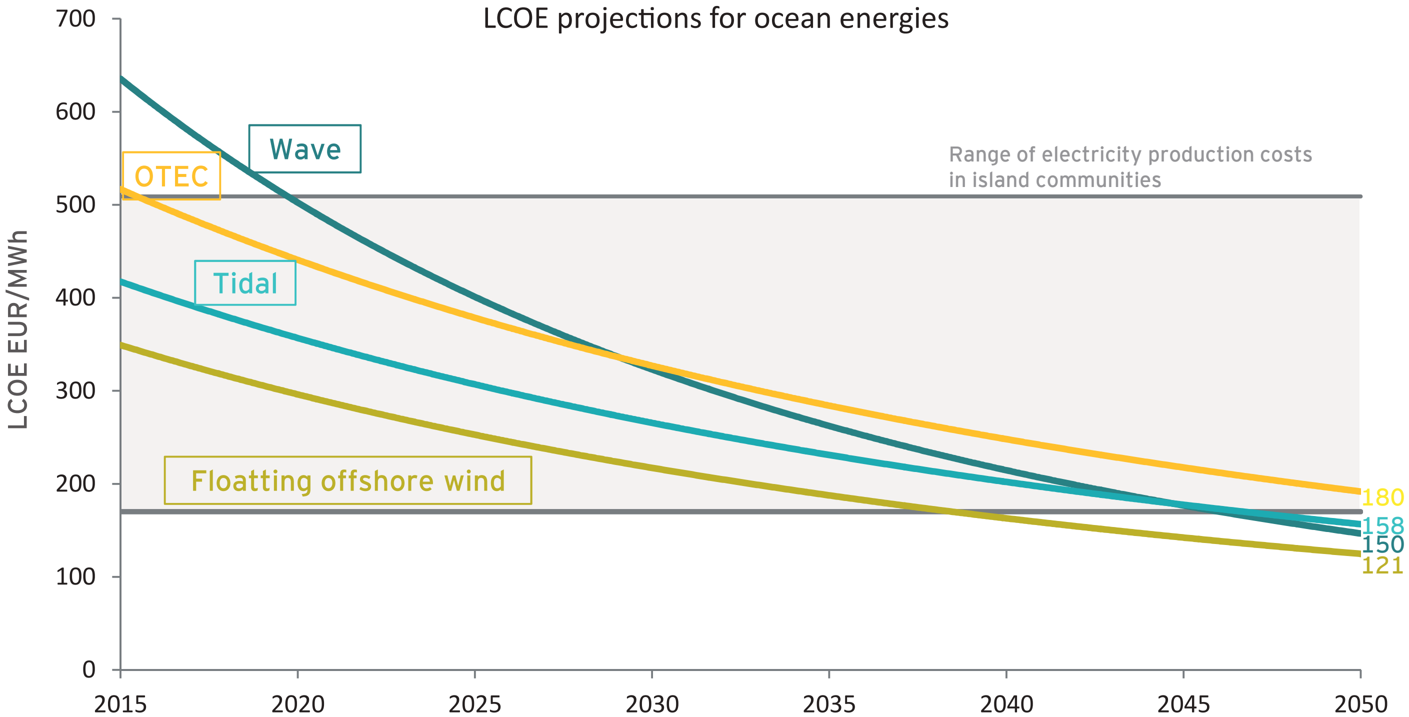
The following case studies provide a detailed overview of the development of ocean energies, with a focus, when relevant, on opportunities in island territories.

*"In today's state of maturity of the sector, financially profitable projects seem more likely to emerge on islands. For project developers, the term islands is not limited to its geographical definition, but also covers fragile networks and off-grid communities."*

*Jean-François Daviau, Sabella*

**Exchange rates: 1EUR = 0,78GBP = 1.13USD*

** These are the exchange rates at the time of cost data collection from project developers.*




*Sources: Ocean Energy Systems (2016), Annual Report 2015; EY (2016), Strategic assessment on floating offshore wind (confidential), Carbon trust (2015), Floating Offshore Wind: Market and Technology Review*

*Costs decrease timing will depend on technologies capacity to shift from concept to commercial stage*

Country focus

# Australia

## Current status of progress

According to projections, Australia is to drive the wave and tidal energy market in Asia Pacific by creating a capacity of almost 25 MW before 2020. With the award of approximately EUR 71 m by Federal and State Governments, Australia saw several commercial demonstration plans in the wave energy sector between 2013 and 2015. Ocean energy is striking a blow since it is attracting a lot of interest and technologies are edging closer to maturity. There are three main Australian technologies that have reached pre-commercial stage, including a fully submerged device developed by Carnegie Wave Energy Limited, a partially submerged device developed by BioPower Systems Pty Ltd and a sea-floor membrane (mWAVE™) developed by Bombora Wave Power.

### *Carnegie Wave Energy project*

The Perth wave energy project is Australia's first commercial scale grid-connected wave energy project. In 2015, Carnegie Wave Energy signed a MOU with Western Australian government power utility Western Power to connect CETO 6 to an electricity network. The company will supply electricity to Australia's largest naval base located on Garden Island in Western Australia. In addition to a 1 MW CETO 6 device, the project involves an integration of different renewable energy technologies, including solar (2 MW), battery storage (0.5 MW) and a desalination plant. A high level comparison of the features of the CETO technology CETO 6 and CETO 5 is presented in the table below.

The Clean Energy Finance Corporation (CEFC) has provided a EUR 17.9 m five-year loan facility to Carnegie Wave Energy to accelerate the development of stage 6 of its CETO wave power technology. Carnegie Wave Energy is the first ocean wave energy to secure a loan with the CEFC and recognise that ARENA's grants and equity from shareholders have been critical to secure the loan from CEFC.

Comparison of the features of CETO 5 and 6 technology

| Device | CETO 5 | CETO 6 |
|---|---|---|
| Output | 0.240 MW | 1 MW |
| Diameter | 11 m | 18 m |
| Location | Offshore 3 km | Offshore 9 km |
| Water depth | 25 m | 30-35 m |
| Wave energy | 8 kW/m | 23 kW/m |

### *Bombora project*

Bombora Wave Power is an Australian based company that commenced development of its membrane wave energy converter (mWAVE) in 2007 and has evolved from prefeasibility stage in 2013 to commercial viability in 2016. The mWAVE technology is a large sea floor membrane capable of supplying high power output at low cost. A detailed analysis of the levelised costs of electricity (LCOE) has been performed in 2015-16 for the Portugal project (see below). The results of the study yet to be released indicate a competitive LCOE for mWAVE compared to other sources of renewable energy. In addition, this technology has three key features that enable community acceptance:

- Fully submerged system similar to an offshore reef with no visible impact or coastal use
- No oil nor hydraulic systems hence limiting the environmental impacts
- No exposure to storm waves

Bombora is currently moving to full scale plant in Peniche, Portugal consisting in 40 units of 1.5 MW each for a total 60 MW wave farm. The mWAVE array will be submerged 10m and installed along a coast line length of 2.5 km. The first unit will be ready by the first half of 2017 including environmental approval. Power output, environmental assessment and general performance will be monitored for at least 6 months before commencing to progressively build the full wave farm.

> *"Australia has developed some of the most advanced wave energy technologies and the most of the commercial opportunities are overseas. The challenge is to bring cost down and this is where ARENA has been helping and continues to fund technology development"*
>
> *Ivor Frischknecht – CEO ARENA*

| Project Proponent | Description | Location | Maturity | Capacity | Development stage | Government support |
|---|---|---|---|---|---|---|
| Swinburne University of Technology | Impact modelling of wave energy converters on each other in an array | Victoria | R&D | N/A | Started in August 2014 | ARENA: EUR 0.5 m |
| Carnegie Wave Energy Limited | CETO 5 | Western Australia | Commercial demonstration | 1 MW | Started operations in January 2015 | ARENA: EUR 8.5 m |
| Bombora Wave Power | mWAVE | Western Australia | R&D | N/A | Started in December 2015 | ARENA: EUR 0.12 m |
| BioPower Systems Pty Ltd | bioWAVE | Victoria | Commercial demonstration | 0.25 MW | Started operations in February 2016 | ARENA: EUR 7.1 m<br>Victorian Gov.: EUR 3.2 m |
| University of Western Australia | Location and array configuration research | Western Australia | R&D | N/A | Started in April 2016 | ARENA: EUR 0.61 m |
| CSIRO | National wave energy atlas that will allow users to better assess feasibility of wave power projectss | Tasmania | R&D | N/A | Completion in 2017 | ARENA: EUR 0.84 m |
| Carnegie Wave Energy Limited | CETO 6 | Western Australia | Commercial demonstration | Up to 3MW | Scheduled completion 2020 | ARENA: EUR 8.38 m<br>CEFC: EUR 12.9 m |
| | | | TOTAL | 4.25 MW | | |

## Policy developments: Strong pipeline of R&D projects with significant support from ARENA

The Federal and State Governments, in liaison with the Australian Renewable Energy Agency (ARENA), have provided over EUR 29 million in the form of grant to the ocean energy sector in the last three years. Table 2 shows that the project pipeline includes four R&D projects and three pre-commercial/commercial technology projects, including Carnegie Wave Energy Limited, Bombora Wave Power and, BioPower Systems Pty Ltd. Through these grants, ARENA contributes to the knowledge sharing process to demonstrate the viability of these technologies and enhance the sector capability.

*"Reaching financial close on the CEFC facility is a watershed moment for Carnegie as this is the first time ever that Carnegie has achieved a pure debt finance deal. It follows on from the commissioning of the Perth Wave Energy Project and is representative of the maturing nature of the CETO technology."*

*Aidan Flynn – CFO Carnegie Wave Energy*

Australian universities have played an important role in the technology development phase, partnering with project developers and bringing capabilities on specific technical components, including greater fluid dynamic modelling skills and geological knowledge to develop more cost-efficient foundations. For example, the University of Plymouth worked on tank testing, wave testing validation and engineering design, whereas the University of Western Australia performed wave modelling, engineering design optimisation and wave testing. Tenax Energy has created with Charles Darwin University a Tropical Tidal Testing Centre or T3C which aim is to stimulate collaboration in tropical tidal energy generation globally across research institutions and device manufacturers.

The Commonwealth Scientific and Industrial Research Organisation's (CSIRO) research will provide clear, credible and independent knowledge of Australia's wave resources, while setting a methodology for assessing impacts of wave energy extraction on the marine and coastal environment. This research will not only bring benefits to the ocean energy sector but also to other industries, such as port developers and coastal infrastructure organisations (e.g. wave intensity and erosion).

*"Our analysis of the levelised cost of energy for a 60 MW wave farm in Peniche revealed that Bombora wave farms will deliver comparable cost of electricity to off-shore wind farms and solar arrays in Europe by 2023. The detailed ARENA supported LCOE study results are due for release in June 2016."*

*Sam Leighton – CEO Bombora Wave Power*

*"Universities and researchers have a key role to play working with ocean energy technology developers. We are supporting three research projects that are tremendously important in helping out the ocean energy industry and should be useful for overseas developers as well as Australian ones."*

*Ivor Frischknecht – CEO ARENA*

### *Australia's Renewable Energy Target (RET)*

The RET is a Federal Government policy designed to ensure that at least 33,000 GWh of Australia's electricity comes from renewable sources by 2020. The RET was reviewed by the Government and reduced in June 2015 from the previously legislated 41,000 GWh to 33,000 GWh. The RET has been operating since 2001 and is already about halfway to meeting the revised 33,000 GWh target.

Currently, States run feed-in tariffs schemes for grid-connected solar however there is no federal programme.

### *Power purchase agreements (PPAs) in Australia*

The main PPAs for large scale renewable energy projects in Australia have been signed by Australian major electricity retailers including Origin Energy, AGL and EnergyAustralia. Since 2010, they have provided over 45% of PPAs to projects in the market.

There are also a number of other PPA providers in the market that have supported projects since 2010, including amongst others Hydro Tasmania and ACTEW AGL (through the ACT large scale wind feed-in-tariff auction). Other PPAs have also been provided to renewable energy projects from mining projects, desalination projects and other energy intensive users.

## Presentation of the sector: Australian technology and IP recognised on the international market

Australian companies have exported their experience and technologies and established strategic relationships with key stakeholders in Africa, Europe and, South-East Asia. Both Carnegie Wave Energy and Bombora recognise the importance of the international market. It provides the potential for large scale ocean energy projects and competitive advantage for ocean energy technology for remote islands communities where diesel displacement opportunities are significant.

Carnegie Wave Energy is working on a project in Mauritius focusing on high penetration roadmap for renewable energy, wave resource assessment and detailed design of the wave integrated market grid. The main challenges for international projects are having a robust engineering design and securing the off-take agreement with local authorities. For example, some locations have a policy framework that does not allow independent energy providers to come into the local market.

Carnegie Wave Energy is confident that its CETO technology can compete in international markets where electricity price is around EUR 160-196/MWh. However, this price could be reduced while economies of scale play a bigger role; Carnegie Wave Energy estimates that a 10 MW wave farm is the minimum size to bring the LCOE down and amortise associated costs, such as plant and power cable installation.

Beyond the commercial scale project in Portugal, Bombora is also operating in South-East Asia. Bombora's technology could be able to supply electricity in remote diesel-powered islands. In June 2015, Bombora Wave Power signed a technology evaluation agreement with Indonesian company Anoa Power, in order to manufacture and distribute its mWAVE technology. Key stakeholder collaboration will increase the chances of wave energy to thrive within the energy sector. Worley Parsons, an Australian engineering company, has recognised that there is a global market, and that offshore suppliers operating in the oil and gas sector are willing to play a bigger role. In addition, the increasing interest of large energy infrastructure companies including DCNS and ALSTOM may lead to other potential investors investing in wave technologies.

> *"In the near term, marine energy will be economically viable where the cost of local energy is high and there is an opportunity to displace diesel-generated electricity through avoiding shipping and transports costs."*
>
> *Ivor Frischknecht – CEO ARENA*

> *"Europe provides the right conditions to develop the first Bombora wave farm with advantageous feed-in tariffs, funding opportunities and programmes to facilitate site approvals."*
>
> *Sam Leighton – CEO Bombora Wave Power*

## Perspectives

The domestic market is likely to be impacted by the proposed changes to ARENA's funding model. On March 2016, the Federal Government announced that a new EUR 893 m Clean Energy Innovation Fund will commence in July 2016 and will be run by ARENA and CEFC. Funds will be based on equity and debt investment and projects would need to repay loans carrying an interest rate 1 per cent above the government's long-term borrowing rate. With the upcoming 2017 elections, more details will be available to gain a better understanding of the impact on the ocean energy market.

Commercial scale ocean energy projects such as the Perth wave energy project and forthcoming Peniche wave energy project in Portugal places Australia at the leading edge of the emerging ocean energy sector. These developments will provide insights on key success factors including technology performance, supply chain and manufacturing costs, funding arrangements and off-take agreements that will benefit the ocean energy industry more broadly.

> *"In some countries, the tricky part to launch a project is not necessarily to access funds, but rather to secure the agreement with the off-taker."*
>
> *Greg Allen – COO Carnegie Wave Energy*

# Canada

## Current status of progress

Several achievements have been made over the past few years in the marine renewable energy sector. Canadian developers have made significant progress in the development of marine energy technologies and are now targeting the deployment of offshore wind capacities in Canada and abroad. Several technology fields are concerned, including tidal stream and wave power energy. The main projects that have recently emerged are summarised in the following table.

The pilot projects listed below have emerged over the past two years and most of them take part in the bigger projects summarised in the table.

- At the CHTTC in Manitoba. New Energy Corp., developed a vertical axis turbine of 5 kW which was installed in 2014 and 2015 in order to test a patented fully-submersible bearing, mechanical design, control systems. The test was successful and a similar tidal pilot project was set up on Vancouver Island. Mavi Innovations tested an innovative floating ducted crossflow turbine for the first time at the CHTTC in November 2014 and since then works with CHTTC staff to measure mooring loads and turbine performance to validate standards.
- On Vancouver Island. In 2015, a wave energy point absorber buoy developed by Accumulated Ocean Energy Inc. was tested at a 1/12 scale system. No results have been yet published. Other scaled systems are to be tested in Ireland.
- At the Canadian National Research Council's Ocean Engineering Basin. Grey Island Energy conducted testing of its 750 kW SeaWEED wave energy surface attenuator prototype which results were beyond expectation.
- On Dent Island. A 500 kW tidal energy device was deployed in November 2015 by Water Wall Turbine Inc.'s off the coast of British Columbia. A new floating structure, based on a patented technology, is to be installed during summer 2016.
- Canada. A floating tidal turbine platform collaboration between Canada's Instream energy Systems and IP Power Consulting (UK) aimed at developing second-generation floating tidal turbine platform design.

Besides, several projects are planned for the coming 3-5 years, mainly located in the province of Nova Scotia which aims at increasing in-stream tidal energy (its main ocean energy resource) capacity by 22 MW.

| Project Proponent | Technology | Location | Maturity | Capacity | Start up | Government support |
|---|---|---|---|---|---|---|
| Tidal stream energy projects | | | | | | |
| Fundy Ocean Research Centre for Energy (FORCE), In-stream Tidal Energy | DP Energy, Fundy Advanced Sensor Technology | Minas Passage, Nova Scotia | Operational | 64 MW | Launched in 2014, expansion started in 2015 | CEF: EUR 22.4 m |
| Nova Scotia Power (Emera) | Barrier type technology | Annapolis Royal | Operational | 20 MW | Launched in 1984 | Not available |
| Mermaid Power | Power Take-Off (PTO) mechanism | Vancouver and Keats Island | Operational | NA | Launched in December 2015 | Not available |
| Canadian Hydrokinetic Turbine Test Centre (CHTTC) | Clean Current (tidal turbines) | Winnipeg River, Manitoba | Operational | 0.065 MW | Launched in 2013 | ecoEII: EUR 2.2 m |
| Wave energy projects | | | | | | |
| Wave Energy research Centre, College of North Atlantica | Water-powered wave pump coupled to a shore-based aquaculture system | Lord's Cove, Burin Peninsula, Newfoundland & Labrador | Prototype, Operational | 0.09 MW | Launched in 2015 | Not available |
| | | | TOTAL | 84.16 MW | | |

With borders on three oceans and near-limitless waterways, Canada possesses extensive marine resources, which could satisfy over 25% of Canada's electricity demand.

### *Ocean energy potential in Canada (in GW)*

| | Tidal Stream Energy (ocean) | Tidal Stream Energy (river) | Wave | Total |
|---|---|---|---|---|
| Extractable mean potential power | ~6.3 | > 2.0 | ~27.5 | ~35.8 |
| Provinces with potential power | ‣ Nova Scotia<br>‣ New Brunswick<br>‣ Quebec<br>‣ British Columbia<br>‣ Arctic | ‣ Quebec<br>‣ Ontario<br>‣ Manitoba<br>‣ British Columbia<br>‣ Arctic | ‣ British Columbia<br>‣ Nova Scotia<br>‣ Newfoundland and Labrador | |
| Canadian electricity demand (rated capacity, 2010) | | | | 134 GW |

*Source: Marine Renewable Energy Technology Roadmap, October 2011*

## Policy developments

Canada's Marine Renewable Energy Technology Roadmap sets targets of 250 MW by 2020; and 2.0 GW by 2030 for tidal and wave energy generation. These targets are expected to generate EUR 1.8 bn in annual economic value to the Canadian marine sector.

At the federal level, the Canadian Department of Natural Resources continues to take a leading role in the development of a policy framework for administering marine renewable energy activities, having invested approximately EUR 33.2 m in research and development in this sector since 2010.

Following the development of Nova Scotia Power's 20 MW Annapolis Tidal Power Plant in 1984 no commercial-scale marine projects have been developed in Canada. However, several pilot projects have been implemented over the last years across the country.

Besides, local governments are conducting policies to promote ocean energy projects in their provinces. This is especially true for Nova Scotia, British Columbia and New Brunswick. The Nova Scotia government has established one of the most attractive feed-in tariff procurement mechanisms in the world for tidal power, targeting both community-based and larger-scale projects. In British Columbia and New Brunswick, tidal in-stream energy (river and estuaries) conversion projects are allocated through a Crown Land leasing policy.

In 2015, a sector-specific legislation (the Marine Renewable Energy Act) was passed in the province of Nova Scotia, a 5th berth at the in-stream tidal pilot site is to be developed according to the FORCE, new monitoring instruments for accurate river tidal stream and turbulence measurements were developed, and international collaborative R&D projects between Canada and the United Kingdom were announced.

## Presentation of the sector

Canada has an active developer community, clustered around the available natural resources. Among them can be cited New Energy Corp., Mavi Innovations, Instream Energy Systems, Idénergie, Mermaid Power, Accumulated Ocean Energy Inc., Grey Island Energy, Fundy Tidal Inc. and Jupiter Hydro. Augmenting Canadian developers, the Ocean Renewable Energy Group is a network of marine research centres supporting technology and policy development across Canada. The image below shows a selection of Canada's research and development (R&D) community, and clearly illustrates R&D clustering on Canada's most accessible coasts:

## Perspectives

The marine renewable energy sector in Canada presents a range of medium to long-term opportunities: developing wave energy technologies on British Columbia's Pacific coast; developing hydro-kinetic technologies across the country; and developing tidal energy generation on Nova Scotia's Atlantic coast.

Moreover, several calls for tenders for pilot projects are expected: Cape Sharp Tidal venture in the Bay of Fundy (deployment of the first 4 MW by the end of the first semester of 2016), Idénergie (6 rivers turbines in north eastern Canada in 2016), Mermaid Power's Neptune 4 (on Vancouver Island late 2016), etc. These projects illustrate that R&D activities are gaining momentum on both Canadian coasts.

Canada's marine energy is well placed to compete on the international stage, having many base industries in marine engineering and related sectors co-located close to some of the best global resources. Domestically, Canada is also endowed with conventional energy resources, creating policy challenges to increase focus on any emerging renewable energy technologies, including marine technologies, despite their potential. A lack of market pricing in many of Canada's electricity markets from continued public ownership has turned electricity pricing into a highly political issue and a view that any changes to the historic cost of power is unacceptable. These factors could contrive to serve as an anchor on Canada's marine energy industry's growth prospects.

## Country focus

# China

## Current status of progress

Held in May 2015, the 4th China Marine Renewable Energy Conference (CMREC) was the opportunity for the government, universities, institutions, industries and stakeholders to discuss their common ocean energy strategy that can be summarised in the theme of the annual conference: "strengthen planning, scale development, lighting the blue energy". According to the State Oceanic Administration (SOA), China has an estimated 1,058 GWh natural potential ocean energy reserve, and has the technical potential to harness 650 GWh. This is mostly due to its 18,000 km coastline and its 6,500 islands. To date, the potential of marine energy has been assessed mainly by research projects and field observations.

Since 1985, year of construction of the 3.9 MW Jiangwia Tidal power Plant (Zhejing), one of the longest-operating tidal power plants in the world, several R&D and pilot projects have been set up. Four tidal power plants are currently under construction, representing a total capacity of 61 MW. The government has set a target of 100 MW commercial-scale tidal power plants installed by 2020.

Developing commercially viable marine hydrokinetic pilot test sites off the coasts is acknowledged as a mean to avoid the country's power shortage in the coastal areas. A governmental funding programme supports three test sites that are being developed to tackle this issue :

- A small scale test site in Weihai (Shandong), designated for both tidal current and wave energy technologies
- A tidal energy full scale test sites in Zhoushan (Zhejiang), initiated by China Three Gorges Corporation, developer of a 3.4 MW tidal power generator. A 60 kW prototype floating tidal turbine was installed at the begging of 2015 and electricity production is expected to start mid-2016.
- A 300 kW wave energy plant in Wanshan (Guangdong).

In October 2015, organisations from the province of Qingdao (eastern China) signed a Memorandum of Understanding with the European marine Energy Centre in order to support the development of the wave energy test site in Qingdao through the sharing of knowledge and the carrying out of fundamental research.

Moreover, a few local projects have been implemented over the last two years, R&D projects on wave and tidal energy are progressing to sea trials, and hybrid power stations (combining ocean, wind and solar energy) are generating increasing interest, including :

- The Jiangxia Tidal power Plant, which was upgraded in August 2015 from 3.9 MW to 4.1 MW
- The 100 kW Sharp Eagle Wanshan Converter, deployed in November 2015 and operated jointly by Guangzhou Institute of Energy Conversion and China Shipping Industry Co.
- An isolated hybrid power pilot station on Dawanshan Island, comprising a 300 kW wave energy device, 100 kW wind turbines and 300 kW solar panels
- Tidal current energy turbines deployed near Zhairuoshan Island by Zheijang University between May 2014 and October 2015, which results were encouraging. A new 300 kW turbine is to be tested by end 2016.
- Pre-feasability studies on tidal power completed in Jiantiao (21 MW), Rushan estuarine (40 MW), Bachimen (30 MW) and Maluan Bay (24 MW)
- Pre-study and investigation conducted off Dongshan Island in Jufian province, which revealed that the site is to date one of the best sites for dynamic tidal power utilisation
- Ocean Thermal Energy Conversion (OTEC) small scale tests initiated in Weihai city on Chudao isle (Shandong province)

To support the development of these projects, a branch dedicated to marine renewable energy issues was established within the China Association of Oceanic Engineering in 2013 and gathers more than 130 members from 49 organisations.

The table below provides a list of ocean energy projects implemented to date.

| Project Proponent | Year of operation | Capacity (MW) | Location |
|---|---|---|---|
| Tidal stream energy | | | |
| Wanxiang I | 2002 | 0.07 | Guishan Channel<br>Zhejiang Province |
| Wanxiang II | 2005 | 0.04 | Gaoting Bay<br>Zhejiang Province |
| Haiming I | 2011 | 0.01 | Xiaomentou Channel<br>Zhejiang Province |
| Haineng I | 2013 | 2 x 0.15 | Guishan Channel<br>Zhejiang Province |
| Tidal range energy | | | |
| Jiangxia Tidal PowerPant | 2012 | 4.1 | Jiangxia |
| Wave energy | | | |
| Duck I, II and III | 2009 | 3 x 0.01 | Wanshan Island |
| Eagle I | 2014 | 0.01 | Wanshan Island |
| ZLB | 2012 | 0.03 | Daguan Island |
| FLB | 2012 | 0.05 | Not available |
| Nezha I | 2012 | 0.01 | Wanshan Island |
| Nezha II | 2013 | 0.02 | Wanshan Island |
| SDU Buoy | 2013 | 0.12 | Not available |
| Hailong I | 2014 | 0.15 | Not available |
| OTEC RD&D | | | |
| Closed-cycle OTEC device | 2013 | 0.015 | Not available |
| Deep Water Source Cooling (DWSC) | 2013 | Not Available | Yellow sea |

*Sources:*

*- Marine renewable energy in China: Current status and perspectives, by Yong-liang Zhang, Zheng Lin and Qiu-lin Liu, Water Science and Engineering (2014).*

*- Governmental Initiatives and Relevant projects on Ocean Energy in China by Dr. Xia Dengwen, NOTC, SOA (2014).*

## Policy developments

According to the National Ocean Technology Centre (NOTC), the Chinese government has committed that carbon emission per unit of GDP in 2020 would decrease by 40 to 45% relative to 2005. To meet this target, a EUR 116.6 m funding programme was created in 2010 for renewable energy and has to date supported 96 programmes, including the three recent test sites in Shandong, Zhejiang and Guangdong.

Other public-financed programmes for marine renewable energy include:

- Over 900 fundamental investigation projects financed by the State Oceanic Administration (SOA)
- About 860 Hi-Tech and key technology R&D programmes funded by the Ministry of Science and Technology (MOST)
- The theoretical research programme of the Natural Science Foundation of China (NSFC)

The "Renewable Energy Development Plan (2016-2020)", released in 2014 by the MOST, was reviewed a year later by the National Advisory Committee who pointed out the two key issues of fundamental study on MRE technology and of the development of R&D and pilot projects. The plan includes an "Ocean Energy Development Strategy" which was developed by the NOTC.

The government is also supporting the development of electricity supply on the 6500 Chinese islands greater than 500$m^2$ through the National Plan for Island Protection (2011-2020) which puts forward the use of ocean energy to improve the living circumstance in remote islands.

Regarding the permitting and licensing process for ocean energy projects, authorisations are granted based on agreements between local oceanic agencies, maritime agencies and fishery agencies. Military sectors may also be involved in the process.

## Perspectives

China is a country endowed with abundant wave and tidal energy resources. Ocean energy is getting increasing attention from society and local governments. The latter introduce various policies and incentives in order to encourage the development of RD&D of technology and pilot test sites and thus promote the ocean energy industry as a whole. Such initiatives are to continue and take part in local authorities' plans to integrate renewables in their electricity consumption, since 31 provinces recently set themselves the target to generate by 2020 between 5% and 13% of electricity from non-hydro renewable energy resources, including wave and tidal energy.

However, Chinese ocean technology is not mature enough to be exported at an international level or to be used at commercial-scale. In fact, several test centers and pilot sites have been launched with the hope of improving China's ocean energy technology by attracting international advanced technology developers, for instance through joint-ventures.

# France

## Current status of progress

With more than 11 million km² of water under its jurisdiction, France is endowed with major natural potential with regards to ocean energy, in metropolitan France and French overseas territories. It is amongst the highest potentials for ocean energies in Europe. The French Ministry for Ecology, Sustainable Development and Energy estimated the potential resource to range from 3 to 45 GW (including floating offshore wind and tidal range)[15].

Several calls for tenders have been launched in the past few years to support the emergence of the industry, fostering the development of technologies (tidal stream, floating offshore wind) or specific components to support the whole ocean energy industry (turbines, testing technologies, etc.). As a result, a number of projects have been developed or planned since 2014 – they are listed in the following table. Tidal stream is the most advanced to date, with several demonstration projects at sea, on the shores of Normandy (Nepthyd – GE (Alstom), Engie, and Normandie Hydro - DCNS, EDF EN) and Brittany (D10 – Sabella). Nearly ten projects of wind farms have been submitted in April 2016 for the recent national call for projects for floating offshore wind, involving French and foreign companies. A decree published in April 2016 (see Policy Developments) also announced two new calls for tender to move the industry further towards commercialisation: one for tidal stream energy and one for floating offshore wind power. Recent declarations from the French Minister of Ecology, Sustainable Development and Energy - Ségolène Royal - indicate that the call for tenders will be lauched by 2019-2020 or earlier.

In addition, several testing and pilot sites, all connected to the national grid, have been identified and dedicated to the development of ocean energies:

- SEM-REV, near Le Croisic on the Atlantic coast, was opened in August 2015 and is dedicated to wave power and floating offshore wind turbines.
- Paimpol Bréhat, on the northern shore of Brittany, was opened in 2013 and is dedicated to tidal stream technologies and already hosts 2 demonstrators.
- SEENEOH, located in the estuary of the Gironde River (Bordeaux) is dedicated to river tidal stream technologies and opened in 2016 with 3 berths for full scale river devices and intermediate scale ocean tidal devices, with a capacity of 250 kW).

*15. French Ministry for Ecology, Sustainable Development and Energy (MEDDE), 2013, Report on the strategic mission on ocean energies.*

- MISTRAL, in the Gulf of Fos-sur-Mer in the Mediterranean coast is dedicated to floating offshore wind turbines.
- Two pilot sites are dedicated to tidal stream turbines in the Raz Blanchard in Normandy.
- Four other testing sites have been identified for the first floating offshore wind turbine pilot farms call for tender. They are located in Brittany (Groix) and the Mediterranean coast (Leucate, Gruissan and Faraman).

France has acquired exceptional industrial experience from the tidal range energy power plant in the Rance estuary which operates since 1966, currently the world's second largest tidal energy plant, with a power capacity of 240 MW. France also builds upon the recognised capabilities of its engineering firms specialised in marine installations, its energy facility manufacturing industry, and offshore construction companies. Research organisations and laboratories in the country also have critical skills and expertise to foster the development of a marine energy industry.

| Project Consortium* | Project name | Location | Technology | Capacity | Project maturity | Total cost and financial support |
|---|---|---|---|---|---|---|
| Floating offshore wind energy projects** | | | | | | |
| EDF EN, Technip, Nénuphar, Converteam (GE) | Provence Grand Large (ex-Vertimed) | MISTRAL Fos-sur-mer (Mediterranean Sea) | Vertical axis turbine on semi-submersible platform | 30 MW | 2 MW onshore demonstrator installed in Fos-sur-Mer in 2015<br>2 MW offshore demonstrator planned to be installed in 2016<br>26 MW pilot plant of 13 turbines planned to be installed in 2018 | Total cost: EUR 130 m<br>Support: EU under NER300 Fund (EUR 37 m), ID Invest Partners (EUR 3 m), ADEME |
| IDEOL, Bouygues Travaux Publics, Ecole Centrale Nantes, University of Stuttgart, Fraunhofer Institute, RSK Environment, Gamesa, Zabala Innovation | Floatgen | SEM-REV, Atlantic coast | Ring shaped surface floating platform | 2 MW | Offshore demonstrator planned for commissioning late 2016 | Total cost: EUR 21.5 m<br>Co-funded by the EU under the FP7 |
| DCNS, ALSTOM | SEA REED | na | Turbine with semi-submersible platform (Haliade 150) | 6 MW | Feasibility phase started in November 2013 - scheduled until end of 2016 | Total cost: EUR 18.9 m<br>Support: ADEME (EUR 6 m) |
| Tidal stream energy projects** | | | | | | |
| EDF<br>DCNS (OpenHydro)<br>STX | OpenHydro | PAIMPOL BREHAT, Northern Brittany | Tidal turbine | 2 MW | First demonstrator installed in 2011/2012 and again in 2013/2014 | Total cost: EUR 40 m<br>Support: Britany Region, ADEME, FEDER (7.2 m) |
| EDF EN, DCNS (Open Hydro) | Normandie Hydro | Raz Blanchard, Normandy | Gravity based turbines with a unit power of 2 MW | 14 MW | Installation of an array of 7 tidal turbines, due to be deployed in 2018 | Total cost: EUR 112 m<br>Support: ADEME |
| ENGIE (Eole Génération)<br>Sabella | Sabella 10 | Brittany (Atlantic coast) | Pilot D10 tidal turbine | 1.1 MW | Commissioned in 2015 | Total cost: EUR 10.3 m<br>Support: ADEME |
| ALSTOM, TE Connectivity, Silec Cable, Sector, Gipsa-lab, G2E Lab, ENGIE, JIFMAR | PRISMER | Nantes, Grenoble, Montereau | Several components for electric cables including a subsea hub, wetmate and optical connectors | na | Development of the project from November 2013 to end of 2017 | Total cost: EUR 25.1 m<br>Support: ADEME (EUR 8 m) |
| Geocean, Mojo Maritime, 3SR, M2C | Pile & Tide | Raz Blanchard, Normandy; Cassis (Mediterranean coast) | Drilling device | na | Development of the project from May 2014 to mid-2018 | Total cost: EUR 6.9 m<br>Support: ADEME (EUR 3.2 m) |

| Project Consortium* | Project name | Location | Technology | Capacity (MW) | Project maturity | Total cost and financial support |
|---|---|---|---|---|---|---|
| Wave energy project | | | | | | |
| Fortum, DCNS, AW-Energy | Wattmor Wave Roller | Brittany (Atlantic coast) | Submerged panel anchored to the seabed. | 1.5 | First stage of development (feasibility, impact, community engagement) started in 2013 – currently on hold for lack of funding. | Total cost: NC |
| OTEC | | | | | | |
| DCNS, Akuo energy | NEMO | Martinique | Offshore OTEC plant | 10 | Commissioning planned for 2018 | Total cost: EUR 300 m Support: EU NER300 (EUR 72 m) |

* *These are the initial consortium members and may have evolved.*

** *These projects were supported through the several ADEME funding programmes.*

*Sources: Ernst & Young, various press releases*

## Policy developments

In August 2015, France passed the Law for Energy Transition and Green Growth, setting a new policy framework and raised ambitions for the development of renewable energies. In line with the 2012 "Grenelle Law", France has set a target to increase the share of renewable energy to 23% of its total energy consumption by 2020, and to 32% in 2030, with renewable energies representing 40% of the electricity production. These overarching objectives are detailed in the Energy Planning Reference Document (PPE, Programmation Pluriannuelle de l'Energie), which formulates sectoral strategies and targets for the development of renewable energies over the 2016-2018 and 2019-2023 periods. A decree of investment planning (PPI) was published in April 2016. 100 MW of ocean energies (apart from fixed offshore wind) are expected to be installed by the end of 2023, and an additional 200 to 2,000 MW should be consented by then, depending on feedback from the first pilot projects, feasibility studies and costs. This target is significantly higher than in the initial versions of the document.

Several R&D supporting instruments have been supporting the French ocean energy sector for several years, such as research funding grants and demonstrator financing. Other initiatives have aimed at creating a favourable environment for the emergence of these technologies. Several examples can be mentioned:

- the construction of 5 demonstrators co-financed up to EUR 40 m by the Investing for the Future programme, under the management of ADEME (the French agency for the energy and the environment): 2 Floating offshore wind energy projects (WinFlo et VertiMed/Vertiwind), 2 tidal current energy projects (Orca et Sabella 10) and 1 wave energy project (S3);
- the creation of the Institute "France Energies Marines" in 2012, labelled as Institutes in Carbon-Free Energies (IEED), and financed by the French Government up to EUR 34.3 m over a 10-year period. Led by the French Research Institute for Exploitation of the Sea (IFREMER), France Energies Marines brings together a wide range of relevant stakeholders: private companies, research organisations and higher education institutions with R&D and demonstration objectives, such as the creation and management of shared test sites;
- support to small and medium enterprises (SME) and innovative start-ups granted through other public mechanisms, with the support of competitiveness clusters such as Pôle Mer Bretagne and Pôle Mer PACA;
- the adoption of a feed-in tariff to encourage the development of marine renewable energy since 2006 (EUR 130/MWh for offshore wind).

## Presentation of the sector

France's marine energy assets (natural resource potential, industrial experience, economic fabric), together with the implementation of French Government policy to support R&D activities, open up possibilities for the development of a French industrial ocean energy sector. France can build upon a dense network of research organisations (IFREMER, SATIE laboratory, CNRS-ENS Cachan Bretagne) and Universities active in this field (Centrale Nantes, Navale Brest, ENSTA Bretagne and IFP Energies nouvelles). The involvement of major utility providers (General Electric, EDF, ENGIE) and industrial firms (DCNS, VINCI, EIFFAGE, Bolloré etc.) is another

key element of the dynamism of the French ocean energy industry. These multinational companies contribute to scaling up projects and innovative technical solutions developed by SMEs in France and abroad and to progress towards commercialisation stages. Other players such as Akuo Energy (Electricity provider) and Sabella (tidal stream technology developer) are also gaining substantial expertise in the industry and leading commercial development prospects on the international market.

## Perspectives

The PPI provides the French Ocean Energies industry with strong prospects for development and visibility over the next stages of capacity developments. The upcoming call for tenders should result in the emergence of commercially viable technologies. Meanwhile, most technology developers are already planning development on the international market and in particular in Island communities where energy self-sufficiency and high costs of electricity are a strong drivers to leverage the development of commercial scale projects of ocean energies.

## Developments in French Overseas Territories

In the non-interconnected French overseas communities, the cost of electricity production varies from EUR 200/MWh to EUR 510/MWh. Energy self-sufficiency has become a major concern in most islands and renewable energies represent a growing share of their energy mix (up to 20%).

Local authorities have a growing interest in ocean energies which could be less constrained than onshore renewable energies such as solar in terms of land requirements. However, the environmental costs have yet to be specified and the natural potential should be considered with regards to possible conflicting land use with activities such as leisure cruising and fishing.

The leading technology tested overseas is the ocean thermal energy conversion (OTEC) relying on a temperature difference of at least 20°C between the warm surface water and cold deep water. DCNS is working in partnership with the electricity provider Akuo Energy and the regional authority of Martinique to develop the NEMO project, a 10 MW OTEC pilot plant. This project was awarded EUR 60 m through the NER300 European funding programme and should be operational in 2018. OTEC technologies are one of the three strategic focuses of renewable energies strategy of Martinique, however high capital costs for OTEC are still prohibitive and large public grants are necessary: economies of scales will be required to develop larger capacities.

In Guadeloupe, Local Authorities are waiting for the NEMO project to be installed and deliver its first kWh to advance development of OTEC technologies and undertake feasibility studies. A resource assessment for floating offshore wind was conducted with Akuo Energy and revealed a significant natural potential. Feasibility studies are now necessary to intersect the resource with technical and societal constraints. Although Guadeloupe is at the very beginning of its involvement in ocean energies, according to local authorities the Island will work on framing the natural resource and feasibility of ocean energy plants as well as on creating the most favourable policy framework.

*"Beyond their potential to produce a clean energy with indigenous resources, ocean energies have a number of socioeconomic advantages for island communities such as Martinique, such as the opportunity to develop business tourism and nurture a local human capital highly skilled in ocean technologies and likely to transfer local know-how to the broader market."*

*Anthony Nobour,*
*Energy Officer for the Local Government of Martinique*

Likewise, French Polynesia is considering ocean energies as a means to diversify its energy mix and achieve the target of 10% of renewable energies in the Archipelago's energy mix and 50% of the electricity production being from renewable sources by 2020. Currently, 70% of the electricity is produced by thermal power plants. In 2010, a resource assessment for OTEC revealed substantial potential, with strong temperature gradients (up to 24°C). Another resource assessment is under way for tidal stream energy (Takaroa – Manihi – Tuamotu archipelago) and for wave energy, which should be completed by the end of 2016 and allow projects to develop in the coming years. The Energy and Climate Programme, which was published at the end of 2015, puts once again the emphases on the development of OTEC projects.

French overseas territories such as Martinique, Guadeloupe and French Polynesia could be a unique showcase location for ocean energy technology developers to then access regional markets such as the Caribbean, Latin America and the Pacific region.

*"The market for ocean energies will primarily be located in island communities that are not inter-connected. Near the mainland, ocean energies will hardly be competitive against resources such as nuclear, coal and gas that are easily accessed and transported."*

*Jean Ballandras,*
*Akuo Energy's Secretary-General*

Country focus

# Indonesia

## Current state of progress: Abundant natural resources but few pilot projects operating

Indonesia is the world's largest archipelago, and has one of the largest potentials of ocean energies in the world. Demand for energy is growing. Between 2000 and 2013, Indonesian electricity consumption has grown by almost 140%, and reached 188 GWh[16]. In this context, there is a real need for an alternative source of energy throughout the country. In addition, 16% of the population (i.e. 50 million people) living on the 17,500 islands of the archipelago do not have access to electricity[17].

On the resource side, with 54,716 km of coastline, Indonesia's estimated potential for ocean energy is between 10 MW and 35 MW per kilometer of coastline[18]. Main ocean resources include tidal stream, waves and ocean thermal (see table below).

| | Theoretical potential (GW) | Commercial potential (GW) |
|---|---|---|
| Wave | 140 | 2 |
| Tidal stream | 290 | 18 |
| OTEC | 4,250 | 41 |

Despite this major potential, only few pilot projects have already been launched in Indonesia (see table below). However, recent announcements suggest that the sector will experience a more rapid growth in the years to come (see section on perspectives).

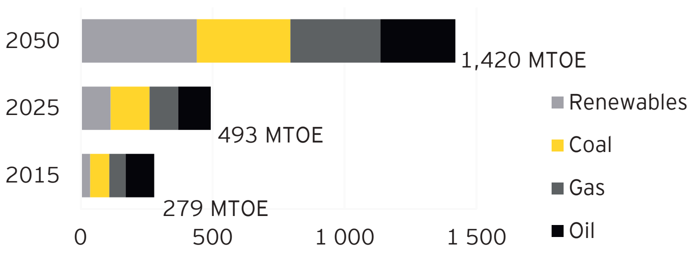
16. *Ministry of Energy and Mineral Resources, Republic of Indonesia (2014) - Handbook of energy and economic statistics of Indonesia*
17. *IBP (2015) - Indonesia energy policy, laws and regulation handbook*
18. *US Department of Commerce (2010) – Renewable Energy Market Assessment Report: Indonesia*

| Project proponents | Technology | Location | Capacity (MW) | Development stage |
|---|---|---|---|---|
| Ponte di Archimede SpA (Italy) - PT Walinusa[19] | Tidal stream | East Lomboc island | 0.18 | Platform built and on site, waiting for a budget to deploy at sea |
| PLN - Institut Teknologi Sepuluh Nopember[20] | Wave power | Madura - East Java | 0.02 | Early stage of development |
| BPDP-BPPT IHL[21] | OTEC | Flores island | 0.01 | Early stage of development |

## Policy developments

The Indonesian government is well aware of the important potential of ocean energies for the country. The government's energy strategy is a diversification of energy sources, with renewables representing 23% of the energy mix by 2025 and 31% by 2050[6]. No precise percentage is indicated for ocean energies, although their share can be estimated at below 1%. In order to support this trend, it will invest approximately EUR 8 m over the next five years.

Indonesian energy mix scenario
Million Tons Oil Equivalent




In a country where fossil energy prices are highly subsidised (subsidies for oil represent 15% of national budget), the government has yet to design feed-in tariff in order to incentivise ocean energy IPPs to deliver bankable projects with a fair return on investment.

*"Indonesia has been pursuing an active policy to increase electrification throughout the country and to develop renewable energy sources to go beyond fossil fuels."*

*Michael L.S. Abundo, Ocean Pixel*

## Presentation of the sector

The Indonesian ocean energy sector is composed of a comprehensive range of actors. In addition to governmental announcements regarding the Indonesian energy mix, the state-owned power entity PLN has published a power supply business plan for 2015-2024. This document comprises a development plan for new and renewable sources of energy, encompassing mini hydro power plants, wind turbines, biomass, biofuel, solar and marine energies. PLN will conduct small scale pilot tests on several ocean technologies as R&D projects (similarly to what it has been doing in Madura), with an expected capacity of 1 MW in 2016, 5 MW in 2020 and 10 MW in 2024[22].

On the research and development side, multiple actors are involved:

- The Indonesian ocean Energy Association (INOCEAN) is in charge of promoting the development of ocean energies through research and advocacy.
- International development agencies such as French AFD and British DFID support the development of ocean energies in Indonesia, mostly by organising and funding pilot programmes in the sector (e.g. AFD has granted EUR 500,000 for OTEC projects, see below).
- Finally, Indonesian and foreign private technology providers are starting to initiate pilot projects and partnerships with local partners (e.g. Ponte di Archimede SpA and PT Walinusal; Sabella, PLP and Meindo; Bombora Wave Power and Anoa Power). This process allows foreign technology providers to adapt their product to the local content before bringing it to the market.

*19. UNIDO (2015) - Promotion and transfer of marine current exploitation technology in China and South East Asia*
*20. Mukhtasor et al. (2016) - Performance modeling of a wave energy converter: PLTGL-SB*
*21. Indonesian Ocean Energy Association (2014) - Ocean Energy in Indonesia*
*22. PLN (2015) - Electricity supply business plan*

# Perspectives: A growing number of projects

The recent period has been characterised by several major announcements from technology providers and development agencies, that are expected to boost the development of the ocean energy sector in Indonesia in the years to come:

French company Sabella signed in February 2015 a MOU with Indonesian companies PLP and Meindo to commercialise its D10 submarine tidal turbines. Sabella will be in charge of engineering and manufacturing of the turbines, PLP will provide technical assistance and project management and Meindo will take over the construction phase.

*"The feedback from pilot projects in Indonesia will serve as a springboard for further project developments in other parts of South East Asia."*

*Michael L.S. Abundo, Ocean Pixel*

The Australian company Bombora Wave Power has signed in June 2015 a technology evaluation agreement with Indonesia company Anoa Power, in order to manufacture and distribute its Wave Energy Collector. Each collector has a 1.5 MW capacity.

British company SBS engaged in a technology transfer partnership with PT Pertamina. Both companies are now working on the launch of the first ocean energy technology at a commercial scale in Indonesia. The first site will be developed with a 150 MW tidal stream power generation facility, for a total cost of EUR 672.8 m (100% privately funded). After the launch of this first facility, two other facilities will be built on other sites. In order to sell the electricity produced, an agreement was signed between PT Pertamina and Indonesia's first ocean energy independent power producer (IPP), PT SBS Energi Kelautan.

In April 2016, PT Pertamina, French company Akuo Energy and French development agency AFD have signed an agreement to develop solar PV energy, wind energy and OTEC. AFD contributed with a EUR 500,000 grant specifically dedicated to the development of OTEC in Indonesia. A first phase of the project will consist in the identification of the most appropriate sites to develop OTEC projects.

Together with Indonesian Ministry for Energy (EBTKE), PLN and DFID, AFD has initiated a programme to identify appropriate sites to develop tidal stream facilities and select technology providers to develop these facilities. A request for proposals is expected by the end of 2016.

Projects developed in recent years focused mainly on tidal stream, wave power and OTEC. These technologies have the capacity to develop in Indonesia, especially on islands where electricity is provided by diesel powered generators. Ocean energies aim at becoming a financially competitive alternative to diesel, whose LCOE is EUR 0.27/kWh on some islands. Ocean technologies could also benefit from the national strategy which foresees a development of renewables by 2050. They represent a complementary source of energy alongside existing energy sources, such as solar PV.

*"Ocean energies offer some benefits compared to solar or onshore wind. They offer a better predictability of production, and do not require onshore land acquisition. Both issues are critical in a country like Indonesia."*

*Stéphane Tromilin, AFD*

Country focus



# Ireland

## Current status of progress

Ireland is taking measures at different levels to promote business opportunities seizing its abundant wave and tidal energy resources. Significant progress has been made in 2015 concerning the development of test sites infrastructure, the support of technology developers and the investment in academic research, enabling some flagship projects to materialise. The following events and initiatives recently rythmed the ocean energy market in Ireland:

- In 2013 was created a research centre part of the Irish Maritime and Energy Resource Cluster (IMERC), a partnership between University College Cork, Cork Institute of Technology, the Irish Naval Service and the Science Foundation Ireland Research Centre. The mission of this new centre is to create an international focal point for the marine renewable industry. Scientists concentrate on several fields such as new offshore, wind, wave and other marine energy devices and related infrastructure, and technology and materials to survive tough ocean conditions.
- Marine Current Turbines (MCT), former Siemens subsidiary, was sold to Atlantis Resources Limited in mid-2015. The company is responsible for the successful operation of the 1.2 MW SeaGen S device at Strangford Lough.
- The SEAI signed a Memorandum of Understanding with Apple in November 2015 to promote the development of ocean energy in Ireland. The EUR 1 m funding granted by Apple aims at helping developers to test their ocean energy prototypes in the Galway bay Ocean Energy Test Site.
- In March 2016 was announced the creation of Verdant Isles Ltd, a joint venture involving Verdant Power Inc. (a New-York-based marine and hydrokinetic energy specialist) and Belleville Duggan Renewables Ltd. The objective is to develop tidal energy projects in Ireland and the UK, focusing mainly on site extension and the establishment of a manufacturing base in the region.
- The MaREI, Ireland's Marine and Renewable Energy Centre is strongly involved in EU projects including FloTEC (Floating Tidal energy Commercialisation project), INNOWAVE and MARIBE (maximising the technical and economic performance of real wave energy devices), OPERA (Open Sea Operating Experience to Reduce Wave Energy Cost), RICORE (Risk Based Consenting of Offshore Renewable Energy Projects). To date, the company

has secured a total of EUR 6 m in EU funding. In April 2016, it received a EUR 750,000 funding from the NTR Foundation for R&D into low carbon renewable energy solutions, representing the largest single investment from the private sector to date in MaREI.

- Seatricity Ltd launched in June 2016 its Oceanus 2 WEC off the coast of Hayle, Cornwall. The device is the first of some 60 devices planned as part of a 10 MW, grid-connected array.
- The Electricity Supply Board (ESB, the state-owned electricity company operating in Ireland) is planning to open in 2018 the first wave energy farm in Europe off the western coasts of Irish waters. Called the West Wave project, the aim of the project is to prove the commercial viability of five wave energy devices. The project was granted a EUR 1.3 m funding by the SEAI to help complete the feasibility studies required before the installation of the devices.

## Policy developments

Ireland has committed to a 2020 target of 40% of all electricity consumed to be from renewable sources. The Strategy for Renewable Energy 2012-2020 has re-affirmed this 40% penetration commitment. One of the key objectives of this strategy is a commitment to realising the economic potential of Ireland's wave and tidal resources.

Within this context, a collaborative environment in the field of ocean energy has emerged since the publication of the Offshore Renewable Energy Development Plan (OREDP) in 2014, especially through the Offshore Renewable Energy Steering Group, composed of relevant agencies and Government departments. The OREDP is considered as a framework for the development of this sector. Its mission consists in highlighting the potential opportunities for the country in relation to marine energy as well as the key principles, specific actions and enablers needed for the realisation of projects in three areas: Environment, Infrastructure and Job Creation. A report from the Steering Group is to be addressed to the Minister before end 2017.

Besides, the White paper "Ireland's Transition to a Low carbon Energy Future 2015-2030" was published by the Irish Government's Department of Communications, Energy and Natural Resources (DCENR) and reinstates the role of ocean energy in Ireland's energy transition in the medium to long term.

## Presentation of the sector

Renewable energy resources are seen as a key competitive advantage by many stakeholders in Ireland, given the potential to generate significantly more renewable energy than the domestic market needs and thus creating an export opportunity. A range of ocean energy technology companies are currently active in Ireland including Aquamarine, MCT, OpenHydro and Wavebob. Local utilities ESB, Bord Gais, technology from Ideas, GKinetic and SSE Renewables are active participants in the ocean energy sector.

The strength of Ireland is its unique ladder of development and test site infrastructure, which allows developers to move from a laboratory test facilities to another scale test bed and to a full test facility located elsewhere on the Island. An active R&D policy is implemented through two test sites :

- The National Quarter Scale Test Site in Galway, dedicated to quarter-scale floating wave energy devices and has been operational since 2005.
- The Atlantic Marine Energy Test Site in Belmullet (AMETS), developed by Sustainable Energy Authority of Ireland (SEAI) with the objective to foster full scale WEC tests in an open ocean environment. The site is expected to be grid connected and to generate a maximum power of 10 MW once operational.

## Perspectives

Recent emphasis by the Irish Government for the country to become a world-leader in this sector has highlighted the potential the country can offer, given the research and development capabilities, the notable renewable energy targets, the mature and experienced domestic renewable energy sector and the very significant wave and tidal resources available. This holds true especially for tidal energy: according to the SEAI's projections, the "viable" tidal current energy resources that could be developed annually in Irish waters amount to 900 GWh.

The above strengths are further emphasised by Ireland's need to increase energy security. Government departments are focussing on simplifying and accelerating the foreshore licensing process to enable the rapid development and deployment of ocean energy technology. The integrated Marine Plan for Ireland outlined in the recent Government publication 'Harnessing our Ocean Wealth' has highlighted for the first-time the required actions to fast-track the development of the Ocean Energy sector in Ireland. This has been highlighted by the MoU between the UK and Irish Governments outlined above, and the development of the ISLES project to increase interconnection between Ireland and the UK and capitalise on the offshore wind, wave and tidal energy resources.

The OREDP is currently working on the introduction of an initial Market Support Tariff for Ocean Energy, which will amount to EUR 260/MWh and be limited to 30 MW for wave and tidal, focusing on pre-commercial trials and pilot. This initiative takes part in a national scheme designed to support renewable electricity that was launched in January 2016.

Besides, public funding programmes include the Sustainable Energy Authority of Ireland's Prototype Development Fund (65 projects subsidised since 2009, 15 new projects in 2015) and the OCEANERA-NET scheme, an innovative component of the European Union's Framework Programme which supports cooperation of national/regional research funding programmes.

# Japan

## Current status of progress

### *Ocean energy potential in Japan*

Japan has the world's 6th largest exclusive economic zone (EEZ) with rich marine resources of total size 4.47 million $km^2$. The Japanese Government has defined marine development as a priority issue and actions for such development will accelerated in the future.

The New Energy and Industrial Technology Development Organisation (NEDO) investigated energy potential of ocean energy in the EEZ of Japan:

- Tidal Stream 225 GW
- Waves 195 GW
- Ocean Wind 1,570 GW

The Central Environment Council of the Ministry of the Environment posits that the cumulative amount that can be commercialised by FY2050 is at most 12.03 GW for wave power and 1.92 GW for tidal power. Another major potential growth area for ocean energy generation in Japan is offshore wind. Japan has an estimated 1,570 GW of offshore wind potential in comparison to 280 GW of onshore wind, which is constrained by land availability and geography. However 80% of the offshore wind resource is located in a water depth greater than 100 m which will require bespoke deep water turbine technology, for example floating turbines. According to the Japan Wind Power Association (JWPA), a realistic offshore wind potential would be around 600 GW, out of which 85 % could be exploited using floating technology and the remaining using bottom-fixed turbines. Furthermore, the national target set by the Japanese government, 37 GW of offshore wind power is expected to be installed by 2050, including both bottom-fixed and floating offshore wind turbines.

### *Projects under development*

The Japanese clean energy market only started to move with the Great East Japan Earthquake and the Fukushima Daiichi Nuclear Power Plant accident in 2011.

According to Japan's Ministry of the Environment (MOE) several offshore wind power generation facilities have been installed for the purpose of demonstration experiments since 2012. In June 2012, a small-scale experimental power generation system (the world's first Hybrid Spar-type system) with a capacity of 0.1 MW which was connected to the power grid was installed in the area of Kabashima, Goto City (Nagasaki Prefecture), as Japan's first floating offshore wind turbine to gain insight into its environmental impact and safety. Based on the results of the experiment, Japan's first commercial scale wind turbine (2 MW) started operation in October 2013 to collect information about impacts on the environment, suitability to Japan's meteorological and oceanographic features and safety.

Aiming at commercial operation of the world's first floating offshore power plant (wind farm), a 2 MW floating offshore power generation facility and floating offshore electric substation installed in November 2013 has started operation. The world's largest 7 MW floating offshore wind turbine was installed in July 2015 and started operation in December 2015. Another floating offshore wind turbine with a capacity of 5 MW is scheduled to be installed to launch the world's first demonstration project with multiple floating offshore fine turbines.

In order to accelerate the implementation of offshore wind turbines in port areas, a bill to amend the Ports and Harbours Act was endorsed by the Cabinet of Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in February 2016 to allow offshore developers to occupy harbour space for a period of 20 years, far exceeding existing arrangements. By the end of January 2014, Wakkanai Port (Hokkaido), Ishikari Bay New Port (Hokkaido), Mutsu Ogawara Port (Aomori Prefecture), Noshiro Port (Akita Prefecture), Akita Port (Akita Prefecture), Kashima Port (Ibaraki Prefecture) and Omaezaki Port (Shizuoka Prefecture) were all designated as ports where wind turbines can be installed. Kita Kyushu Port was also added to the list in December 2015. The offshore developers for Mutsu Ogawara Port, Noshiro Port, Akita Port, Kashima Port and Ishikari Bay New Port have been selected by August 2015. In addition, based on the "National Policy Framework for Promotion of the Use of Marine Renewable Energy" (formulated by the Headquarters of Japan Ocean Policy in May 2012), local governments have been asked to provide their marine zones for experiments and received proposals from seven prefectures for eleven marine zones out of which seven marine zones were designated as the demonstration fields. In 2015, fourteen prefectures in Japan were involved in ocean energy development: tidal current (Hokkaido, Aomori, Saga, Nagasaki, Kagoshima); wave energy (Aomori, Iwate, Yamagata, Niigata, Tokyo, Shizuoka, Okinawa); ocean wind (Fukushima, Iwate, Niigata, Shizuoka, Saga, Nagasaki, Ehime); ocean thermal energy (Saga, Okinawa); salinity energy (Fukuoka); oceanic current (Okinawa, Kagoshima, Wakayama, Niigata).

Since 2011, 22 demonstration projects and development of element technologies have been underway to commercialise power generation utilising ocean energies such as wave power and ocean current power.

| Project Proponent | Technology | Location | Maturity | Capacity (MW) | Start up | Government support |
|---|---|---|---|---|---|---|
| Ocean Thermal Energy Conversion | | | | | | |
| Japan Institute for Ocean Energy Research | Closed cycle - around 90% goes to pumping and energy used to operate the plant | Nauru (Nauru) | For scientific research | 0.12 | operated in 1982-1983 | N/A |
| Xenesys Inc., Saga University | Multi-purpose | Imari (Japan) | Demonstration plant; several other have been built in earlier stages | 0.03 | 2003 | N/A |
| Xenesys Inc., IHI, Yokogawa, Japan Marine United Corporation, Saga University | Land-based plant used for electricity generation and research on other OTEC applications, aquaculture, agriculture, cooling | Okinawa, Kumejima (Japan) | Research, development and demonstration plant (possible scaling up to 125 MW) | 0.05 | Completed on 16 June 2013 | N/A |
| | | | TOTAL | 0.20 | | |
| Salinity Gradient Energy | | | | | | |
| Statkraft (Norway) Nitto Denko (Japan) | Pressure Retarded Osmosis (PRO) Power Plant | Torte (Norway) | Pilot plant | 2 | Open 2006, closed 2013 | Lack of long-term financial support mechanisms |
| Toray Industries, Inc. (Japan) | PRO System (part of the national project "MegaTon Water System") | Fukuoka (Japan) | Pilot plant | 0.1 | Prototype 2009 Commercia-lisation 2015 | EUR 38.3 m government-backed research initiative |
| Fujifilm (Japan) REDStack (Netherlands) | PRO System ("Blue Energy") | Afsluitdijk (Netherlands) | Pilot plant (plans for extended installation up to 200 MW in 2020) | 0.05 | opened on 11 October 2013 | |
| | | | TOTAL | 2.15 | | |
| Floating Offshore Wind Turbines | | | | | | |
| Sasebo Heavy Industries, Kyoto University, TODA Corp., Nippon Hume Corp., | Steel/concrete hybrid Spar-type floating wind turbine platform | Sasebo (Japan) | 1:10 scale prototype | 0.001 | Open 2009 closed 2013 | N/A |
| Fuji Heavy Industry, Kyoto University, TODA Corp. | GOTO FOWT (floating offshore wind technology) - hybrid Spar-type system | Kabashima, Nagasaki (Japan) | Demonstration project (plans for extended installation up to 2 MW) | 0.1 | Open 2012 closed 2013 | N/A |
| Fuyo Ocean Development & Engineering Co., Ltd., Kyoto University, TODA Corp. | GOTO FOWT (floating offshore wind technology) - hybrid Spar-type system | Kabashima, Nagasaki (Japan) | Demonstration project (It aims to reach up to 5.6 GW by 2030) | 2 | Open 2015 | EUR 13.8 m |

| Project Proponent | Technology | Location | Maturity | Capacity (MW) | Start up | Government support |
|---|---|---|---|---|---|---|
| Floating Offshore Wind Turbines | | | | | | |
| Fukushima Forward Consortium: Marubeni Corporation, Mitsubishi Heavy Industries, Mitsui Engineering & Shipbuilding etc. | Floating Substation, Compact Semi-Sub 2 MW, Advanced Spar 7 MW, V-shape Semi-Sub 7MW | Fukushima (Japan) | Demonstration project (plans for extended installation up to 1000 MW) | 2<br>7<br>7 | Open 2012, fully operated 2015 | EUR 166.8 m |
| Iwate Prefecture (local government) | 3 Spar Floater | Kamaishi (Japan) | Concept / Early planning | N/A | 2014 | N/A |
| Kyushu University | Semi-Submersible Platform (large foundation will support turbines and solar panels) | Ehime (Japan) | Concept / Early planning | 1 | 2014 | N/A |
| Principle Power Inc. | WindFloat Japan (WFJ), Offshore wind farm, with additional units to flow (Semi-Submersible Platform) | Sea of Japan | Concept / Early planning | 6 | Commis-sioning date 2017 | N/A |
| | | | TOTAL | 27.1 | | |
| Tidal Stream Energy | | | | | | |
| Mitsui Ocean Development & Engineering Inc (MODEC Inc.), NEDO | Hybrid - Savonius Keel & Wind Turbine Darrieus | Kabeshima, Saga (Japan) | Development & demonstration | 0.5 | Open 2014 | *EUR 16.1 m for fiscal years 2013-2015 |
| Oshima Shipbuilding Co., Ltd., NEDO | Interior Permanent Magnet Type Vertical Axis Turbine | Yobikonoseto, Nagasaki (Japan) | Research and development | N/A | 2014 - 2015 | *EUR 16.1 m for fiscal years 2013-2015 |
| Sasebo Heavy Industries Co., Ltd., NEDO | Double Rotor & Twin Nacelle Turbine | Goto, Nagasaki (Japan) | testing | 0.11 | prototype 2013-215 | *EUR 16.1 m for fiscal years 2013-2015 |
| Toa Corp, Ministry of Environment | Horizontal Axis Turbine | Goto, Nagasaki (Japan) | N/A | N/A | N/A | *EUR 16.1 m for fiscal years 2013-2015 |
| Okinawa Institute of Science and Technology (OIST) | Tidal turbine that could harness the energy of the Kuroshio Current flowing along the Japanese coast | Okinawa (Japan) | Development stage | 1,000 | Prototype 2012, in development stage from March 2016 | N/A |
| | | | TOTAL | 1,000 | | |

| Project Proponent | Technology | Location | Maturity | Capacity (MW) | Start up | Government support |
|---|---|---|---|---|---|---|
| Wave Energy | | | | | | |
| Mitsui Engineering & Shipbuilding Co., Ltd., Ocean Power Technologies, Inc. | Point Absorber (modified from Powerbuoy) | Kouzu, Tokyo (Japan) | Development stage | 350 | 2013-2017 | EUR 2.4 m |
| Mitsubishi Heavy Industries Bridge & Steel Structures Engineering Co. Ltd. TOA Corporation, MM Bridge Co., Ltd, TOA Corporation, NEDO, Saga University | Multiple Resonance Unit OWC and Wave Power Device (Impulse turbine) | Sakata, Yamagata (Japan) | Demonstration experiment | 0.015 | Open 2015 | N/A |
| The University of Tokyo, Ministry of Environment | Blow Hole Wave Energy Conversion System | Echizen, Fukui (Japan) | System Demonstration | 0.03 | 2012 - 2014 | N/A |
| Mitsui Engineering & Shipbuilding Co., Ltd., Ministry of Environment | Wave Power Generation System on the Coast | Oarai, Ibaraki (Japan) | Demonstration experiment | 0.1 | 2014 | N/A |
| Ichikawa Doboku Co., Ltd., NEDO | Overtopping Type Wave Energy Converter | Omaezaki, Shizuoka (Japan) | Demonstration experiment | 0.025 | N/A | N/A |
| | | | TOTAL | 350.17 | | |

** Total government supply for all ocean energy projects in Nagasaki and Saga area.*

# Policy developments

After the Fukushima disaster, Japan was forced to reconsider its energy policy. In 2015, the Japanese government announced a goal of reducing dependency on nuclear energy and increasing the amount of renewable energy used to 22-24 % by 2030. The decision was also made to lower $CO_2$ emissions to 26 % below 2013 levels, as presented at COP 21 in Paris. Japan's energy policy defines marine renewables as one of the higher priority technologies. The creation of a renewable energy site is specifically highlighted as an important measure to secure the future of the marine energy sector in Japan and to deliver a range of benefits including: reduced development costs; improved safety; increased private investment; enhanced international competitiveness; and a revitalised local economy.

Aiming to promote a comprehensive and systematic implementation of the policies related to the ocean, the Japanese Government endorsed the "Ocean Basic Law" in July 2007. Based on this "Ocean Basic Law", the Cabinet later issued the so called "Basic Plan on Ocean Policy" in March 2008. In 2013, a new "Basic Plan on Ocean Policy" was formulated. In this five year plan, the development of ocean renewable energy is structured around the following topics:

- Promotion of ocean renewable energy technology development with a view to realising commercialisation: development of demonstration fields, promotion of cooperation between industries, emphasis on safety.
- Promotion of practical application and commercialisation of ocean renewable energy: measures to preserve marine environment, development of the legal framework, deepen and share knowledge on resources and results of pilot projects (performance, costs), make Japan a leader in ocean energies by setting international standards on ocean technologies.

In the "Basic Plan on Ocean Policy" the highest attention is paid to the floating offshore wind power generation:

- Promotion of technological development: A small scale (0.1 MW) offshore floating wind power generation system that takes into account the characteristics of the weather and sea conditions of Japan was constructed off Kabashima Island, Nagasaki Prefecture in 2012. The Project was followed by a 2 MW unit constructed in 2013 at the same place; the two projects aim to promote research in real sea conditions that lead to the establishment of technology by the year 2015.
- Development of safety standards: In order to ensure the safety of the floating offshore wind power generation facility, technical issues related to the security of the various parts of the system are being investigated, including the floating body, protection against capsising, sinking, etc. From the results of these studies, it was possible to formulate safety guidelines by the end of the year 2013, and lead the establishing of international standards in the International Electrotechnical Commission (IEC).

A feed-in-tariff has been launched in Japan in 2012 for traditional renewables, and was completed by ministry ordinances to cover other renewable energy sources such as ocean energy. The tariffs for ocean wind energy, wave energy and OTEC are as follows:

| FIT in EUR/kWh | 2015 | 2020 | 2030 |
|---|---|---|---|
| Ocean wind energy | 0.11-0.24 | 0.08-0.12 | 0.04-0.14 |
| Wave energy | 0.32 | 0.16 | 0.04-0.08 |
| OTEC | 0.32-0.49 | 0.12-0.20 | 0.06-0.11 |

*Source: (New Energy and Industrial Technology Development Organisation, NEDO)*

# Presentation of the sector

### *Japan's ambition to be the world leader in floating offshore wind technology*

While the availability of land is limited, Japan has extensive sea areas. In offshore wind power generation, large-scale facilities can be established, since wind turbines can be installed on the flat sea surface and there is nothing to block the wind. Furthermore, since offshore facilities are away from residential areas, there are no problems of affecting residents with impacts such as noise, low-frequency waves, and shadow flickering (the phenomenon where the shadows of wind turbines' rotating blades cause the ambient light to flicker). It is expected that offshore wind power generation will be further developed to become one of the pillars of renewable energy resources in Japan. Because the track-record in terms of bottom-fixed wind turbines in Japan is limited, and these turbines are sensible to earthquakes, tsunamis and typhoons, FOWT projects represent a good alternative.

In an effort to maximise the advantages of floating offshore wind farms, the Fukushima Offshore Wind Consortium was created by ten companies (Marubeni Corporation, Mitsubishi Corporation, Mitsubishi Heavy Industries, Japan Marine United Corporation, Mitsui Engineering & Shipbuilding, Nippon Steel & Sumitomo Metal Corporation, Ltd., Hitachi Ltd., Furukawa Electric Co., Ltd., Shimizu Corporation, Mizuho information & Research) and one university, with Marubeni Corporation, one of Japan's major general trading firms, as the project integrator, and the University of Tokyo as technical adviser. The consortium is implementing the floating offshore wind farm project off the coast of Fukushima Prefecture. The aims of this demonstration project are to overcome various technical challenges, ensure collaboration with the fishing industry, secure marine navigation safety, and establish a method for environmental impact assessment - all of which are essential to create large-scale offshore wind farms in the future. Furthermore, the project also has its eyes on developing floating offshore wind farms into one of Japan's main export industries. Since 2013, the project has so far successfully developed and from 2015, as a demonstration, the project is focused on evaluating the safety, reliability, and economic feasibility of the floating offshore wind farm by collecting and analysing meteorology data, oceanography data, and operation data. At the same time, it will try to establish the operation and maintenance practices. With the total facility output to 16 MW, the project demonstrates the economic feasibility of large-scale floating offshore wind farms, including the cost-reduction effect of construction of larger wind turbines.

### *Japan's plans to create a home-grown tidal industry*

In 2015, EUR 8.1 m have been assigned for the creation of a "Japan Marine Energy Centre", similar to the European Marine Energy Centre (EMEC), with two sites for full-scale marine energy device testing. Nagasaki could be a front-runner for this facility thanks to its strong ocean currents. Nagasaki prefecture is proposing waters off the islands of Kugashima and Ejima for tidal testing, and Kabashima for floating offshore wind. The other main contender for a tidal site is nearby Saga Prefecture, which is proposing a location off Kabejima island that will also serve for offshore wind testing. The site is expected to be home to Japan's first pilot tidal technology, a hybrid design featuring a three-bladed vertical-axis Darrieus wind turbine on a floating foundation housing a Savonius ocean-current machine.

The Carbon Trust, the Wind Energy Institute of Tokyo and the Nagasaki Marine Industry Cluster Promotion Association (NaMICPA), are working on the development of offshore renewable test site in the Nagasaki Prefecture, commissioned by the Nagasaki government. Development of the test centre is ongoing with the aim of opening a fully operational testing site from 2018. From April 2016, Orkney-based energy (UK) and environmental consultancy Aquatera (UK) has further strengthened ties with Japan by becoming a member of a Marine Energy Association in the country, and entering into a partnership with a Japanese offshore operations company. Aquatera has become a member of NaMICPA, which helps support the development of marine renewables in Japan and stimulate further international collaboration.

### *Development of ocean thermal energy conversion (OTEC)*

Currently the only continuously operating OTEC system is located in Okinawa Prefecture, Japan. The Governmental support, local community support, and advanced research carried out at Saga University were key for the contractors, IHI Plant Construction Co. Ltd, Yokogawa Electric Corporation, and Xenesys Inc, to succeed with this project. Work is being conducted to develop a 1 MW facility on Kume Island requiring new pipelines. In July 2014, more than 50 members formed the Global Ocean reSource and Energy Association (GOSEA) an international organisation formed to promote the development of the Kumejima Model and work towards the installation of larger deep seawater pipelines and a 1 MW OTEC Facility.

> *"Research at the Institute of Ocean Energy at Saga University (IOES) is mainly focused on OTEC and Wave Energy converter. In particular, IOES has been conducting experimental research on OTEC for over 40 years."*
>
> *Takeshi Yasunaga*
> *OTEC expert and coordinator of the research project at Saga University*

### *Wave energy*

Ocean Power Technologies (OPT) has entered into a letter of intent with Mitsui Engineering and Shipbuilding (MES) to provide engineering support and potentially lease its APB350 PowerBuoy for the project off the coast of Kozu island in Japan. APB350 PowerBuoy is a self-powered autonomous mission platform fitted with a wave energy harvesting system designed to provide up to 350 W of continuous power to the mission-specific payload. The OPT project scope would also include associated deployment planning and logistics, ocean performance data collection and processing for state of calm sea off Kozu-island. Initial engineering tasks has commenced this March (2016) with expected in 2017 PowerBuoy shipment and deployment to Japan by the USA-based wave energy developer.

## Perspectives

The Japanese government is conducting an active policy to develop the ocean energy sector and make it both capable of supplying electricity to the national grid and to boost export of Japanese companies. Indeed, as part of the 2010 New Growth Strategy, the Japanese government announced it expects to create a EUR 406 bn market in energy and environmental services and create 1.4 million new jobs in the sector.

The first results from projects under development will be key to encourage private companies to invest further, in addition to existing incentives provided by public authorities.

# Focus on the ocean energy project in the island community Goto City

Goto City is located in the westernmost Kyushu region, which is the south-westernmost part of Japan's main islands. The city consists of 11 inhabited islands and 52 uninhabited islands across the East China Sea, with a total population of about 40 000. The city has developed an extensive renewable energy plan, with a mission of "Islands of Energy – Energising the town by producing energy". By maximising its natural resources, it is planning to cover 132.4 % of its total energy needs (oil, gas and electricity) with renewable energy by 2030. The city will accelerate renewable production to 731 GWh by 2030, of which 72 % will be provided by offshore wind power, followed by 17 % from tidal power.

To use the resources, the nation's Ministry of the Environment (MOE) launched the six-year FOWT demonstration project in April 2010. TODA Corporation led the project development, with a consortium of seven other entities, representing the industry, university, local governments and residents. First, a 0.1 MW pilot model was built in 2012, then the nation's first full-scale (2 MW) floating offshore wind turbine was installed and became operational in October 2013, at 1 km off the coast of Kabashima Island. Hitachi developed the 2 MW wind turbine with three 80-meter long blades. The FOWT is grid-connected; electricity generated is carried via undersea transmission cables to Kabashima, which has a population of 150. Electricity also can be transmitted to Kabashima's neighboring island, Narushima via undersea transmission cables connecting the two islands. Until 2005, Goto City, with about a dozen of the inhabited islands, did not have interisland transmission systems and depended on fossil fuel-fired plants installed on each island. The main inhabited islands are now connected with the mainland by the nation's longest undersea transmission cable (53 kW), developed by Kyushu Electric Power Co., the regional investor-owned utility. Due to the small energy demand on the islands and the limited transmission capacity, the FOWT has been operating only at a capacity of 600 kW. The system should be able to produce 5.78 GWh per year when it operates fully, but last year, it produced just over 1 GWh.

As the demonstration FOWT project has come to an end by March 2016, the MOE set aside about EUR 1.8 m for another project to help local governments to deploy wind projects suitable to their local environment. The MOE selected four locations, including Goto City. Along with the city, TODA Corporation submitted a project plan, which is to deploy over 100 units for a total of 552 MW off the coast of Fukueshima (the largest island with a population of over 36,000) and Oushima. Currently the city is talking to local fishermen to decide where to install offshore wind turbines so that any negative effects to the local fishing industry can be minimised.

As all of the projects at Goto City have been funded by the nation's Ministry of the Environment (MOE), the role of the national government remains critical for rural island economic development.

# Norway

## Current state of progress

Norway is characterised by a broad range of technologies in development, and a large number of pilot projects tested and in the pipeline.

One of the first ocean energy projects in the country was launched in 2004, when Andritz Hydro Hammerfest installed a pilot-project of its HS100 tidal stream turbine. Between 2004 and 2010, the turbine produced over 1.5 GWh to the grid and showed a 98% availability during test runs[23].

Norway is also the first European country where a full-size floating wind turbine was installed[24]. Indeed, a utility-scale floating wind turbine was deployed in 2009 by Statoil. The device, called Hywind I, was equipped with a 2.3 MW turbine (Siemens). Statoil is expecting the decision for a 30 MW pilot farm.

In 2014 and 2015, Havkraft AS has tested the Havkraft Wave Energy Converter (H-WEC) at Stad in Sogn og Fjordane[25]. The 200 kW pilot project demonstrated its reliability and survivability when exposed to extreme weather conditions. Next step for H-WEC is to add other functionalities to the device, for instance by combining it with a wind turbine to increase the capacity of the device.

Waves4power has installed its WaveEL buoy in Runde's test site (see below) in early 2016[25]. If this first full-scale pilot project is successful, and after the first production results have been collected, Waves4power aims at installing a farm of about 10 wave energy devices.

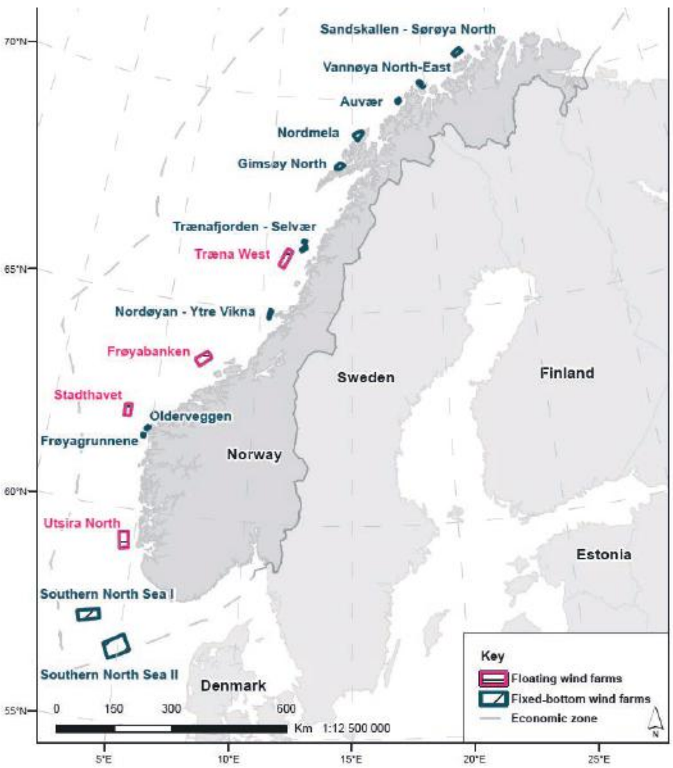
The world's first salinity gradient power generation plant using pressure-related osmosis was discontinued by its operator Statkraft in 2014, after having been in operation since 2009.

# Policy developments

Norway provides a combination of grant incentives (for the short term) and market incentives (for the longer term).

The Ocean Energy Bill from 2010 regulates the offshore renewable power production, by defining the licensing process for project developers. According to this bill, NVE, Norway's licensing body, prioritises small-scale pilot projects located near shore. The licensing process appears to be efficient[25].

Following this bill, 15 geographical areas were flagged as suitable sites for large scale wind power projects (for a total estimated capacity of 10 GW), including five sites for floating wind devices (see map). These 15 sites benefit from the petroleum taxation regime, with the aim of fostering the deployment of a Norwegian offshore wind market. In the short term, this could be an appropriate incentive for project developers to install pilot projects[24].




*Map of priority offshore wind areas*

*Sources: Ocean Energy Systems (2016), Annual Report 2015; EY (2016), Strategic assessment on floating offshore wind (confidential), Carbon trust (2015), Floating Offshore Wind: Market and Technology Review*

In addition to a favourable taxation regime, Norwegian public authorities resort to two other types of incentives to encourage the development of ocean energy projects. First, the joint green certificate market foresees that a green certificate will be given for each MWh produced by a renewable energy source, independent of technology. Although the price of EUR 50-55/MWh is a good incentive for maturing renewable energy technologies, it is certainly insufficient for ocean energy project developers due to the high CAPEX of these technologies[25]. At this early stage of development of the sector, government grants represent a more incentivising tool for project developers. The Norwegian Energy Agency (Enova) offers grants for full-scale pilot projects, covering up to 50% of the costs[26], although total financial resources of Enova are limited. For instance, Enova granted EUR 7.6 m for the development of Hywind I by Statoil, and EUR 6.5 m for the deployment of a 5MW tidal power pilot using Flumill technology in Rystraumen in 2012[27].

# Presentation of the sector

As mentioned above, Enova is the most active public agency in the ocean energy sector, providing grants to full-scale projects.

Regarding earlier stage R&D projects, the leading research institute on ocean energy is the Trondheim research cluster, composed of the Norwegian university of Science and Technology (NTNU) and the Norwegian Marine Technology Research institute (SINTEF-MARINTEK)[27]. This cluster conducts research and provides information on devices (design, monitoring systems etc.). Small-scale devices can also be tested in the cluster's wave tank.

Several test sites have the infrastructure required to host pilot projects. Runde Environmental Centre's facilities can host wave energy projects on several sites. Converters can be connected to the grid via a 3km cable under sea. A new tidal test site is expected to be built in Drammen.

Companies in Norway vary across a broad range of size and technologies. Statoil and Statkraft are public-owned, employ thousands of people in several countries and develop different technologies (tidal, wind, salinity gradient) while Havkraft and Wave4power are SMEs working mainly in Norway and focused on wave power technologies.

23. *Andritz Hydro Hammerfest (2016) – Tidal current turbines*
24. *INNOSEA (2015) – Floating offshore wind market outlook*
25. *Ocean Energy Systems (2016) – Annual Report 2015*
26. *Norwegian Research Centre for Offshore Wind Technology (2014) – Status og perspektiver for teknologiutvikling av vindøller til havs*
27. *The Research Council Norway, Innovation Norway, Enova (2010) - Norway, powered by nature*

## Perspectives

Norway has a long list of projects in preparation, at various stages of development (from early development to pre-commercial phase) and based on various technologies (wave power, tidal stream, tidal range). Deployment of several wave and tidal stream projects is scheduled for 2016 and 2017. Several Norwegian project developers have signed agreements to deploy their technology abroad, such as Andritz Hydro Hammerfest in Scotland or Ocean Energy in Spain.

| Project proponent | Technology | Name of the technology | Capacity (MW) | Development stage |
|---|---|---|---|---|
| Tidal stream | | | | |
| Andritz Hydro Hammerfest | Tidal stream | HS100 | 4.5 | Commercial deployment in Scotland in 2016 |
| Deep River | Tidal stream | Deep River Turbine | 0.250 | Full-scale testin in 2015 and 2016 |
| Flumill | Tidal stream | Flumill System | 2-5 | Deployment in 2017 |
| Tidal Sials AS | Tidal stream | Tidal Sails | - | Early development |
| Tide Tec | Tidal range | Tide Tec | - | Early development |
| Wave power | | | | |
| Ocean Energy | Wave power | Storm Buoy | Up to 40 | Full-scale testing in 2017 – agreement signed for a testing phase in Gran Canaria |
| Langlee Wave Power | Wave power | Langlee Robusto | - | Early development |

# Philippines

## Current state of progress

No ocean energy project are in operation as of today in the Philippines, but several pilot projects are planned and are expected to be implemented in the years to come (see section on perspectives).

The country is heavily dependant to fossil fuel imports (43% energy dependency in 2013), and forecasts a strong demand, driven by both economic growth (+6.1% in 2014) and demography (+1.8%/year). Production of electricity is 77,261 GWh in 2014, for an installed capacity of 18 GW[28]. Sources of electricity are mainly coal (43%), natural gas (24%), geothermal (13%) and hydro (12%),

In relation to the country's fragmented geography, 20% of the population does not have access to electricity, and a larger share have access only few hours per day. The price of electricity is one of the highest in the region (approx. EUR 0.2/kWh). This is due to the costs to import fossil fuel, the high number of not connected and isolated networks, the lack of public subsidies and the persistence of long-term PPAs signed in the 1990s at a high price.

The ocean energy potential of the country is estimated at 170,000 MW[29], with approximately 1/3 on OTEC and 1/3 on tidal[30]. However, these estimates are based on limited studies. The University of the Philippines (UP) has received a USD 445,000 (EUR 407,635) grant from the Department of Science and Technology to generate a resource map of tidal currents in the country, and to include suitability studies and device matching, in order to facilitate decision making by project developers[31].

*"The Philippines have a mature policy framework. This facilitates the activity of project developers, who can explore commercial opportunities and apply for projects together with local counterparts."*

*Michael L.S. Abundo, Ocean Pixel*

## Policy developments

The Renewable Energy Act (2008) is the overarching framework for renewable energies in the country. It aims at incentivising private investment in renewables. This act sets advantageous feed-in-tariffs for renewables such as solar (EUR 0.186/kWh), wind (EUR 0.164/kWh), biomass (0.128/kWh) and hydro (EUR 0.114/kWh)[32]. This act is complemented by the Philippine Energy Plan and the National Renewable Energy Programme, published by the Department of Energy, which aims at increasing total electricity installed capacity from 18 GW to 29 GW by 2030, while multiplying the capacity of renewables by three (see following table)[33]. Estimates by the IAE are more conservative, due to the fact that most of the funding necessary (EUR 23.3 bn) will need to come from the private sector.

The objective set by the Department of Energy is a 70 MW ocean energy capacity by 2030.

### *Objectives for renewable energy capacity by 2030, in MW[33]*

| | Current capacity | 2030 capacity |
|---|---|---|
| Hydro | 3,400 | 8,794 |
| Geothermal | 1,966 | 3,461 |
| Wind | 33 | 2,378 |
| Biomass | 39 | 316 |
| Solar | 1 | 285 |
| Ocean | 0 | 70 |
| Total | 5,439 | 15,304 |

*"A feed-in-tariff is in discussion in the Philippines. Its implementation could depend upon the performance of the first pilot projects that will be implemented in the country."*

*Michael L.S. Abundo, Ocean Pixel*

A feed-in-tariff for OTEC was discussed between project developers and the government (EUR 0.37/kWh)[34], which could serve as a basis for project developers to estimate the competitiveness of their projects.

## Presentation of the sector

The 2001 Electric power and Industry Reform Act (EPIRA) led to the privatisation of the energy sector, formerly exclusively managed by state-owned National Power Corporation (NPC). Electricity production is now a competitive landscape driven by private projects. Transmission is entrusted to a private consortium (National Grid Corporation of the Philippines), and distribution is managed by local entities, which can be local cooperatives, local government unites or private companies. Local cooperatives are especially active in rural areas where electricity supply is unsufficient. This ecosystem is favourable for ocean energy project developers, who can contract with local cooperatives without the same bargaining power asymmetry as in PPAs negotiated with large national power companies.

Major public actors include the previously mentioned Department of Energy, in charge of designing and monitoring the implementation of government energy guidelines. The Energy Regulatory Commission regulates the sector by supervising electricity tariffs between IPPs, distributors and cooperatives.

28. *Department of Energy (2015) - Philippine Power Statistics*
29. *Philippine Department of Energy (2012) - Biomass, solar, wind and ocean*
30. *Robles Quirapas, Lin, Lochinvar Sim Abundo, Brahim, Santos (2015) - Ocean renewable energy in Southeast Asia : A review*
31. *Seacore (2016) - Summary report for ocean renewable energy*
32. *Nanyang Technological University (2014) - Barriers to ocean energy technology adoption and role of policies & institutional system to promote in Asia*
33. *Philippine Department of Energy (2011) - National Renewable Energy Programme*
34. *Interview with Ocean Pixel (2016)*

Project developers include both foreign and local companies (regulation request foreign companies to have a local partner to develop projects in the Philippines). For instance, Sabella partnered with H&WB to enter the market. Some companies such as US based project developer Deep Ocean Power and Singapore based company Ocean Pixel have chosen to incorporate local subsidiaries in the Philippines. Local companies such as the Energy Island consortium are also working on the development of projects.

The University of the Philippines' Marine Science Institute is a member of the SEAcORE (Southeast Asian Collaboration for Ocean Renewable Energy). SEAcORE is acting as a transnational platform for R&D, industrial actors and knowledge sharing in the Southeast region[35].

> *"In the Philippines, private funders and public authorities are waiting for the feedback from the first pilot projects. Investors and lenders will focus on financial profitability, while public authorities will also be interested in the environmental performance and social acceptability of these projects."*
>
> *Jean-Christophe Allo, Sabella*

## Perspectives

In 2015, Sabella signed a memorandum of agreement with local project developer H&WB. The project consists in installing two D15 tidal turbines in the San Bernardino strait by the end of 2017, for a total capacity of 5 MW. Analysis are being undertaken in three sites to scale-up the project, which could reach a total capacity of 500 MW.

In 2016, Akuo Energy partnered with local power generation company Bell Pirie Power Corp. to sign a MOU with PNOC-RC (subsidiary of the Philippine National Oil Company, acting as project developer) to develop a 10 MW OTEC plant in the Philippines[36].

Bell Pirie Power Corp. and Energy Island were awarded a service contract from the Department of Energy to develop an OTEC pilot plant located in Zambales, off the west coast of Luzon island. The same consortium has planned several projects, namely a 0.1 MW wave farm off the coast of Quezon, a 0.05-0.1 MW OTEC plant off the coast of Pangasinan, and a 0.05-0.1 MW OTEC plant off the coast of Davao Gulf.

Deep Ocean Power Philippines' contract, awarded in 2011, was terminated by the Department of Energy due to a lack of progress[37].

The favorable policy framework, based on both the Renewable Energy Act and the privatised electricity market, is expected to facilitate the emergence of new projects in the Philippines. Tidal, OTEC and wave projects such as the ones listed in the table below are expected to grow in number following the installation of the first pilot projects scheduled by the end of 2017.

| Project proponents | Technology | Location | Capacity (MW) | Development stage |
|---|---|---|---|---|
| Sabella - H&WB | Tidal stream | San Bernardino | 5 (1st step)<br>500 (total capacity) | Early stage of development - first step scheduled by end 2017 |
| Akuo Energy - Bell Pirie Power Corp. | OTEC | unknown | 10 | MOU signed |
| Energy Island - Bell Pirie Power Corp. | OTEC | Zambales | 10 | Service contract awarded - Early stage of development |
| | Wave power | Quezon | 0.1 | Resource assessment and feasibility study |
| | OTEC | Pangasinan | 0.05-0.1 | Resource assessment and feasibility study |
| | OTEC | Davao | 0.05-0.1 | Resource assessment and feasibility study |

35. *Seacore (2016) - Summary report for ocean renewable energy*
36. *Interaksyon (2014) - DOE receives proposals for ocean power projects*
37. *Akuo Energy (2016) - Press release, cooperation agreement in the Philippines*

Country focus

# Portugal

## Current status of progress

Ocean energy-related activities have accentuated over the past few years in Portugal, with substantial developments in the policy framework, dynamic research and development programmes and the multiplication of funding opportunities accessible for ocean energy technology developers.

The Portuguese Atlantic coast has significant wind resource and deep waters that preclude fixed-bottom offshore wind projects. Subsequently, the floating offshore wind sector has been rather active in Portugal[38], with the installation in 2011 of Principle Power's 2MW turbine on a semi-submersible platform (WindFloat I) - the world's second full-scale demonstrator at sea. A scaled-up development should occur in Agucadoura in the next two years, with a total capacity of up to 27 MW (WindFloat II). This extension was awarded a EUR 19 m grant by the Portuguese Government as well as European funds through the FP7 and NER300 programmes. The existing electrical infrastructure in Agucadoura had been installed for the development of the Pelamis wave device demonstrator. This demonstrator was the world's first wave energy power plant and had a capacity of 2.25 MW. The farm opened in September 2008 but after two months in operation, the devices had to be brought back to the harbour due to technical incidents.

Another sea testing site of 320 km$^2$ dedicated to wave energy was identified by the Portuguese State in 2008. This site should be connected to the national grid through a concession agreement with a subsidiary of the Portuguese Grid Transmission System Operator however the infrastructure is yet to be developed. Nonetheless, there has been substantial interest from wave energy technology developers for the Portuguese coasts. Following successful trials in Peniche in 2007 and 2008, AW Energy, developer of the WaveRoller technology formed a consortium with local authorities to later develop the Simple Underwater Renewable Generation of Energy (SURGE) project – a grid connected wave energy converter. A first farm of three 100 kW WaveRoller units was installed in 2012. The total capacity of the license is 1 MW and AW Energy may expand the wave energy farm in the site of Peniche. WavEC has also been overseeing a wave energy pilot plant in the Azores Islands since 2004. This plant is connected to a grid and has been extensively used as a testing structure for mechanical characteristics, as well as for data collection and training purposes.

38. *Carbon Trust (2015), Floating Offshore Wind: Market and Technology Review*

Looking towards 2017, Australia-based developer Bombora Wave Power is planning to develop its first full-scale membrane converter, which should have a capacity of 1.5 MW. After several months of environmental and operational monitoring, Bombora will develop a 60 MW wave energy farm with 40 devices.

# Policy developments

Portugal is one of the few countries that have a public policy dedicated to ocean energies. This dedicated policy framework was formulated in the National Ocean Strategy 2013-2020, the public document that draws strategic orientations to foster sustainable development in the marine industry, including the energy sector[39]. This Strategy contains an action plan, which defines key areas for priority action. Supporting new technologies and innovation in the marine industry is one of the strategic actions that was identified, and should be implemented by enhancing opportunities for the installation, testing and development of emerging technologies. Spatial planning and the simplification of administrative procedures are also addressed by the strategy in order to ensure a balanced and coherent development of various maritime activities. Maritime planning is specifically addressed in the National Maritime Areas Planning and Management law, passed in March 2015, which provides a clear legal framework for the use of maritime areas and marine spatial planning. No specific capacity targets are defined to date though.

Several funding programmes are in place in Portugal and are accessible to ocean energy stakeholders although they are not necessarily directly targeting this industry. Approved in July 2015, a new financial mechanism, the Financial Instrument for Energy, will channel European structural and investment funds to promote clean energy sources and the diversification of the renewable energy sector. This instrument is meant to run for the 2014-2020 period. Other funding opportunities come through the OCEANERA-NET European network of which the Portuguese Foundation for Sciences and technology is a member. Funded by the EU, this network fosters ocean energy development by launching call for proposals for innovative technologies and components. In addition, the Portugal 2020 programme was signed by Portugal and the European Commission to determine financing priorities for business investment through the European Structural and Investment Funds. This programme runs from 2014 until 2020 and covers two areas that could be an opportunity for ocean energy players to be granted funding: Competitiveness and internationalisation and Sustainability and efficient use of resources. Finally, the Agência Nacional de Inovação fosters research activities with a focus on business-oriented research.

Portugal also implemented a basic Feed-In-Tariff for wave and offshore wind energies, for both pilot and pre-commercial projects. The remuneration is set to EUR 80/MWh for the first 25 years of the project and could increase by EUR 20/MWh under certain conditions[40].

# Presentation of the sector

Portugal hosts the non-profit association WavEC, an organisation involving public and private stakeholders that is dedicated to promoting ocean energies. WavEC delivers technical and strategic support to ocean energy technology developers as well as to public bodies willing to encourage the development of these energies. WavEC is a strong player in the industry and coordinated two projects, fostering capacity building for the wave energy sector and floating offshore wind. WavEC was also involved in several research and development consortium at the European level, leading work on consenting processes, design tools and a couple of different wave energy technologies.

Major research and development activities have also been under way with the Instituto Superior Tecnico (IST), from the University of Lisbon, concentrating on wave energy conversion. The IST benefits from good modelling and testing facilities and conducted laboratory tests in order to experiment technology components and understand crucial performance factors.

Portugal plays a strong role in federating European and international ocean energy players. In 2014 and 2016, the International Conference on Renewable Energies Offshore was held in Lisbon, counting a number of substantial research and development contributions.

# Perspectives

Over the next 5 years, Portugal should see the installation of several pioneering projects, amongst the first pre-commercial arrays developed in the world for wave energy and floating offshore wind turbines. As sea testing and commercial deployment confirm the potential of Portugal for ocean energies, the policy framework, spatial planning regulations and intense research and development activities will continue to build capacity and maturity within the Portuguese industry.

39. *Governo de Portugal (2013), National Ocean Strategy 2013-2020*
40. *Ocean Energy Systems (2015), Annual report*

# South Korea

## Current status of progress

South Korea is surrounded by water with three seas (Yellow Sea, East Sea, and Korea Strait), which endows Korea with significant ocean energy resources. By utilising favourable geographical conditions, feasibility assessments and research, development, and demonstration investments in ocean energy technologies are taking place actively, with a strong focus on tidal range power, following the completion in 2011 of the Sihwa tidal power plant.

| Total potential of Ocean energy in South Korea (ktons of oil equivalent) | |
|---|---|
| Potential energy that can be produced with current technologies | |
| Tidal | 2,599 |
| Tidal stream | 288 |
| Total | 2,887 |

*Source: 2012 New & Renewable Energy report by Ministry of Knowledge Economy Korea Energy Management Corporation*

| Year | Ocean Energy (MW) | Name of Power station | |
|---|---|---|---|
| 2009 | 1.5 (to be increased) | Uldolmok Tidal Stream Power Plant | In operation – total capacity increase is scheduled |
| 2011 | 254 | Sihwa Tidal Power Plant | In operation |
| 2015 | 520 | Garorim Bay Tidal Power Plant | Suspended |
| 2017 | 1,320 | Incheon Bay Tidal Power Plant | Cancelled |
| 2017 | 1 | Yongsoo OWC Wave Power Plant | In construction |
| 2017 | 840 | Ganghwa Tidal Power Plant | Feasibility study |
| 2017 | 53 | Wando Tidal Stream Power Plant | Feasibility study |
| 2017 | Unknown | Goseong Ocean Thermal Power Plant | Feasibility study |

*Source: The Fifth Basic Plan for Long-Term Electricity Supply and Demand by Ministry of Knowledge Economy of South Korea*

From a market point of view, the authority responsible for the Renewable Portfolio Standard (RPS) estimated that renewable energy represented 3.5% of total electricity production in 2015 and has set the target of increasing this share to 10% by 2022 compared to the introduction of the RPS in 2012. The tradable Renewable energy Certificate supplements the RPS policy as a market incentive.

The Government's National Basic Plan for New and Renewable Energies (NRE) sets the target of providing 11% of the total primary energy supply with NRE by 2035, with a mean annual NRE growth rate of 6.2% from 2014 to 2035. The mean annual growth rate of marine energy is targeted at 6.7% of the total electric energy supply by NRE by 2035.

In South Korea, installed capacity of ocean energy is mainly driven by tidal technologies. In fact, most ocean energy projects in South Korea are being developed on the West and South coasts, due to high tides and strong tidal currents in these regions, and are mainly led by six power generators and conglomerates in engineering & construction such as POSCO, Hyundai Heavy Industry, Daewoo E&C and GS Engineering & Construction.

Sihwa tidal power plant, the world's largest tidal power station, was completed in 2011 by Korea Water Resource Corporation (K-water) and Daewoo E&C with a total capacity of 254 MW. Uldolmok tidal stream power plant was built in 2009 with a capacity of 1,500 KW. A feasibility study for the construction of test beds for the wave and tidal energy devices was carried out in 2015 and pointed out several strategic ocean energy plan sites to be utilised for future test projects. These areas include the Uldolmok tidal power plan (which capacity will be expanded progressively), Yongsoo OWC wave energy plant (Jeju Island) and Goseong ocean thermal energy plant. The construction of the first ocean energy test bed (of a wave energy technology) of a 5 MW capacity and with 5 berths began in January 2016.

In spite of ambitious projects, ocean energy is undergoing harsh reluctance of local residents and restrictions from environmental protection organisations which have led the government to revise its initial targets downwards. Garorim Bay Tidal Power Plant and Incheon Bay Tidal Power Plant have been postponed due to environmental issues. In the case of Garorim Bay Tidal Power Plant, the project was technically revoked in November 2014 as effective date was expired according to related policy (Basic Plan for Reclamation of Public Waters). The Ministry of Environment, however, has extended the project duration until 2020, leaving the door open to a renewal of the project.

In addition to projects in operations, numerous R&D projects have been achieved or are planned, as shown in the table below.

| Technology | Project proponents* | Project Period | Capacity (MW) | Start up |
|---|---|---|---|---|
| Tidal energy | | | | |
| MW Class Tidal Current Device (HHI,MOTIE) | Pile, Pitch Contro | 2010-2015 | 1 | Sea Test in 2014 |
| Active Control Tidal Current System (KIOST, MOF) | Caisson, HAT with Pitch Control | 2011-2018 | 0.2 | Sea Test in 2016 |
| Semi-active Flow Control Turbine (Inha Univ., MOTIE) | Moored Submersible, HAT with Flow Control | 2013-2016 | 0.01 | Based on CFD |
| Active Impeller Tidal Turbine System (Daum Eng., MOTIE) | Vertical impeller with Flow Control | 2013-2016 | 0.05 | Sea Test in 2016 |
| | | TOTAL | 1.26 | |
| Wave energy | | | | |
| Pendulum WEC Utilising Standing Waves (KRISO, MOF) | Oscillating Surge, Floating Twin Hull | 2010-2018 | 0.3 | Sea Test of Pilot Plant in 2017 |
| Swinging Semi-Sphere with Hinged Arm (Hwa Jin Co., MOTIE) | Floating Point Absorber, Jack-up Platform | 2013-2016 | Expandable 0.015 | Sea Test in 2016 |
| Controllable Resonant WEC with Yoyo Oscillator (iKR, MOTIE) | Point Absorber with Variable Spring Stiffness, Moored Array of Cylinders | 2013-2016 | 0.01 | Sea Test in 2016 |
| WEC for Navigational Lighting Buoy (KPM, MOTIE) | Point Absorber with Solenoid, Single Point Moored Buoy | 2013-2016 | 0.05 | Sea Test in 2016 |
| INWave WEC with Multi Degree of Motion Converting Pulleys (Ingine Inc., MOTIE) | Point Absorber with Pulleys, Floating Disk with Touted Mooring Lines | 2014-2017 | 0.14 | Sea Test in 2016 |
| | | TOTAL | 0.52 | |

| Technology | Project proponents* | Project Period | Capacity and start up |
|---|---|---|---|
| OTEC, Salinity Gradiant & other ocean energy R&D projects | | | |
| OTEC Using Deep Ocean Water (KRISO, MOF) | | 2010-2015 | Cooling & heating system of 60 RT in 2011, 500RT in 2012 and 1.000 RT in 2013 OTEC pilot plant of 20 kW in 2013 and 200 kW in 2014 |
| Hybrid OTEC Using Plant Array (KEPRI, MOTIE) | | 2010-2015 | Use of cooling water discharged from pilot power plant of 10 kW in 2015 |
| Establishment of Infra System for Ocean Energy (KAIST, MOTIE) | | 2011-2016 | Education programme for ocean energy experts in graduate school |
| Low Temperature Working Fluid and Radial, Flow Turbine for OTEC (KMOU, MOTIE) | | 2011-2015 | Design of organic Rankine cycle radial flow turbine for 200 kW OTEC using low temperature working fluid |
| 10MW Class Floating Wave-Offshore Wind, Hybrid Power Generation System (KRISO, MOF) | | 2011-2016 | Development of analysis technologies and optimal design of a pilot plant for a hybrid ocean energy system with multiple FOWTs and WECs |
| Key Technologies of RED Stack for salinity gradient utilisation (KERI, MOTIE) | | 2014-2017 | Development of reverse electro dialysis stack and optimised ion-exchange membrane for kW-class salinity gradient power generation |
| Ocean Energy Professional Development Programme (Inha Univ. MOF) | | 2014-2018 | MOF programme promoting ocean energy education, research and development in universities |

*Source: OES – Annual Report 2015*

* *HHI: Hyundai Heavy Industry Co., Ltd.*
*MOTIE: Ministry of Trade, Industry and Energy*
*KIOST: Korea Institute of Ocean Science and Technology*
*MOF: Ministry of Oceans and Fisheries*
*KMOU: Korea Maritime and Ocean University*
*KPM: Korea Plant Management Company*
*KRISO: Korea Research Institute of Ships & Ocean Engineering*
*MOF: Ministry of Oceans and Fisheries*
*KAIST: Korea Advanced Institute of Science and Technology*
*KEPRI: Korea Electric Power Research Institute*
*KERI: Korea Energy Research Institute*
*KMOU: Korea Maritime and Ocean University*
*KRISO: Korea Research Institute of Ships & Ocean Engineering*
*MOF: Ministry of Oceans and Fisheries*
*MOTIE: Ministry of Trade, Industry and Energy*

# Policy developments

Two plans have been published over the past few years, aiming at shaping the national strategy in the ocean energy sector.

The Ministry of Oceans and Fisheries and Ministry of Trade, Industry and Energy of Republic of Korea published the "Mid- and Long-term development plan on Ocean energy 2015-2025" in July 2015, based on performance assessment of ocean energy technology development programme and internal/external market analysis. The plan promotes investment on technology development and improves existing relevant policies. As proposed on the plan, accreditation criteria on ocean energy facilities are prepared to promote renewable energy dissemination. In perspective of financial support, ocean energy developers can utilise renewable energy incentives and other cost factors. This scheme will encourage private sector's engagement in ocean energy development. Also, permission on ocean energy power plant is clarified and streamlined through clear statement of energy facilities (e.g. tidal current) on Public Waters Management and Reclamation Act.

According to the plan, building large-scale test bed to commercialise the Uldolmok tidal stream power plant and the Jeju pilot wave power plant by 2025 will help secure South Korea's development in the sector, along with countries such as the U.K, the U.S, France and Japan.

In addition, the "R&D plan on Ocean and Fisheries 2014 – 2020" published by Ministry of Oceans and Fisheries in 2014 suggested national vision and strategies for ocean technology development. The government aims to provide stable energy supply through developing ocean resources and energy. Specifically, original technology of integrated generation (combination of floating type offshore wind power and wave energy) with demonstration infrastructure, seawater desalination technology and generation from unexploited ocean energy (e.g. ocean thermal energy conversion power generation, deep sea pressure and etc.) development are major prioritised technologies to be developed. Within these plans, profitability of renewable energy can be guaranteed at the national level. By 2020, the government estimates ocean energy production to hold approximately 5.2% in renewable energy mix (2013: 0.9%; 2017: 3.3%).

## Presentation of the sector

The South Korean ocean energy sector is characterised by a variety of actors. Regarding projects development by private companies, the ocean energy development is led by six power generators (see above) and conglomerates in engineering & construction such as POSCO, Hyundai Heavy Industry, and Daewoo E&C.

On the R&D side, several institutes are active in the sector, such as the Korea Maritime and Ocean University, the Korea Advanced Institute of Science and Technology, and the Korea Energy Research Institute. Private companies are also active on the R&D side. Korea Southern Power Co., Ltd is leading the way on the R&D side. In 2015, it has selected five Korean companies (namely Heriana Co., Ltd., Aquacell, Sung-il Turbine, Dongin and DSE Bearing) who will be cooperating in the field of R&D projects for ocean energy.

On the public side, the main actors involved in ocean energies include the Ministry of Oceans and Fisheries and the Ministry of Trade, Industry and Energy, which have published a mid- and long-term development plan for the sector and a R&D plan. In addition, the Korean government has committed to invest EUR 11 m over three years (2016-2018) to construct the Deep Sea Water Industrial Centre. This centre will be in charge of promoting ocean-related projects, including ocean energy and fisheries industries.

## Perspectives

Major projects have been announced in 2016 by the Ministry of Oceans and Fisheries, at different levels of maturity depending on the technology. Regarding wave power, the wave power generation system on Jeju island is being built to pave the way for further coastal wave power generation system. In a similar manner, the design of a 1 MW OTEC power generation test bed (2016 – 2017) and operation under real sea (2017 – 2018), aims at building the foundations for an oversea expansion. With the "Mid- and Long-term development plan on Ocean energy 2015-2025", public authorities are encouraging the private sector's engagement in the development of active control tidal stream turbines with a horizontal axis. Tests under real sea conditions are expected by 2020. Finally, the 2025 development plan foresees the development of hybrid power generation technologies, combining wave energy and offshore wind power.

| Projects | Budget allocation of 2016 | Project duration |
|---|---|---|
| Design of 1 MW OTEC power generation test bed | EUR 0.56 m | (whole period) |
| Construct test bed for wave power generation under real sea condition | EUR 1.1 m | Less than five years |
| Development of seawall-connected wave power generation and other convergence technology | EUR 0.52 m | Less than four years |

The Ministry of Oceans and Fisheries and the Ministry of Trade, Industry and Energy cooperatively promoted the dissemination

of domestic ocean energy. Starting from 2017, the Government will undertake on building "Eco-friendly Energy Town" in Gosung, Kangwon-do. The region has well established infrastructure necessary for constructing OTEC system. In addition, starting from 2018, supplying small-scale wave energy in ports and fish port facilities will be promoted. Public institutions are increasingly interested in developing ocean energies, motivated by the mandatory quota for renewable energy (at least 30% by 2020). To encourage private enterprises' investment on ocean energy, the government actively suggests cooperative R&D and technology transfer programme.

In addition to pilot projects, an increased R&D effort is planned by public authorities. The Tech-Bridge Programme, which aims to transfer the government-funded R&D programmes led by public institutes to the private sector, will be started from 2017. The Programme intends to take technologies that government-funded R&D institutes possess to the market, by transferring them to private companies. Moreover, the government plans to select the top five ocean energy companies and support them until 2025. The development of ocean energies in South Korea aims at both developing plants in the country, and to allow Korean companies to enter foreign markets and reach a 20% market share by 2030.

# Sweden

## Current status of progress

Sweden has relatively good potential for ocean energy, which for wave ocean energy is estimated at 10-15 TWh. There are currently two main research and test sites, both operated by Uppsala University: the Lysekil wave power research site, that was grid connected in January 2016 and is planning to deploy at least two more Wave Energy Converters (WEC) during the first half of 2016; and the Söderfors marine currents research site, that consists of a 7,5 kW vertical axis turbine with a directly driven permanent generator. Launched in 2013 on the west coast of Sweden by Seabased, the Sotenäs Plant - the world's largest wave energy plant – achieved a major milestone at the beginning 2016, having deployed its first unit and successfully connected to the Swedish national grid. Several other technology developers are establishing pilot and demonstration projects, primarily outside Sweden.

## Policy developments

Sweden introduced an electricity certificate system in 2003 to support the build-up of renewable electricity generation. Norway joined the Swedish electricity certificate system in 2012. The overall intention is to increase liquidity, lower volatility, and reduce the political risk in the system. In particular, the joint target is to stimulate new renewable energy production corresponding to 26.4 TWh by 2020, mainly from wind, biomass and hydropower. There is no separate target for ocean energy in Sweden but ocean energy projects benefit from the same support system as other technologies.

In addition, renewable energy producers can apply for certificates concerning Guarantee of Origin, which can be sold on the market (but this remains a marginal source of revenue for producers at this stage).

The Swedish Energy Agency is responsible for Sweden's national energy research programme. It finances energy research, technological development and demonstration activities, in parallel with private capital and the industry. Seabased, a developer of a wave power technology originating from the University of Uppsala, received a EUR 17 m support from the EU Horizon 2020 research and innovation programme and a EUR 15 m support from the Swedish Energy Agency for its 10 MW pilot project, which is coordinated by the

Finnish utility company Fortum. Other earlier stage developers have received smaller grants for pilot installations. Moreover, in the beginning of 2015, the Agency launched a national ocean energy programme that will invest about EUR 5.7 m over the next four years. In June of the same year, and part of this programme, the company Corpower Ocean was granted a supplement of EUR 2 m to conduct Atlantic sea trials of its innovative wave power converter. The project HiWave, in which the trials take place, is developed with KIC InnoEnergy (Sweden), Iberdrola (Spanish) and the Research Institute WaveEC Offshore Renewables (Spanish). The Swedish Energy Agency also recently decided to finance two new research projects dedicated to the improvement of the performance and survivability of large scale wave energy farms, and the study of ecosystem services in relation to wave energy installation.

# Presentation of the sector

There are several developers of wave power technology in Sweden, with Seabased being the most advanced. The company has developed a technology based on small units with all parts deployed on the seabed, except for a buoy on the surface. This technology makes the power plant well safeguarded, and avoids issues experienced when the Wave Energy Converter ("WEC") is placed on the surface Seabased, as the operator of the Sotenäs Project, is in the process of setting up the world's largest wave energy plant (10 MW), with the sea cable and the first MW put in place in December 2013, the subsea generator switchgear having been deployed and connected to the Swedish national grid in December 2015, and the remaining 9 MW to be installed in 2016. In total, approximately 400 units will be deployed off the coast of Lysekil on the Swedish west coast. However, Seabased projects expansion might be slowed down by various financial issues the companies is facing, which already translated into the cancellation of EUR 8.9 m investment in 2016. The company, which is also expanding to new markets such as Ghana, is currently working with investors to raise short-term capital in order to match an investment bank project in the short run.

Swedish developers of wave technology include:

- CorPower Ocean, with a Wave Energy Converter, with a buoy on the ocean surface and the WEC between the surface and the bottom. Collaboration with the Norwegian University NTNU has enabled to reduce the costs of its new phase control technique, and the company will be testing a prototype at the European marine Energy Centre (EMEC) test site in Scotland in 2017.
- Waves4Power, a developer of a WEC placed in a buoy. The company will complete the launching of its demonstration installation of a full scale prototype on the Norwegian west coast in 2016, project which is supported by the Swedish Energy Agency.
- Minesto, which has developed a tidal energy device named Deep Green. The device converts energy from tidal stream flows into electricity by way of a novel principle, somewhat similar to the posture of a wind kite, and is based on technology originally developed by SAAB.
- Ocean Harvesting Technologies (OHT), developer of a power take-off technology, and is currently developing a system design for a 10 MW demonstration array in an open innovation strategy in cooperation with WEC developers, suppliers, test centres and research institutions. Test rigs are planned for 2016 and 2017.
- Vigor Wave Energy, which develops a WEC based on a floating hose, using water and air as mechanical parts to absorb wave energy. This innovation enables to produce large amounts of electricity at low cost.

Current Power Sweden, developer of complete system for energy transformation based on the extraction of energy from streaming water. The turn-key power plants are based on marine current turbines, direct-driven generators and grid-connection infrastructure. In addition to companies engaged in developing wave energy technology, Swedish Hexicon has developed large scale floating platforms for off-shore wind energy production. Hexicon's platform technology includes a centralised swivel anchoring system which enables the platform to turn around its own axis and thereby to automatically align itself to the wind. The wind turbines of the Hexicon platform are therefore always facing the wind in an optimised configuration, leading to significantly increased electricity production efficiency.

In addition to off-shore wind turbines, Hexicon's 700x500 m platforms can also house wave energy converters and the total capacity can be in excess of 70 MW per platform.

The Department for Shipping and Marine Technology at Chalmers University of Technology hosts the innovation platform Ocean Energy Centre, which aims to advance the ocean energy sector by initiating and coordinating joint research and development initiatives. The partner organisations are Minesto, Ocean Harvesting, Vigor Wave Energy, Waves4Power, IMCG, SP, SSPA, Chalmers and the Region of Västra Götaland.

# Perspectives

As Sweden has no separate targets for installation of ocean energy, with technology-neutral public support of renewable energy, the commercial build-up of ocean energy plants is likely to be slow as it competes with other more mature technologies, such as onshore wind and biomass. When wave energy technologies become competitive, the potential would however increase for build-up.

In addition, ocean energy is an area of focus at several technological institutes and universities, the most important of which are Uppsala University, Chalmers university of Technology, SP Technical Research Institute of Sweden and SSPA Sweden. This, together with the government aided support for developing new renewable energy technologies and innovation, which is relatively large as a percentage of GDP, has helped fostering an early stage development of technologies with strong potential.

Country focus

# United Kingdom

## Current status of progress

Most technology developers agree that the UK has a sheer potential for most ocean technologies, including FOWT and see it as one of the main target markets due to government commitment and levels of revenue guaranteed by the government. The UK has seen important progress over the past years with a number of pilot projects being planned and some under construction. In addition, the UK has benefited from a strong industrial base in shipping and offshore engineering, meaning that there is a relatively well-developed supply chain, and a favourable regulatory and licensing environment, from the "5 ROCs" market support mechanism to the approach of the Crown Estate.

The tidal stream sector has been remarkably active and successful. Notably, the beginning of the construction of the MeyGen project, the world's first and largest multi-turbine tidal stream array in January 2015. The project is currently in its first phase, which will first lead to the commissioning of a 7 MW power plant early 2017. In later development, the MeyGen project could reach up to 400 MW (269 turbines). A second major achievement for the tidal stream industry was the deployment of Tidal Energy Ltd's DeltaStream device, installed in Ramsey Sounds (Wales). After a 12-month trial, a commercial array of nine DeltaStream devices should be installed in Pembrokeshire for a total capacity of 10 MW.

The wave energy sector was also very dynamic. Several pre-commercial wave arrays have made substantial progress, taking advantage of the opportunity to use the Wave Hub sea testing site: Carnegie Wave Energy's CETO 6 array (10-15 MW), Fortum's 10MW WaveRoller, and Simple Blue Energy's Seabased 10MW project. In addition, Wave Energy Scotland (Scottish Government's wave energy technology development body) awarded over £7m (EUR 8.9 m) to innovative technology developers in Power Take-off systems. Tidal range technologies have also received renewed interest, in particular for tidal lagoon technologies, and the UK government is exploring potential for a dedicated tidal lagoon programme. A 320 MW tidal lagoon project was funded in Swansea Bay, having received planning consent in June 2015. Another 30 MW commercial tidal range pilot, Perpetuus Tidal Energy Centre, has been pre-consented in the Isle of Wight and should be operational in 2018.

There is a significant potential for floating offshore wind turbines in the UK that has excellent offshore wind resource in deep water. Scotland in particular has extensive deep water locations with more than 70% of its offshore wind potential located in water depths

exceeding 60 m (Scottish Enterprise, 2015). Glosten's PelaStar 6MW tension leg platform, meant to be installed at the Wave Hub testing site, went through front end engineering and design study and was supported by the Energy Technologies Institute, which allocated £25m (EUR 31.7 m) to the project. The planned deployment was cancelled in 2015 due to consenting delays. Scotland will host major FOWT pilot projects, notably Statoil's Hywind Pilot Park (Statoil, 30 MW commissioning in 2017) and Principle Power's Windfloat in Kincardine (48 MW, commissioning in 2018).

There has been growing interest in Welsh waters and the Welsh government is working on establishing partnerships with developers to maximise the socioeconomic benefits of future projects. Important efforts have been undertaken to streamline permitting and planning procedures. Two demonstration zones are being developed in Wales and 4 tidal stream projects have been consented. The Welsh Government supported Minesto, a tidal stream developer, in obtaining a EUR 13 m investment from the European Regional Development Fund. This grant will support the installation of Minesto's first commercial array in North Wales.

# Policy developments

In 2013, the Department for Energy and Climate Change published the Renewable Energy Roadmap, which formulated scenarios to meet UK's national 2020 renewable energy targets (15% of its energy consumption from renewable energies, against 2.5% in 2009). Monitoring of the implementation of this policy indicates that UK is on the right path to meet its objectives in 2020. The Marine Energy Programme Board has been leading work on the ocean energy sector, to support the industry in moving towards the deployment of the first pre-commercial tidal projects and contribute to achieve the Roadmap's scenario. The DECC is now updating the Technology Innovation Needs assessment (TINA) for tidal and wave energies, which will be published in 2016. This assessment will inform the UK government in its decision making process in order to effectively support tidal and wave industries in their leap towards commercialisation. In addition, the Crown Estate started a new leasing process for seabed rights in September 2015. This process will target sites up to 3 MW for tidal stream and wave energy.

The UK Government has been implementing its Electricity Market Reform (since 2013), which granted a reserved allocation of 100 MW for ocean energies within the Renewables Obligation and the Contract for Difference schemes and set a strike price of £305/MWh (EUR 387/MWh) for wave and tidal stream energy, which is the highest of all renewable technologies. In addition, several public funding programmes support Research and Development activities: the Research Councils UK Energy Programme, Innovate UK, Energy Technologies Institute, the Carbon Trust and The European Marine Energy Centre.

The Scottish government is particularly active to support the development of the ocean energies industry in Scotland with a £ 37 m (EUR 47 m) investment in ocean energies project through the Renewable Energies Investment Fund. The overall fund has a reserve of £ 103 m (EUR 131 m) and is committed to helping ocean energies projects becoming commercially viable. In 2015 Wave Energy Scotland is supporting specific components that will underlie the success of the industry through a £ 10 m (EUR 12.7 m) investment in innovation projects and R&D activities. The Scottish public sector was also involved with the MeyGen project and invested £ 23 m (EUR 29 m) through the REIF, Scottish Enterprise and Highlands and Islands Enterprise.

# Presentation of the sector

The UK market is not led by major infrastructure companies as it can be the case in other countries (France, Sweden or Japan for instance). UK technology developers have rather looked abroad for industrial ownership or part-ownership: Marine Current Turbines (Siemens increased their stake to 100% in February 2012), Aquamarine (in which ABB Technology Ventures has a stake), AWS Ocean Energy (part-owned by Alstom) and TidalStream (part-owned by Schottel). There is however a small number of mid-sized engineering and renewable development businesses which are supporting the development of marine energy devices. In addition, owing to its shipping and North Sea oil and gas heritage, the UK is home to a number of major businesses which have adopted a 'watch and wait' strategy, but who are interested over the medium term to form part of the supply chain in marine energy, whether by supplying operations and maintenance services or engineering, procurement and construction. Key supporting stakeholders for R&D activities and permitting include the Crown Estate, Natural Resources Wales, Energy Technologies Institute, Innovate UK, and Offshore Renewable Energy Catapult.

The UK ocean energy industry has nonetheless become stronger over the past few years, as a number of sea testing sites have become operational, allowing for technology developers, energy providers and infrastructure manufacturers to build capacity over the emerging technologies. In addition to testing tanks at the University of Edinburgh and Plymouth University, the UK has currently several test sites at sea. These sites are focused on tidal stream and wave energy but there are prospects of opening up opportunities for FOWT:

- EMEC (Scotland): suitable for 14 full scale devices, EMEC experiences some of the harshest weather conditions and is connected to the national grid. It also includes 2 smaller scale project test sites for early R&D.
- Wave Hub (Cornwall): a 16 km for testing large scale offshore devices. Wave Hub is currently working with local partners to foster industry demand for testing sites and explore funding opportunities.
- Dounreay FOW Development Centre (Scotland): this development centre could be built on the north coast of Scotland, and would have the capacity to site five 6 MW floating devices by 2018.

- FabTest (Falmouth): operational since 2011, however not connected to the grid. Operational and research support is provided by the Renewable Energy Group from the University of Exeter. Several devices are currently pre-consented for wave energy converters, guarded underwater turbines and umbilicals/ components. Negotiations are progressing to extend the lease and licence to also accommodate floating wind devices
- PTEC in the Isle of Wight, still under development.

## Perspectives

A key challenge for the UK as the industry matures will be to retain its lead in technology and array deployment despite the inevitable pressures for industrial owners to deploy in their home markets.

There is also an emerging project developer market in the UK, with a handful of developers moving ahead to gain site consents, grid connections, and to understand sea and seabed conditions with a view to early installation of arrays. These projects are a mix of 'named technology' sites where a particular device has been earmarked for installation, and 'technology neutral' sites where the developer has yet to commit to installing a single tidal or wave device, pending further technical and site development.

# United States of America

## Current status of progress

With respect to wave energy, one pilot project is in operation: the Azura device, developed by Northwest Energy Innovation, is connected to the grid and tested in open-sea (Navy's WETS in Hawaii) since June 2015 (until June 2016). Azura is designed to extract power both from vertical and horizontal wave motion. The data collected from this pilot project will provide US researchers with the opportunity to monitor power capture and to refine the technology's LCOE (1).

In addition to wave technologies, floating wind could play a key role in the US ocean energy sector. Indeed, more than 60% of the offshore wind resource lies over water with depths greater than 60 m. In these circumstances, floating devices may have a competitive advantage over fixed structures, which could require higher construction costs. The first offshore floating wind device in the US was installed in 2013 by the University of Maine's DeepCwind Consortium, off the coast of Castine, Maine. This device, named VolturnUS, is a 1:8 pilot project of a 6 MW turbine using a spar-submersible foundation, and has been delivering electricity to the grid ever since its installation. This project was successful in demonstrating its survivability to storm-events. Consequently, the developers are completing the construction of one or two full-size devices of 4-6 MW each.

In order to allow for a broader number of project developers to test their technologies at a reduced cost, the Water Power Programme (WPP, see section on policy developments) finances and operates a growing number of test sites (see table below)[41]. WPP funded in 2015 the construction of the PMEC-SETS test site in California. Several projects are planned for testing, as explained further in the section on perspectives.

| Name of the testing facility | Technology tested | Location |
|---|---|---|
| Navy's Wave Energy Test Site (WETS) | Wave power | Hawaii |
| PMEC | Wave, tidal stream | Oregon |
| HINMREC | Wave and OTEC | Hawaii |
| SNMREC | Tidal stream | Florida |
| PMEC-SETS | Wave, tidal stream | California |

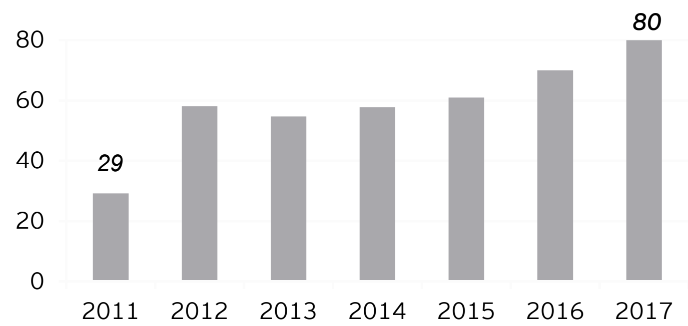
In addition to operational project testing, R&D has been very dynamic is the US over the past few years. The various topics of research include:

- Environmental R&D: in 2015, WPP awarded funds to five projects to undertake research on noise pollution from devices and detection of marine animals.
- LCOE: WPP has developed a LCOE standardisation tool to improve comparability of competitive projects.
- Knowledge sharing: WPP launched a website (called MHKDR) to share knowledge that can be useful for ocean energies project developers in the US.
- Resource assessment: WPP initiated in 2015 a conference to engage other stakeholders (universities, private companies) in the resource measurement effort. A committee was created within the US Marine Energy Council to regularly gather experts from different organisations and push resource assessment forward.
- Design of devices: WPP started in 2015 a research project on the performance, reliability and survivability of ocean energy devices. Research is underway until 2016, and results will be made publicly available, in order to help technology providers developing more performing and resistant devices, even in extreme sea conditions.

# Policy developments

The national ocean energy strategy is driven by the US Department of Energy (DOE) WWP[42]. The WPP aims at facilitating the development of ocean energy projects at different stages of maturity (research, testing and evaluating projects). Among other things, the WPP uses DOE national laboratories to boost innovation projects and coordinates with other government agencies to create a favourable legal environment for these energies. The WPP invests primarily in technologies which seem to be capable of lowering down their LCOE to compete with local energy sources. Consequently, the emphasis is put on early-adopters high-hurdle rate markets[42]. Financial resources of the WPP are growing, as the programme's budget has grown from USD 29 m in 2011 to USD80 million in 2017 (requested amount)[43]. The WPP identifies and funds ocean energy projects qualified for their LCOE reduction capacities, after a competitive funding solicitations and Funding Opportunity Announcements. In 2015, the WPP allocated USD 17.9 m to such projects (the majority of which are wave energy projects)[43].

***WPP budget history, in USD m*** [43]




Apart from the WPP, Ocean energies in the US benefit from several sources of financial support. The Federal production Tax Credit (PTC) provides a EUR 0.110/kWh tax credit for projects with a capacity above 0.15 MW. The Business Energy Investment tax Credit targets specifically tidal projects, which can (on a voluntary basis) benefit from a tax credit equal to 10% of CAPEX, instead of the PTC. Other state funding solutions include the Alaska Energy Authority's Emerging Technology Fund and Renewable Energy Fund, as well as the Oregon Wave Energy Fund[41].

Several legislative texts aiming at favouring the development of renewable energies (Renewable Electricity Standard Act, American Renewable Energy and Efficiency Act, Climate Protection Act, Prioritising Energy Efficient Renewables Act) and ocean energies (Marine and Hydrokinetic Renewable Energy Act, Advancing Offshore Wind Production Act) have been discussed in the Senate over recent years, but none was enacted. One of the major barriers that could be addressed by legislation is the complexity, duration

41. *Ocean Energy Systems (2016) - Annual Report 2015*
42. *US Department of Energy (2016) - Water Power Programme*
43. *Office of Energy Efficiency & Renewable Energy (2016) - Water Power Programme Budget*

and cost of the permitting and licensing process. Although the WPP has dedicated resources in 2015 to facilitate this process by better informing regulatory bodies, the permitting process can still restrain certain project developers from applying for permits[44].

## Presentation of the sector

The US ocean energy sector is articulated around several types of actors:

- Public agencies and funds: The US DOE and its WPP are the major forces that allow the sector to develop. In addition to the WPP, state funds (such as in Alaska or Oregon) provide project developers with funds to implement pilot projects. At a regional level, the National Ocean Council and the Bureau of Ocean Energy Management are in charge of coordinating planning efforts by various local entities.
- National laboratories: Four main national laboratories (SNL, NREL, PNNL and ORNL) use their technical expertise and resources to foster R&D's support to project development (e.g. on topics such as design of devices and LCOE modelling).
- The US Navy provides technical assistance to project developers, especially in the Navy's Wave Energy Test Site in Hawaii, where technology providers can test their devices.
- Technology providers: Companies such as Ocean Energy, Resolute Marine Energy, Fred Olsen and Columbia Power Technology are developing projects that will be tested in WPP's test sites (see table in the perspectives section).

*44. US Department of Energy (2016) – Water Power Programme*

## Perspectives

After a successful scale-testing phase, several technologies will be shifting towards a full-scale testing phase by 2017. Most of the projects scheduled for full-scale testing in the coming year are wave power based (see table below)[45]. Most of these projects will be tested in WETS testing facility in Hawaii.

With the testing of these different designs, project proponents in the US will be able to monitor the energy-capturing efficiency of their technology, as well as to refine their LCOE projections, hence paving the way for further full-scale installations.

In March 2016, the U.S. Bureau of Ocean Energy Management announced that it would evaluate Trident Winds LLC's project of a 800 MW wind farm (composed of about 100 floating turbines of 8 MW each) off the coasts of California.

| Project proponent | Technology | Name of the technology | Location | Development stage | Capacity (MW) |
|---|---|---|---|---|---|
| FOWT | | | | | |
| AW Hawaii Wind, LLC. | FOWT | WindFloat | Hawaii (Oahu South) | Early Project Development | 408 |
| AW Hawaii Wind, LLC. | FOWT | WindFloat | Hawaii (Oahu North West) | Early Project Development | 408 |
| DeepCwind Consortium | FOWT | VolturnUS | Unknown | Early project development | Development Stage "Permitting", Capacity "12" |
| Principle Power | FOWT | WindFloat | Coos Bay, Oregon | Permitting | 30 |
| Trident Winds LLC | FOWT | Trident Winds | Morro Bay, California | Early project development | 800 |
| Wave power | | | | | |
| Columbia Power Technology | Wave power | StingRAY | WETS (Hawaii) | Full-scale testing in 2017 | N/A |
| Fred Olsen | Wave power | BOLT Lifesaver | WETS (Hawaii) | Full-scale testing in 2017 | N/A |
| Ocean Energy | Wave power (oscillating column) | OE Buoy | WETS (Hawaii) | Scale model testing completed – moving to full scale testing | N/A |
| Resolute Marine Energy | Wave power | SurgeWEC | Camp Rila, Oregon | Full-scale testing scheduled for 2017 | N/A |

45. *Ocean Energy Systems (2016) – Annual Report 2015*

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