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JRC Ocean Energy Status Report 2016 Edition

Technology, market and economic aspects of ocean energy in Europe

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2016

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Title JRC Ocean Energy Status Report – 2016 Edition

Abstract

Assessment of the Ocean Energy status in 2016
This report presents the current status of major ocean energy technologies, focusing primarily on tidal stream and wave energy. Europe is the global leader in the development of ocean energy technologies, hosting most of global developers. Overall, the sector is progressing towards the deployment of demonstration farms, and EU policy is helping shaping the industry.

JRC Ocean Energy Status Report
2016 Edition

Joint Research Centre

Directorate of Energy, Transport & Climate

Davide Magagna, Riccardo Monfardini & Andreas Uihlein

2016

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EXECUTIVE SUMMARY

This report is the 2016 edition of the Joint Research Centre's ocean energy status report. While the 2014 edition gave an overview of the ocean sector in the European Union, including technology descriptions, this second version focuses more on the developments that have taken place in the sector over the past years in terms of technological progress, market creation, and policy instruments available at European and national level. The various ocean energy technologies (tidal energy, wave energy, ocean thermal energy conversion and salinity gradient energy) are at different stages of technical and commercial development. In Europe, tidal and wave energy are those poised to provide the most significant contribution to the European energy system in the short term.

From a policy standpoint, the European Commission has strengthened its support for the development of ocean energy. Ocean energy has been identified as a key technological area within the Strategic Energy Technology Plan of the European Union. As such, cost targets for wave and tidal energy have been agreed to ensure the long term uptake and viability of both technologies.

The Ocean Energy Forum, supported by the European Commission, and the European Technology and Innovation Platform for Ocean Energy have delivered strategic roadmaps identifying key hurdles of the sector, and specific recommendations for each ocean energy technology.

The key bottlenecks that the ocean energy sector faces moving forwards are very similar to those hindering it in 2014: technology development, financing of projects; and concerns regarding unknown environmental impacts slowing down consenting and licensing of projects.

The extent to which each barrier prevents market formation is specific to each technology. Ocean thermal energy conversion and salinity gradient technology are still at early stage of development, requiring research and development to progress further in terms of technology.

Wave energy has yet to prove consistent electricity generation to the level reached by prototype tidal energy converters. Technology progression for wave energy is paramount to ensure the long-term growth of the sector. Reliability, availability and survivability are the three areas that wave energy developers need to address.

The deployment of the first demonstration arrays for tidal energy indicates that technology progression has been achieved. The main challenge for the tidal sector moving forward is to achieve cost-reduction of the technology through the deployment of more demonstration projects. Innovative financial instruments are required for supporting the deployment of the first projects and attracting private investors.

The installation of ocean energy devices is taking place at a slower pace than expected. Europe only accounts for 14 MW of ocean energy installed capacity at the end of 2016, much lower than the expectation set by Member States in their National Renewable Energy Action Plans. According to NREAPs, 641 MW of ocean energy capacity were expected to be operational by 2016, taking into account the 240 MW tidal range currently operational in France.

By 2020, if technological and financial barriers are overcome, the pipeline of announced European projects could reach 600 MW of tidal stream and 65 MW of wave energy capacity. Taking into account only projects that have been awarded public funds, 71 MW of tidal stream and 37 MW of wave energy capacity could be operational within the EU in 2020.

The next few years will be fundamental to understand how far and how fast the markets for both wave and tidal energy technology can be formed.

Seizing the opportunity offered by the development of ocean energy will not affect only the decarbonisation of the European energy system, but will play a direct role in assuring the competitiveness of European industry. The European Union is at the forefront of technology development, with about 50 % of tidal energy and about 60 % of wave energy developers being located in the European Union. The majority of ocean energy infrastructure, such as ocean energy test centres, is also hosted in the European Union. European technology is being employed in key demonstration projects that have become operational at the end of 2016 in the United Kingdom and Canada.

The supply chain is spread across Europe, and the creation of ocean energy market is expected to affect positively many European regions.

A wide number of support mechanisms implemented at European, national and regional levels are currently supporting the development of ocean energy, from research and development through demonstration. Whilst, additional and innovative instruments need to be created to overcome specific barriers and support demonstration projects, the commitment of the European Commission and its Member State is strong to ensure that ocean energy can become a commercial reality.

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ACRONYMS AND ABBREVIATIONS

AMETS	Atlantic Marine Energy Test Site
ARENA	Australian Renewable Energy Agency
BNEF	Bloomberg New Energy Finance
CAPEX	Capital expenditure
CEFC	Australia's Clean Energy Finance Council
CF	Capacity factor
CfD	Contracts-for-difference scheme
DIE	Demonstratie energie-innovatie
EIA	Environmental Impact Assessment
GHG	Greenhouse gas
H2020	Horizon 2020
HAT	Horizontal axis turbine
IEE	Intelligent Energy Europe
IMERC	Integrated Maritime Energy Resource Cluster
KPI	Key performance indicator
LCA	Life Cycle Assessment
LCOE	Levelised cost of electricity
LEED	Western Australia’s Low Emissions Energy Development Program
MEAD	Marine Energy Array Demonstrator
MRCF	Marine Renewables Commercialisation Fund
NER	New Entrants' Reserve of the European Union Emissions Trading Scheme
NREAP	National Renewable Energy Action Plan
OPEX	Operating expenditure
OWC	Oscillating water column
OWC	Oscillating water column
PIA	Programme d'Investissements d'Avenir
RO	Renewable Obligation
ROC	Renewable Obligation Certificates
SDTC	Sustainable Development Technology Canada fund
SEIA	Sustainable Energy Authority of Ireland
SPD	Submerged pressure differential
TEC	Tidal energy converter
TRL	Technology readiness level

WEC	Wave energy converter

ACRONYMS AND ABBREVIATIONS

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1 Introduction

Ocean energy has been the subject of different policy initiatives in the past years, both at European and national level. In the European Union, following the launch of the Ocean Energy communication in 2014 (COM(2014)8) and the subsequent establishment of the Ocean Energy Forum, the industry has been asked to convene together to identify common actions to bring the technology to the market.

Most recently, the inclusion of ocean energy in the new Strategic Energy Technology Plan (SET-Plan) of the European Union (COM(2015)6317) has highlighted the current European leadership in the sector and the need to improve the performance of ocean energy technologies throughout the innovation, supply and value chain (Figure 1)

In line with the SET-Plan communication, the European Commission, Member States and stakeholders have defined a "Declaration of Intent for Ocean Energy" setting out cost-reduction targets for ocean energy technologies to make a significant contribution to the future European energy system [European Commission 2016].

The targets agreed in the Declaration of Intent between stakeholders, Member States and the European Commission are presented in Table 1.

Table 1. LCOE targets for wave and tidal technology presented in the SET-Plan declaration of intent

Technology	Year	Target
Tidal	2025	15 cEUR/kWh
Tidal	2030	10 cEUR/kWh
Wave	2025	20 cEUR/kWh
Wave	2030	15 cEUR/kWh
Wave	2035	10 cEUR/kWh

The policy framework at EU level provides technology developers with the required stability and commitment to bring ocean energy technology to the market. The SET-Plan Declaration of Intent offers scope on top of existing instruments available, to help drive the sector forward towards commercialisation.

Significant technology cost reductions are required to meet the ambitious targets of the SET-Plan: the cost of tidal energy technology has to be reduced by 75 %, and by 85 % for wave energy from the current levels. At the same time, ocean energy farms have to be deployed and investors have to be attracted to the sector. This requires public intervention to help drive the deployment of first-of-a-kind plants.

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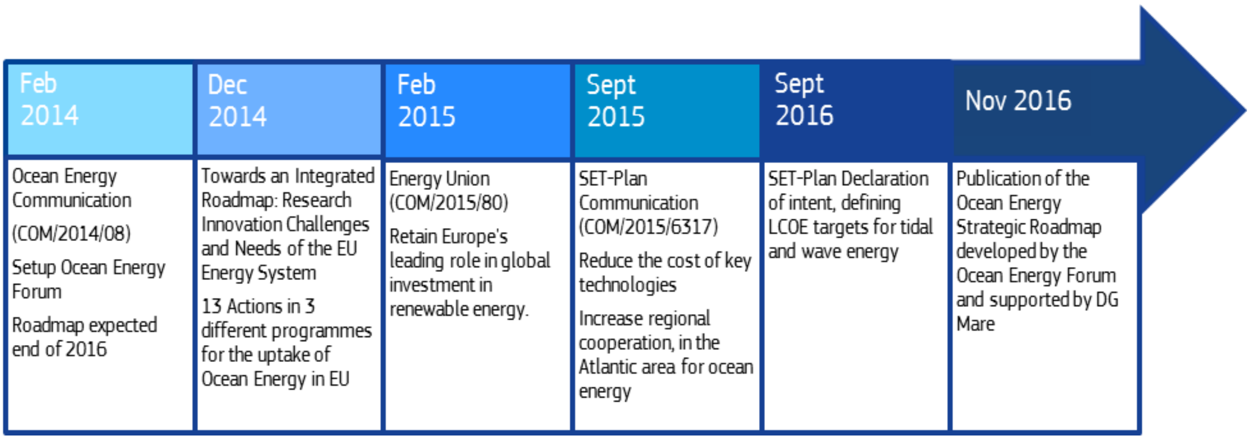

Figure 1. Ocean energy polices at EU level

In November 2016, the Ocean Energy Strategic Roadmap produced by the Ocean Energy Forum [Ocean Energy Forum 2016] was released. Together with the Strategic Research Agenda for Ocean Energy developed by Technology and Innovation Platform for Ocean Energy [TPOcean 2016], it proposed a number of actions to help the sector towards commercialisation and overcome the well identified gaps and barriers that have been hindering the sector [MacGillivray et al. 2013].

Key to the success of the sector will be the improvement of current technologies and the identification of novel financial instruments to sustain the critical phase of moving to demonstration projects. This applies to the sector as a whole and to each of the different technologies involved.

In comparison to 2014, stakeholders have recognised the different development paths of the various ocean energy technologies, and as a consequence the need to develop technology-specific mechanisms to bring them to the market.

Tidal technologies have reached a pre-commercial state, culminated with the installation of the first tidal energy array in the Shetland islands, followed by the four 1.5 MW rated turbines deployed as part of the Meygen project in the Pentland Firth in November 2016. Furthermore, a number of smaller tidal projects have gone live in the EU and in Canada.

Wave energy technologies are more in an advanced development phase. Following the setbacks of 2014, the wave energy industry is in need of identifying ways for de-risking the demonstration phase of technology. National and international initiatives have been created in support of stage-gate metrics to ensure tangible progress made by the technology and alignment with funding available. Ocean Energy System (OES), Wave Energy Scotland (WES), the Sustainable Energy Authority of Ireland (SEAI) and the US the Department of Energy (DOE) are among the key actors pushing for the implementation of stage-gate metrics for wave energy.

The picture is somewhat different for the other ocean energy technologies. OTEC is making technological progress, however it presents limited resources to make a serious contribution to the European energy system. Salinity gradient technology is at early stage of development, with only one 50 kW demo plant currently operational, and is expected to a have limited role in the decarbonisation of the European energy system in the medium term (2025-2030). Tidal range and lagoons technologies are fully developed; however, they require specific site conditions, and will play a role at local or regional level.

This report stems from the need to monitor the evolution of ocean energy technology, industry and markets in Europe, with a view to their global development. This work aims to present an overview of the issues that the sector is facing, and to outline how the existing policy scenario and instruments made available at European, National and Regional level could push the development of the sector to achieve the targets agreed in the SET-Plan declaration of intent.

The report is based on the research and policy-support work that the Joint Research Centre (JRC) is undertaking in order to support European energy and innovation policies. The ocean energy status report aims to portray the state of play of the sector, key achievements, and mechanisms that have been put in place to overcome documented gaps and barriers to commercialisation of the sector. The report, in line with the SET-Plan Declaration of Intent, will focus primarily on tidal and wave energy technologies.

This report is structured as follows: section 2 portrays the status of the technology and ongoing developments. Section 3 presents the market status and its future projections, and an assessment of the European supply chain. In section 4, an overview of policy instruments at EU level are presented. Finally, section 5 summarises the findings and gives a short outlook.

2 Technology status and development

2.1 Tidal energy

2.1.1 Technology status

The development of tidal energy converters (TEC) has progressed steadily over the past few years. The most significant step towards commercialisation of tidal energy technology is represented by the Meygen project, operational since 2016. Four tidal turbines rated at 1.5 MW, that together with the 200 kW Shetland Array developed by NovaInnovation, form the first tidal energy arrays deployed worldwide. A number of pre-commercial deployments have taken place in France (OpenHydro), in the Netherlands (Tocardo and Bluewater TEC), in the UK (Minesto, ScotsRenewable, Sustainable Energy Marine) and in Canada (OpenHydro).

The tidal sector has reached a critical phase of development, where demonstration farms are needed, thus with a clear focus on prioritising deployment and identifying systems for the optimisation of farms.

The increasing number of deployment projects signals that tidal energy has reached a high level of technological maturity. Horizontal axis turbines have reached a technology readiness level (TRL) of 8, with leading technologies on the verge of completing the TRL path.[1] Other technologies that have made considerable progress are enclosed tips and tidal kite devices. Ongoing projects in France and Canada are expected to prove the commercial viability of ducted turbines. Tidal kite technology has reached TRL 5, but the expectation to include current technology learning and to test the technology at TRL 7 in the coming year (Figure 2). There was no significant progress concerning other tidal energy technologies, such as vertical axis turbines, oscillating hydrofoils and Archimedes screw devices.

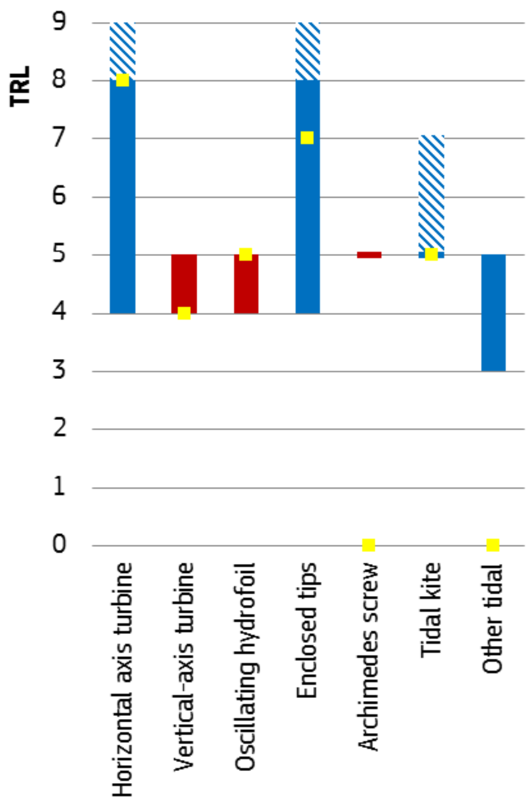

Figure 2. Range of testing for tidal energy devices. Blue bars refer to technology with significant progress in 2016. Red bars indicate technology with no considerable update/progress in 2016. Shaded bars indicated ongoing testing. The length of bar indicates the range of TRL attempted. The yellow dot indicates the maximum achieved TRL.
Source: JRC Ocean Energy Database

The demonstration of increased reliability and survivability of tidal stream turbines achieved through the deployment of first-of-a-kind arrays will help de-risking the sector and attract private investor to further the viability of the sector. Nevertheless, public support mechanisms are needed to fund the deployment the next phase of tidal energy demonstration arrays.

[1] TRL scale can be found here https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

2.1.2 Technology development

In the period 2014-2016 the tidal energy sector has made significant progress towards commercialisation. Key technology developers, such as Atlantis Resources, Andritz Hydro-Hammerfest, Openhydro, have optimised their technologies for deployment in Scotland (Atlantis and Andritz), in France (Sabella and Openhydro) and Canada (Openhydro).

Other developers, such as Tidal Energy Limited (TEL) have deployed full-scale devices. A number of small-size TEC developers such as Tocardo, Sustainable Marine Energy and Schottel have deployed tidal turbines, using both floating structure and storm-protection structures.

In 2014, the tidal energy sector showed significant convergence towards horizontal axis turbine technology (76 % of R&D efforts in the sector according to [Corsatea & Magagna 2013]). In 2016, the picture is the same, with horizontal axis turbines dominate the sector, accounting for about three quarters of companies currently developing full-scale tidal devices (Figure 3).

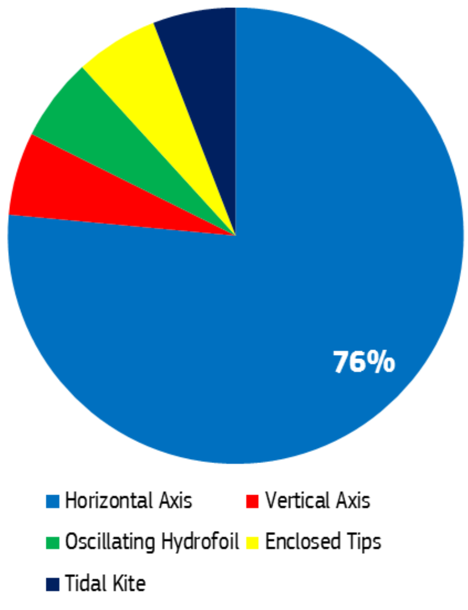

Figure 3. R&D effort for tidal technologies tested at full-scale. Calculation are based on number of active companies identified developing full scale TEC..
Source: JRC Ocean Energy Database

At the end of 2016, fourteen tidal energy projects, including first-of-a-kind arrays and pre-commercial deployments are grid-connected and operational (Table 2). Twelve of these projects are installed in the EU, reinforcing the leading role that European industries and governments have in the creation of the ocean energy sector. The two exceptions are the Cape Sharp project in Canada, with Openhydro turbines, and the Chinese plant deployed in Zhoushan, Zhejiang. The latter, employs a modular tidal energy converter, that could be expanded to about 10 MW [Zoushan Municipal People's Governement 2015]. Prototype deployments have taken place in other locations including the United States of America, South Korea, Australia, Indoneisa and China.

The progress towards commercialisation is seen in the two main areas of the sector: small-size turbines and MW-rated devices.

Andritz Hydro-Hammerfest, Atlantis and Openhydro are deploying arrays after having recorded significant number of operational hours and electricity generation. Scotsrenewables have installed their 2 MW floating turbine at EMEC in October 2016, following the successful testing of their 250 kW device.

Tocardo, Schottel, Nova Innovation and Sustainable Marine Energy have built on their experience and are now increasing their portfolio with new projects. Tocardo is now preparing a semi-submerged platform for deployment at EMEC. Sustainable Energy Marine is also aiming to deploy four Plato systems at EMEC and have already commissioned the production of sixteen SG50 tidal turbines from Schottel. Nova Innovation deployed a second 100 kW Turbine in their Shetland array, in what has become effectively the first tidal energy array deployed.

The development of small-size turbine was identified as one of the key transition of the tidal energy market [MacGillivray et al. 2013], together with floating systems. The increase in the number of deployments of small-size turbines (bottom-fixed and on floating structures) appears to indicate that this type of installations are viable and cost-effective. The deployment of the modular tidal device opens new prospects for tidal energy developers, as well as new market opportunities for developers outside of Europe and Canada. The ongoing developments are encouraging sings for a technology that can be expected to grow considerably in the coming years and play a central role in European energy system.

Table 2. Major tidal current pre-commercial and first-of-a-kind demonstration projects

Project	Country	Location	Capacity	Class	Turbines	Status
Paimpol-Bréhat	France	Paimpol-Bréhat	1 MW	ET	2 x 0.5 MW OpenHydro 16 m	Devices deployed
Passage du Fromveur	France	Ouessant	1 MW	HAT	1 x 1 MW Sabella D10	Retrieved July 2016,. Reinstalled Nov 2016
Ramsey Sound	UK	Ramsey Sound	0.4 MW	HAT	1 x 0.4 MW Daffodil – Tidal Energy Limited	Decommissioned in March 2016.
Oosterschelde	Netherlands	Oosterschelde	1.2 MW	HAT	5 x 0.24 MW Tocardo T2	Operational since 2016
Afsluitdijk	Netherlands	Den Oever	0.3 MW	HAT	3 x 0.1 MW Tocardo T1	Operational
BlueTEC	Netherlands	Texel	0.24 MW	HAT	1 x 0.24 MW Tocardo T2	Floating structure.
DeepGreen 1/10	UK	Stangford Loch	0.012 MW	Tidal Kite	1 x 0.0120 MW DG8 (Tenth scale prototype)	Test in preparation for the 1.5 MW deployment in Wales
Plat-O	UK	Yarmouth	0.1 MW	HAT	2 x 50 kW Schottel SG50 mounted	Operational since 2015
Yell	UK	Yell	0.03 MW	HAT	1 x 30 kW Nova Innovation Turbine	Operational since 2014
Shetland	UK	Shetland	0.2 MW	HAT	2x 100 kW Nova Innovation Turbine	Two of three turbines installed and generating. Operational since 2015
MeyGen Phase 1A	UK	Pentland Firth	6 MW	HAT	4 x 1.5 MW (3 Andritz HS1000, 1x Atlantis)	Operational since November 2016
SR2000 @EMEC	UK	Orkney	2 MW	HAT	1 x 2 MW SR2000 from Scotsrenewables	Installed in October 2016
Cape Sharp	Canada	Bay of Fundy	4 MW	Enclosed tips	2 x OpenHydro (2 MW)	Installed in November/December 2016
Xiushan Island	China	Zhoushan, Zhejiang	3.4 MW	N/A	First component of 1 MW	Modular device to be expanded to 3.4 MW
Tocardo - EMEC	UK	Orkney	2 MW	HAT	5 arrays of 2x T2 turbines rated (200 kW)	Expected 2017
Plato - EMEC	UK	Orkney	1 MW	HAT	16 Schottel Instream turbine (62 kW each)	Expected 2017
Nephtyd	France	Raz Blanchard	5.6 MW	HAT	4 x Alstom Oceade 18 (1.4 MW)	On hold
Normandie Hydro	France	Raz Blanchard	14 MW	Enclosed tips	7 x OpenHydro (2 MW)	Planning, grid connection in 2018
Sound of Islay	UK	Islay	10 MW	HAT	4 X: Andritz HS1000 & Alstom	Consented, installation in 2016
Stroma Tidal (Meygen 1B)	UK	Pentland Firth	8 MW	HAT	To be announced	Meygen acquired the Kyle Rhea NER300 project from Marine Current Turbines
Holyhead Deep	UK	Anglesey	10 MW	Tidal kite	Minesto deep green kites	Initial phase expected to reach 0.5 MW

2.1.3 Electricity generation

The technological maturity of tidal energy technologies was achieved through many hours of operation of stand-alone TECs. Technologies such as Seagen from MCT (acquired by Atlantis), Alstom (acquired by General Electrics) and Andritz Hydro-Hammerfest have generated large amount of electricity from 2009 to 2014 (Figure 4).

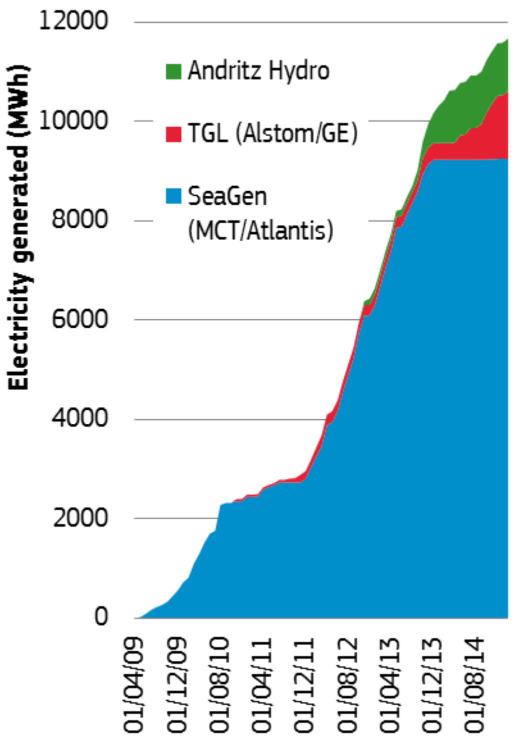

Figure 4. Electricity generation from tidal energy in the UK 2009-2014. No data is available with regards to 2016.
Source:[Ofgem 2015], *own analysis*

The MK1 Andritz Hydro-Hammerfest turbines installed at Meygen are developments of the earlier model (HS1000) tested at EMEC. Similarly, Atlantis Resources limited is incorporating the experience of MCT in their technologies.

Other technologies have clocked significant energy generation. The 1 MW Sabella D10 turbine deployed at Fromveur has produced over 70 MWh in the first months operation, although the grid export is currently still limited to 250 kW due to network capacity issues [Dhomé 2016]. No information about the total electricity generated from Tocardo turbines at Afsluitdijk and on the Bluetec platform was available [Massaro 2016]. However, according to [Massaro 2016], the T1 demonstrator produces (1x100 kW turbine) up to 275 kWh per day; the Den Oever TTC pilot with 3x100 kW turbines produces up to 1200 kWh per day and the T2 turbine (200 kW) at BlueTec between 120 kWh and 340 kWh per day. This corresponds to maximum capacity factors of 11.5 % (T1 demonstrator), 17 % (Den Oever TTC), and 3 % to 7 % in the case of Bluetec Texel.

From the data available in the UK, we see that several devices had managed to deliver electricity to the grid continuously for longer periods. The Seagen device achieved high capacity factors with a maximum of almost 60 %.The average capacity factor values for HAT ranged between 8 % and 20 %, in line reference values for R&D projects. It has to be noted that capacity factors have been calculated on a monthly basis and do not take into account eventual or planned shut-off or maintenance periods of the devices.

2.1.4 Tidal Energy RDI and cost reduction

According to the OEF, the tidal energy industry should focus on the reliability of the technology developed so far, and in bridging the gap towards the creation of a stable tidal energy market. Nevertheless, R&D activities are necessary to ensure that the cost of the technology can be reduced to meet the targets agreed in the SET-Plan declaration of intent. A mix of deployment and technology innovation are needed.

Figure 5 shows that current LCOE ranges between 54 and 71 cEUR/kWh today for an average resource, with a reference value of about 62 cEUR/kWh. Low resource and high resource were represented by using different capacity factors. LCEO predictions have been calculated applying the same methodology as in the previous edition of this report [Magagna & Uihlein 2015]. The learning rates that were applied are 12 % for CAPEX and 3 % for OPEX. The bandwidth of the average resource represents the low and high CAPEX values (Appendix A.3). To meet the 2025 targets agreed in the SET-Plan declaration of intent, the cumulative capacity of tidal energy should reach 1000 MW to 10000 MW.

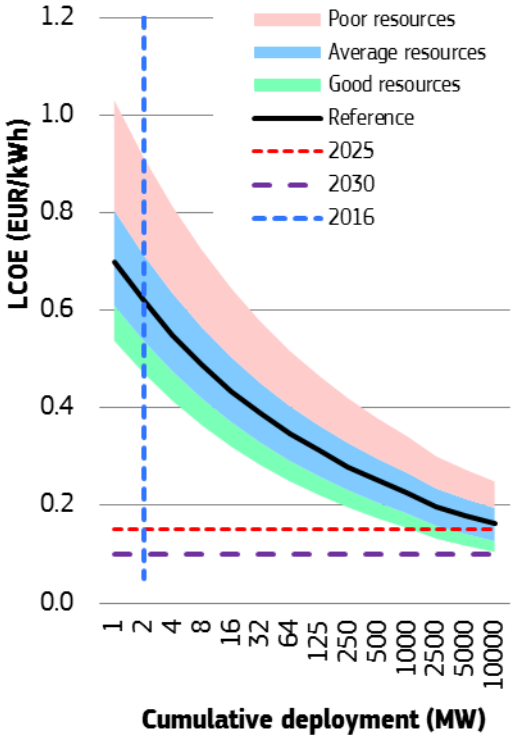

Figure 5. LCOE predictions for tidal arrays.
Sources: [ETRI 2014], *updated; own analysis*

When we look at the possibilities to reduce the levelised cost of electricity of tidal energy, it seems promising to aim reducing CAPEX cost components and improving the device performance in terms of availability and capacity factors.

Since 2014, in the EU, the Horizon 2020 framework programme has funded 10 tidal energy projects for a total of about EUR 30 million. Five of these projects are directed to Research and Innovation Actions (RIA) to improve existing technologies (Table 3).

Most projects share a common goal of reducing the cost of existing technologies; and of incorporating the results of the ongoing R&D activities in their future devices.

Specific area of focus for most of the projects include the optimisation of the Power Take Off (PTO), improved access to the turbine for ease of maintenance, and innovative monitoring solution for the removal of uncertainties related to the environmental impact of tidal turbines on marine mammals.

From a strict technological point of view, R&D activities on PTO could bring a number of advantages to the future generation of tidal devices. Increased power capture will lead to increased capacity factors and to lower LCEO.

Furthermore, H2020 projects such as Tipa and TAOIDE are working in developing wet-gap PTO, rather than in sealed air-gap PTOs. Current systems employ air-gap systems, making the system susceptible to the presence of water in the nacelle. The results of such activities are expected to reduce significantly maintenance intervals of tidal turbines, and thus decrease the cost related to O&M.

Figure 6 provides an overview of the reduction of the LCEO taking into account reduction of cost-centres and capacity factor improvements.

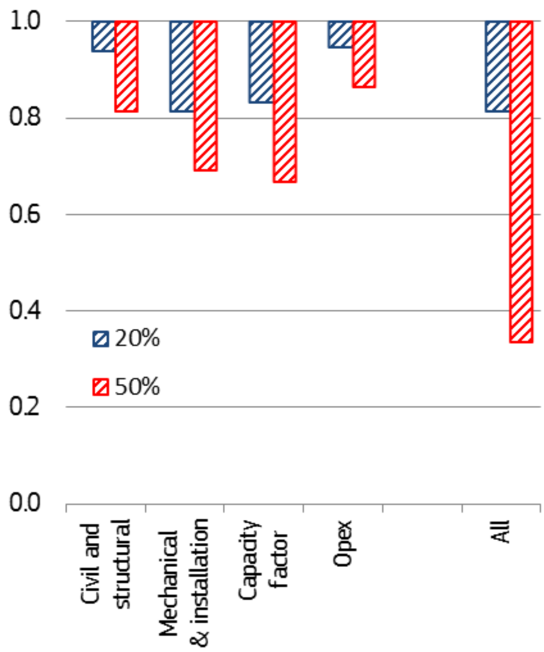

Figure 6. Tidal energy LCOE cost reduction per cost component. Reduction of 20% (blue) and of 50% (red) were assumed for each cost components. For capacity factor improvements of 20% and 50% were assumed.
Source: Own analysis

A reduction of the civil and structural costs (which include structure, prime mover, moorings & foundations) by 50 % could lead to a decrease of total LCOE by almost 20 %. Reducing the costs of mechanical equipment and installation by 50 % would allow a decrease of total LCOE by about 30 %.

Other possible improvement options that are not directly targeting capital expenditure could include a reduction of operating expenditure (OPEX) Assuming a 50 % improvement in OPEX would lead to reduction of the LCOE by 16 %. An increase of the capacity factor (CF) by 20% would translate in a reduction of 18 % of the LCOE, whilst a 50% improvement of the CF would lead to a 33% cost reduction for tidal technology.

When comparing the different options to reduce the overall costs of tidal energy, there is not one option that is more favourable than others. From Figure 6, it becomes clear that a combination of all measures could deliver a LCEO reduction of almost 75 % which would mean costs of about 15 c EUR/kWh.

Table 3. H2020 projects funded to support tidal energy innovation actions

Project Acronym	Project Title	Technology Developer	Focus
FloTEC	Floating Tidal Energy Commercialisation project	Scot Renewables	Reduction of lifetime cost of 20% through expansion of rotor diameter, and improved access for maintenance
InToTidal	Demonstration of Integrated Solution for offshore Tocardo Tidal power plants.	Tocardo	Demonstration of deployment solutions for tidal turbines
PowerKite	PowerKite - Power Take-Off System for a Subsea Tidal Kite	Minesto	Optimisation of power electronics components, reduction of environmental concerns through enhanced monitoring.
TAOIDE	Technology Advancement of Ocean energy devices through Innovative Development of Electrical systems to increase performance and reliability	Ocean Renewable Power Company	Development of wet-gap generators, Life time cost reduction. Achieve availability of 96%
TIPA	Tidal Turbine Power Take-Off Accelerator	Nova Innovation	PTO optimisation and cost reduction of 20% of lifetime costs.

2.2 Wave energy

2.2.1 Technology status

In contrast with tidal energy technologies, the development of the wave energy sector has slowed down over the past few years. Technological drawbacks have reduced the confidence of investors in wave energy technology. On the other hand they have sparked a number of initiatives aimed at assuring a more thorough assessment of wave energy technology throughout the various testing and development phases.

At the end of 2016, the picture is not very different from 2014, with only a handful of devices successfully tested at TRL 8 (see Figure 7).

According to the Ocean Energy Forum, the focus for the wave energy industry is to build on the demonstration of existing prototypes, and to improve the performance of key subsystems and components to increase the overall device reliability and survivability [Ocean Energy Forum 2016].

The most advanced device types are oscillating water column (OWC) and point absorbers, whit some specific devices have been extensively tested at TRL 8. Oscillating wave surge converters (OWSC) and rotating mass devices have reached relatively high TRL, and are expected to follow through to higher TRL.

No significant progress was witnessed for some specific wave energy technologies such as attenuators, overtopping and submerged pressure differential devices (SPD).

A limited number of projects have been installed in the period between 2014 and 2016. The majority of the projects include small-size WECs (rated power < 50 kW), and a limited number of devices with higher power rating, such as CETO5 (240 kW) and WaveRoller (300 kW). To date, the Carnegie CETO5 array deployed off the coast of Perth in Australia represents the most advanced wave energy array in operation, having clocked over 14000 hours since the deployment of the three devices in late 2015. Despite the high TRL reached by some devices, their commercial readiness is still to be proven. Most of devices tested are still to be considered advance prototypes having demonstrated survivability to ocean conditions, but with limited electricity generation.

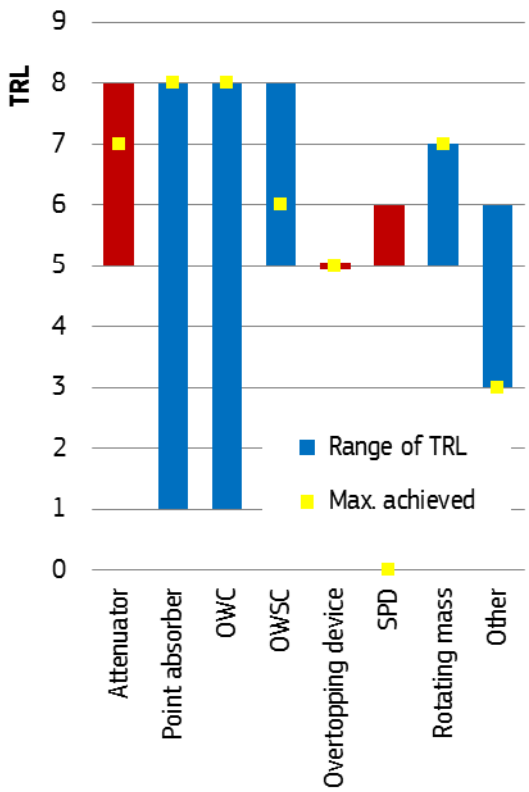

Figure 7. Range of TRL for wave energy devices. Blue bars refer to technology with significant progress in 2016. Red bars indicate technology with no considerable update/progress in 2016. Shaded bars indicated ongoing testing. The length of bar indicates the range of TRL attempted. The yellow dot indicates the maximum achieved TRL.
Source: JRC Ocean Energy Database

Other deployments include the Sotenas array from Seabased, the Albatern WaveNET array in the Isle of Muck, the two Oceanus devices operating at WaveHub, the 40SouthEnergy H24 device installed in Italy and the Oceantec OWC deployed at Bimep in October 2016. Outside of the EU, deployments have taken place predominantly in Australia (Carnegie, as previously mentioned), in Norway (Waves4power) and the Navy Test facility of Hawaii (US) where the Azura Wave device and Fred Olsen Bolt have been deployed. A full list of wave energy projects is presented in Table 4.

In total 21 projects are currently in the water or expected to become operational in the near future. Fifteen projects are located within the EU. Whilst many projects are modular and expected to reach in the long-term a capacity of 10 MW; current installations have a power rating of less than 1 MW.

Table 4. Wave energy pre-commercial and first-of-a-kind demonstration projects

Project	**Country**	**Location**	**Max Capacity**	**Class**	**Devices**	**Status**
Pico	PT	Azores	400 kW	OWC	OWC	In Operation. To be decommissioned
Limpet	UK	Islay	500 kW	OWC	Voith Hydro Wagen	Operations suspended
WaveHub	UK	Cornwall	10 MW	Point absorber	Seatricity Oceanus 2	Currently two devices installed. No grid connection
Sotenäs	SE	Västra Götaland	10 MW (modular)	Point absorber	Seabased	First devices deployed (1 MW)
Perth project	AUS	Perth	0.72 MW (modular)	Point absorber	Carnegie CETO5	Three CETO5 units were deployed in an small array
Ghana	GH	Ada	14 MW (modular)	Point absorber	Seabased	First 6 converters assembled and grid connection installed
WaveStar	DK	Hanstholm	0.6 MW	Point absorber	WaveStar	Grid connected since 2010, 1:2 scale. Project no longer operational
Mutriku	ES	Mutriku	0.3 MW (modular)	OWC	16 OWC chambers rated 18.5 KW	Operational since 2011. One of the chamber is used for R&D testing of new type of turbines.
Isle of Muck	UK	Isle of Muck	22 kW (modular)	Attenuator	Albatern	3 WaveNET unit installed
Westwave	IE	Killard, Ireland	5 MW (modular)	t.b.d.	5 suppliers shortlisted, will be chosen mid 2016	Project funder under NER 300 (34 mio. EUR), planned for 2018
Fred Olsen	US	Navy Test Centre, Hawaii	23 kW	Point absorber	Fred Olsen Life Saver	Device grid connected, operating at 30% (6.7 kW)
Azura Wave	US	Navy Test Centre, Hawaii	20 kW	Point absorber	Northwest Energy Innovations	Half scale prototype. Generating electricity since 2015
Oceantec	ES	Bimep	30 kW	OWC	Oceantec Marmok-A5	Installed in October 2016
40SouthEnergy	IT	Marina di Pisa	100 kW	OWSC	H24 from 40Southenergy	Device installed at the end of 2015.
PB3	US	New Jersey	3 kW	Point absorber	PB3	Device installed in July 2016
Wave4Power	NO	Runde	N/A	Point Absorber	WavEel	Device installed in February 2016. Company does not provide information on rated power
Eco Wave Power	GI	Gibraltar	100 kW (modular)	Point absorber	Wave clapper	Device installed and operative since June 2016
Seapower	IE	Galway Bay	N/A	Attenuator	Seapower Platform	1:4 scale model to be tested in 2016 in Galway Bay
CEFOW	UK	EMEC	3 MW	Roating Mass	3 X Wello Penguins 1 MW	Installation expected in 2017, 2019 and 2019. A device each year within H2020 project

Project	Country	Location	Max Capacity	Class	Devices	Status
Corpower	UK	EMEC	25 kW	Point Absober	1 x 25 KW Corpower	Device built in Portugal. Yo be tested in dry rig in Sweden before deployment at EMEC
Swell	PT	Peniche	5.6 MW (modular)	OWSC	WaveRoller	Funded by NER 300 (9.1 mEUR), planned for 2018, 16 devices
CETO6	AUS	Garden Island	4 MW (modular)	Point absorber	Carnegie CETO6	1 MW device, 3 MW demo array planned
CETO6 Wave Hub	UK	Cornwall	15 MW (modular)	Point absorber	Carnegie CETO6	1 MW device in 2017, to be expanded to 15 MW by 2021
Camp Rilea	US	Oregon	40 kW	OWSC	Resolute Marine Energy	Small project with 2 devices (2017). Water will also be used onshore for desalination
Baby Penguin	ES	Canary Island	N/A	Rotating mass	Wello Penguin	Reliability for new "mild-climate" device
Wedge Global	ES	Canary Island	N/A	Point absorber	Wedge Global	Reliability testing new PA

2.2.2 Technology development

The development of wave energy has been hindered by various setbacks in recent years, due to the slow progress made in developing viable technologies. In 2016 the sector has shown signs of recovery.

In 2012 and 2013 a number of OEM exited the sector. In 2014, the sector was further shocked when companies considered at an advanced stage of development such as Aquamarine Power and Pelamis Wave Power went into administration. Aquamarine Power folded its activities weeks after it had been awarded a EUR 0.8 million Horizon 2020 (H2020) grant [BBC 2015]. These events highlight the risk associated with the development of wave energy, and in particular with the full-scale demonstration of converters.

At the end of 2016 the status of the wave energy sector looks somewhat different, with a more positive outlook, despite difficulties of developers like Wavestar to find investors [Nordicgreen 2016]. 21 projects are currently in the water (as seen in Table 4). A number of array projects are moving forward, such as CETO in Australia, Wello and AW-Energy in Scotland and Portugal respectively. From a technology point of view, it is good news for the sector that the three CETO5 devices installed in Australia have achieved a cumulative 14000 hours of operation in the Perth Project. Assuming that the devices operated for a similar amount of time, the results suggest an availability of 53 %. In Europe, key developments are expected from the deployment of the first 1 MW Penguin developed by Wello Oy as part of the H2020 CEFOW project. Furthermore, the first full scale Waveroller device is currently being manufactured in Finland, for deployment in Portugal.

Positive signs are also seen at lower TRL. The JRC has identified 57 companies active in developing wave energy, 40 of which are still in the early phase of development.[2] There is an increasing development of point absorbers (Figure 8). The early technology status of many new concepts is identified in the "other" slice of Figure 8, since they do not fall under the standard wave energy categories.

[2] Based on JRC Database and application to WES Scotland calls and Wave Energy Prize.

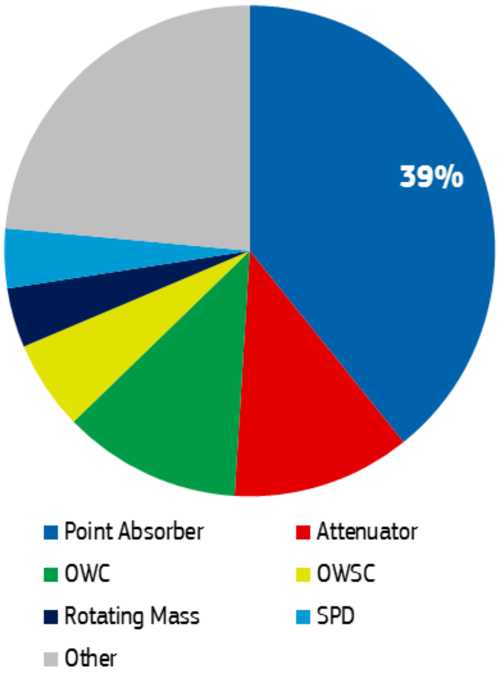

Figure 8. R&D effort for wave energy technologies (full and part scale).

The setbacks witnessed in the sector in 2014 have encouraged funding agencies across the globe to assess the availability of funding schemes for wave energy technology, and ensure that these are accompanied with a thorough assessment of technology status.

Stage-gate metrics offer the possibility of monitoring and comparing success from technology development until technology are commercially viable [EERA 2016]. Technology needs to achieve a minimum threshold to be able to apply for funding at a higher stage. Stage-gate metrics allow de-risking the phase of technology demonstration that has been so critical for wave energy technology, by ensuring that only technologies with a proven track record have access to the funds available.

Stage-gate systems have been developed and implemented by different funding agencies (Wave Energy Scotland, Sustainable Energy Authority of Ireland and the US Department of Energy). Other agencies in Wales, Pays de la Loire and Cornwall are considering the implementation of stage-metrics for wave energy technology. Similarly, this approach, recommended also in the Ocean Energy Forum Strategic Roadmap [Ocean Energy Forum 2016], with the expectation to reduce the risk for both technology developers and funding agencies. The proposition of the Ocean Energy Forum identifies five critical stages: R&D, prototype, demonstration, pre-commercial and industrial roll out; which can be loosely associated with TRLs.

The key requirement for the implementation of stage-metric is the identification of suitable and appropriate technological achievements for each stage. There is an international recognition that stage-gate metrics would be favourable for the development of wave energy, and efforts are being made in order to develop and harmonise the metrics at international level.

2.2.3 Electricity generation

A number of WEC have delivered electricity to the grid. Understanding the progress made by these technologies over the years helps assessing the R&D needs and targets for the coming years. There is limited information available with regards to electricity generation from devices that became operational in 2016. An overview of the energy generated by wave energy devices is provided in Figure 9.

To date, the class of devices that has delivered the most electricity to the grid is the OWC. The 400 kW Pico OWC plant has delivered more than 70 MWh to the grid during 3100 hours of operation [JRC 2014]. The 500 kW OWC at Limpet has produced about 600 MWh from 2006 to July 2013 [Ofgem 2015]. The OWC installed in Mutriku produces about 300 MWh annually [Renewable Technology 2015]. In July 2016, it was announced that Mutriku had surpassed the 1.3 GWh mark - a key milestone for the wave energy industry [EVE 2016].

By contrast, the data available for Pelamis show that the P2 (750 kW) owned by E.ON UK delivered 44 MWh to the grid between November 2011 and April 2012. The P2 owned by ScottishPower Renewables, has instead delivered about 102 MWh to the grid between October 2012 and June 2014. [Scottish Renewables 2014]

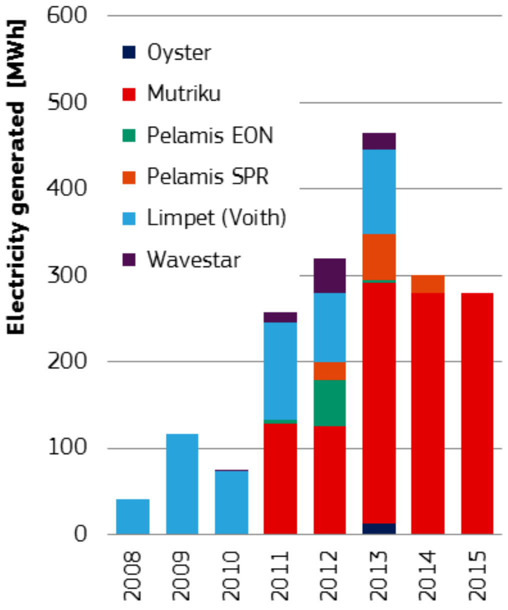

Figure 9. Electricity generation from wave energy in Europe
Sources: [Eurostat 2015], *own analysis*

Aquamarine Power installed the Oyster 2 device (800 kW) at EMEC in 2012 and it fed about 12 MWh of electricity to the grid between February and November 2013 [Ofgem 2015]. The first BOLT device from Fred Olsen was installed and tested at Risør in Norway and produced about 3.4 MWh between June 2009 and December 2010 [Sjolte et al. 2013, JRC 2014]. The following model, the 240 kW BOLT Lifesaver was subsequently installed in 2012 at FabTest in the UK and has delivered about 4.6 MWh to the grid [Taylor 2013, Sjolte 2014]. The 1:2 WaveStar prototype at Roshage device has produced about 70 MWh from September 2009 to April 2013 [JRC 2014].

No information is yet available on the power production of the Perth Wave Energy Project by Carnegie in Australia or by the WaveEl device installed in Norway aside from information regarding the survivability of the devices.

No wave energy converter has thus far been able to deliver electricity to the grid on a continuous base (i.e. in more than twelve consecutive months), aside from OWC. The capacity factors achieved are low, reaching 25 % in the case of OWC and 10 % for other device types.[3] Capacity factors of WECs need to reach 30 % to 40 % for the technology to become economically viable.

2.2.4 Wave energy RDI and cost reduction

Compared to tidal energy, wave energy technologies are still in need of R&D to identify viable solutions and to ensure the survivability and reliability of key components. The full-scale prototypes expected to be deployed in the near future could play a key role in assessing the reliability of key components.

The current LCOE of wave energy ranges between 60 cEUR/kWh and 110 cEUR/kWh today for an average resource, with a reference value of about 85 cEUR/kWh, as reported in Figure 10. At the extreme, values can reach up to 139 c EUR/kWh in case of a poor resource and can go down to about 44 c EUR/kWh in case of a good resource.

Estimates of the LCEO for wave energy technologies are affected by the lack of a dominating technology as well by uncertainties caused by unproven technologies in terms of electricity generation, as reported also by OES [OES 2015].

Based on data from ETRI [ETRI 2014], the reference capacity factor of 25 % for first-of-a-kind wave energy arrays was employed; however as seen in the previous section, current technology is far away from it.

Given current uncertainties, the 2025 target of 20 c EUR/kWh would be reached only after 10 GW of cumulative capacity has been installed. Cost reductions could be achieved quickly, if the right technology progression undertaken, with the SET-Plan

[3] Calculations do not take into account eventual or planned shut-off or maintenance periods of the devices.

target being met at 500/1000 MW of installed capacity in particularly good conditions.

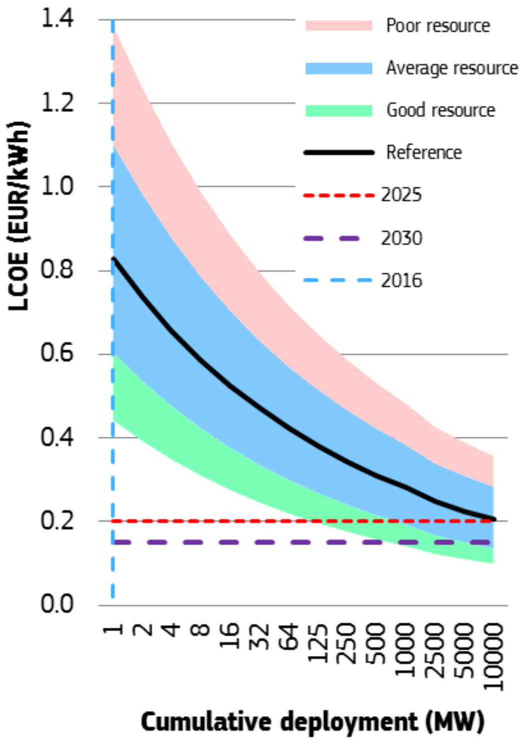

Figure 10. LCOE predictions for wave arrays

Sources: [ETRI 2014], updated; own analysis

Many developers have worked on developing dry test rigs for the optimisation of their PTOs (AW Energy and CorPower). Testing PTOs in a dry environment allows developer to optimise the performance of the PTO, before going through wet tests in open sea.

The development of the PTO is one of the key technological priorities for wave energy. Three of the four EU funded Horizon 2020 projects under the Research and Innovation Actions (RIA) call addressing specifically the development and optimisation of wave energy PTO (Table 5). Horizon 2020 funds directed to wave energy specific R&D accounted for a total of EUR 30.1 million.

The relevance of the PTO as a key priority for wave energy R&D is further highlighted by Wave Energy Scotland funding programmes. WES has funded 16 different projects addressing issues related to Power Take Off for wave energy converters, for a total of GBP 7 million (EUR 9.5 million). Other R&D priorities of funded projects are the optimisation of mooring configurations, and increasing the survivability of the structures.

Table 5. H2020 projects funded to support wave energy innovation actions

Project Acronym	Project Title	Technology Developer	Focus
CEFOW	Clean energy from ocean waves	Wello	This is a demonstration project. The project aims at deploying 3 1 MW Wello Penguin device in 2017, 2018 and 2019 respectively. Investigation will look at reducing LCEO, optimise O&M and achieve high operational hours.
OPERA	Open Sea Operating Experience to Reduce Wave Energy Cost	OceanTEC	The projects will focus on the improvement of the OceanTEC OWC (TRL5) by gathering data from open water deployment of the device, developing testing a new biradial turbine (dry test at Mutriku), and assessing dynamic mooring configurations. Overall aim is reduction of 50% of LCEO
WaveBoost	Advanced Braking Module with Cyclic Energy Recovery System (CERS) for enhanced reliability and performance of Wave Energy Converters	Corpower	The project aims at improving the PTO for the next generation Corpower device. The first Corpower WEC is to be tested in EMEC next year (TRL6), while the project focus on developing further a new PTO (TRL5) to reduce of 30% LCEO to be mounted in future Corpower technology.
WETFEET	Wave Energy Transition to Future by Evolution of Engineering and Technology	OWC (general) and Symphony	The project focuses on technology at low TRL (3/4), by combining tank and numerical model. The project focuses on two different technologies, and aims to achieve breakthough by testing innovative PTO systems.

As in the case of tidal energy, the LCEO of wave energy can be effectively reduced by decreasing CAPEX. If civil and structural costs are reduced by 50 %, the total LCOE can be decreased by about 25 % (Figure 11). A reduction of costs of mechanical equipment and installation by 50 % would yield even higher benefits: LCOE could decrease by about 44 %.

Other improvement options such as a reduction of OPEX or increases of the capacity factor of the device were analysed as well. Assuming a 50 % improvement of those two parameters, total LCOE could be reduced by 40 % (OPEX) and 33 % (CF), respectively.

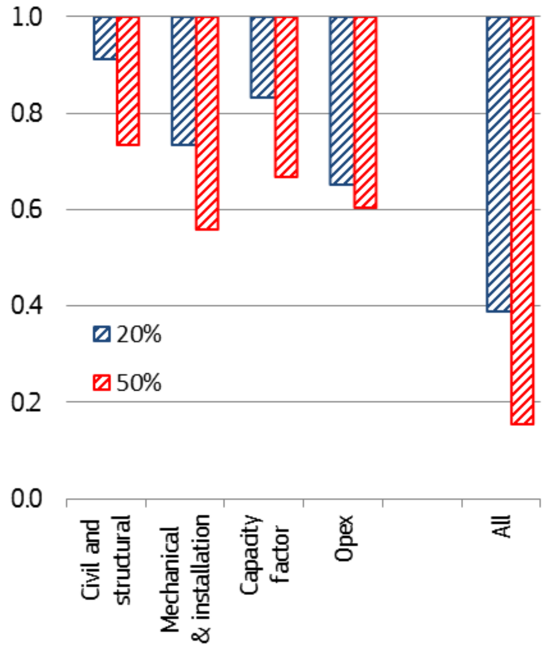

Figure 11. Wave energy LCOE cost reduction per cost component. Reduction of 20% (blue) and of 50% (red) were assumed for each cost components. For capacity factors improvements of 20% and 50% were taken into account.
Source: Own analysis

The comparison of the various cost reduction strategies shows that for wave energy, reduction of OPEX and reduction of mechanical equipment and installation are the most favourable options. A combination of all measures would lead to a LCEO reduction of almost 85 %, which is equivalent to costs of about 16 cEUR/kWh (Figure 11).

2.3 Tidal lagoons, OTEC and salinity gradient

The development on tidal lagoons, OTEC and salinity gradient technology has progressed steadily in 2016.

Tidal lagoons represent the ocean energy technology that is expected to be commercially deployed in the shortest timespan. A 320 MW tidal lagoon is under development in Swansea, with the potential to develop a further 6 GW in the UK. The technology has received widely spread support. From a technical standpoint the technology employs conventional hydro-turbine to generate electricity, while exploiting the rise and fall of tides. The economic benefit of the Swansea tidal lagoon have been largely described [Research 2014]; and discussion is currently taking place to identify suitable agreement between developers and the government in order to identify a suitable contract-for-difference (CfD) that would support the construction of the lagoon.

The development of OTEC has made significant stride forwards. A number of projects are moving forward, including 100 kW Okinawa Plant in Japan, the 1 MW Kriso plant under development in Korea, a 500 KW OTEC Pilot in Curacao developed by Bluerise and the commercial OTEC project expected to be installed in the Maldives developed by Bardot Ocean [OES 2016]. The 10 MW Nemo is expected to become operational by 2019 in Martinique. The project is funded through NER300 for a total of 72 EUR million, and validation works are currently taking place.

Salinity gradient technology is still at R&D phase [Ocean Energy Forum 2016]. A 50 kW demo plant is currently operational in the Netherlands, developed by REDStack. R&D activities are taking place both in the Netherlands and in Korea in order to improve the performance of membranes and reduced the associated cost. The Ocean Energy Forum roadmap predicts that demonstration plants for up to 50 MW could be installed after 2020.

3 Market status

The market for ocean energy technology is still small. A few ocean energy projects are currently being deployed, grid-connected or already operational. According to the NREAPs signed by EU Member States in 2009, the total installed capacity of ocean energy should reach 2253 MW by 2020 [EC 2009]. In 2016, the total ocean energy installed capacity in the EU is only 254 MW based on data made available by Member States in their NREAP progress reports. Table 6 presents an overview of the NREAPs targets for ocean energy and the actual capacity and production achieved.

Table 6. Ocean energy in the EU: NREAP targets and progress

	Capacity (MW)	Production (GWh)
2014 actual	247	483
2014 target*	322	752
2016 actual [JRC]	254**	n.a.
2016 target*	641	1789
2020 target*	2253	6506

* N.B. The NREAP targets do not differentiate between wave, tidal stream and tidal range technology
** Includes Meygen which is not considered in 2016 NREAP updates.

Only 14 MW out of the 254 MW of ocean energy capacity installed are related to wave, tidal and salinity gradient technology. The remaining 240 MW refer to the tidal barrage of La Rance operational in France since 1966. Whilst market formation has been slow, the trends of the recent years appear to be changing with a number of projects having been commissioned and announced in 2016; the majority being tidal energy projects. In the upcoming section an overview of ocean energy market is presented, focussing on key players, expected deployments and announced projects and medium term outlook for the market.

3.1 Tidal energy

3.1.1 Companies

Worldwide, many companies are currently developing tidal energy devices with most of them (about 52 %) being based in the EU (Figure 12). In Europe, the country with the highest number of developers is the United Kingdom, followed by the Netherlands, and France. Major non-EU players are the United States and Canada.

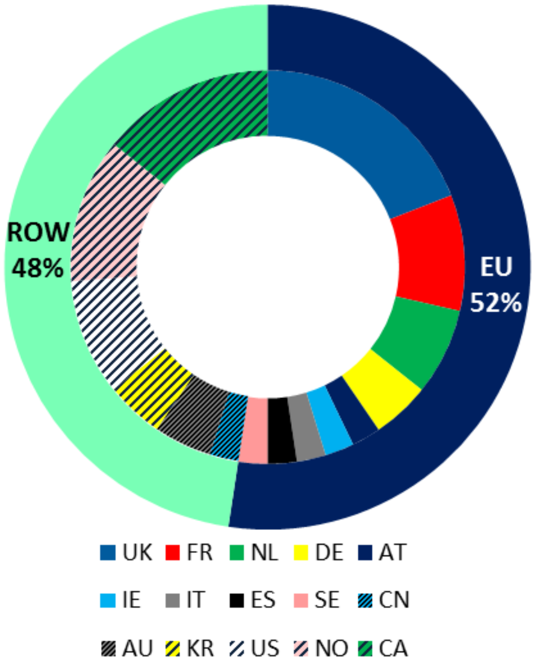

Figure 12. Distribution of tidal energy developers in the world
Source: JRC Ocean Energy Database, own analysis

The development of tidal technology is taking place throughout Europe, despite tidal energy resources are sited mainly in the UK, France, and Ireland. Active tidal developers are located throughout Europe, including countries with limited resources such as Germany and Sweden (Figure 13).

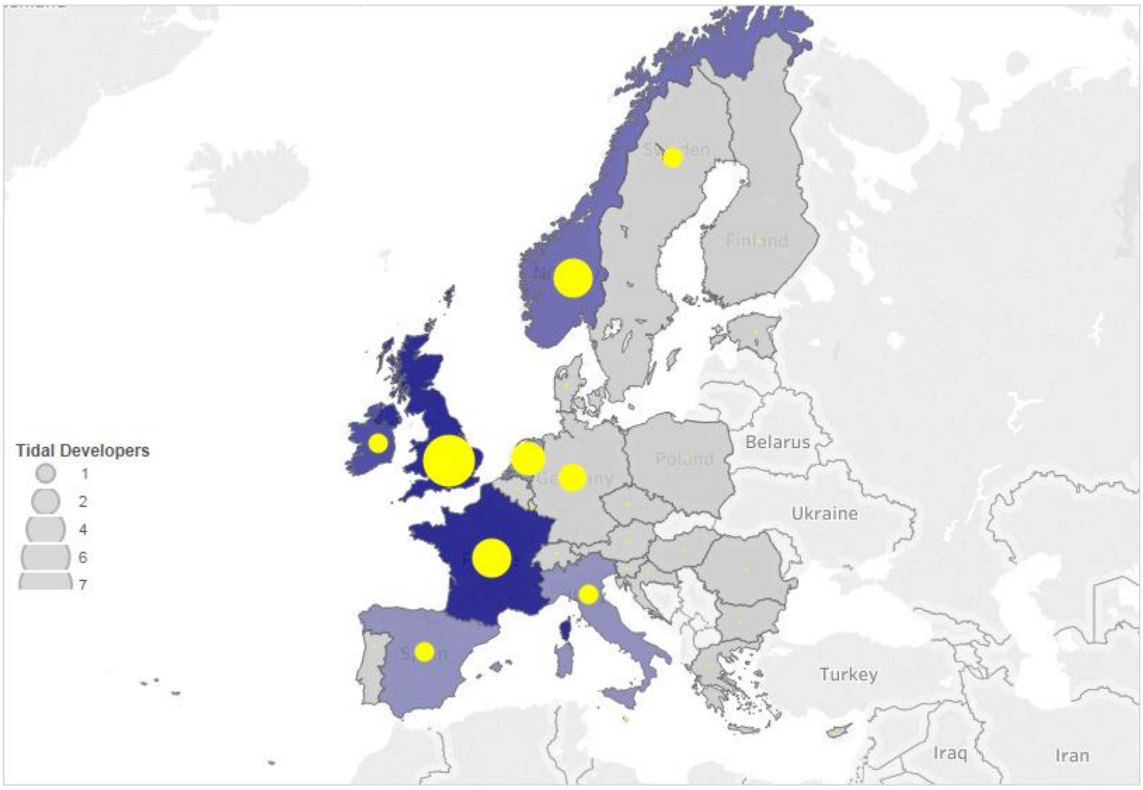

Figure 13. Spread of tidal developers (in yellow) and resource availability in Europe. Dark blue areas refer to high resources, and light blue areas indicate limited resources.

In 2015, the sector saw a further consolidation by mergers and acquisitions. The Dutch company Tocardo acquired IHC Tidal Energy and Swanturbines IP [Tocardo 2015a, Tocardo 2015b]. Atlantis Resources acquired Marine Current Turbines from Siemens [Atlantis Resources 2015a].

Furthermore, Alstom's energy business was acquired by GE, and it seems GE will continue the activities of this business segment. Some companies and developers have left the sector, amongst them Clean Current Power Systems from Canada, and Tidal Energy Limited from the UK that entered administration in October 2016. For some developers, it remains unclear if they still pursue development activities. Currently, about 30 worldwide active tidal energy developers that have tested their devices in open waters or will do so in the near future have been shortlisted (Appendix A.1), a slight decrease compared to 2014 [Magagna & Uihlein 2015]. This shortlist does not imply any assertion regarding future commercialisation or success of individual companies and/or devices.

Some more advanced manufacturers are investing in supply chain and manufacturing capacities. Atlantis has opened the world's first multi tidal turbine integration and assembly facility in Scotland [MeyGen 2015]. A cluster of about 40 local companies have directly contributed to the MeyGen project so far. OpenHydro recently raised about EUR 47 million for turbine production and project pipeline [McCrone 2016]. The facility is expected to manufacture the 7 turbines to be installed in the Raz Blanchard project. The production capacity of the turbine assembly plant is expected to be of 25 turbines per year, which could be expanded to 50. Schottel Hydro has received an order to build 16 SG50 turbines for installation on the Plato devices to be deployed at EMEC from 2017.

All in all, the formation of a tidal energy supply chain can be observed, which is encouraged by a certain design consensus towards horizontal axis turbines.

3.1.2 Project pipeline and market outlook

The majority of projects currently taking place have a nominal planned capacity between 4 MW and 14 MW with individual turbine capacities between 1 MW and 2 MW. These projects rely on public funding from programmes dedicated at low-carbon energy technologies. The only exception is the UK scheme MEAD (Marine Energy Array Demonstrator) which aims specifically at wave and tidal energy projects. Other funding schemes include:

- PIA (Programme des Investissements d'Avenir), France;
- NER 300, European Commission;
- SDTC (Sustainable Development Technology Canada), Canada.

Table 7 presents an overview of the funds made available for tidal array demonstration projects.

Table 7. List of ongoing tidal energy pre-commercial and demonstration projects identified by JRC

Project name	Capacity	Funding	Status
MeyGen phase 1A	6 MW	10 m GBP from MEAD	Operational since November 2016
Sound of Islay	10 MW	20.65 m EUR from NER 300	Entry into operation expected in 2018
Stroma/MeyGen phase 1B	8 MW	16.77 m EUR from NER 300, 10 m EUR upfront	Entry into operation expected in 2017
Nephtyd	5.6 MW	ADEME, Investment for future' programme (PIA), 51 m EUR	Entry into operation expected in 2017
Normandie Hydro	14 MW	ADEME, Investment for future' programme (PIA), 51 m EUR	Entry into operation expected in 2018
Skerries Array	10 MW	10 m GBP from MEAD	Project was halted by Siemens/MCT but Atlantis Resources considers to revive
Bay of Fundy	4.5 MW	5 m C$ from SDTC	Turbine deployment expected in 2016
Bay of Fundy	4 MW	6.3 m C$ from SDTC	Deployed in 2016

Sources: [Hydro World 2015, Pulse Tidal 2015, ScottishPower Renewables 2015a, SDTC 2015, Verdant Power 2015, Wales Online 2015a, Atlantis Resources 2015b, EC 2015b]

Market uptake for tidal energy continues to be slow. For a third time in a row, Bloomberg New Energy Finance (BNEF) reduced deployment forecasts for tidal in 2020 from 167 MW (2013) to 148 MW (2014) and now to 100 MW (2015) [BNEF 2015a]. The strategic roadmap of the Ocean Energy Forum expects a cumulative deployment of about 95 MW by 2018 and 105 MW by 2020 in Europe [Ocean Energy Forum 2016].

Public support for demonstration projects is fundamental to ensure the development of a tidal energy market and an increased project pipeline in the future. The European tidal energy pipeline consists of 23 projects for total capacity of 1.1 GW. The majority are in planning stage (16 projects), two are currently under construction and five are fully commissioned now. A number of projects with capacities of up to 15 MW are coming online between 2016 and 2018. For some bigger arrays (30 MW and more), begin of construction is mainly envisaged after 2018 with expected dates of full commissioning beyond in 2020 or later.

Figure 14 provides an overview of the tidal energy pipeline in the EU based on all ongoing leased EU projects identified by the JRC is available (list available in Appendix A.2).

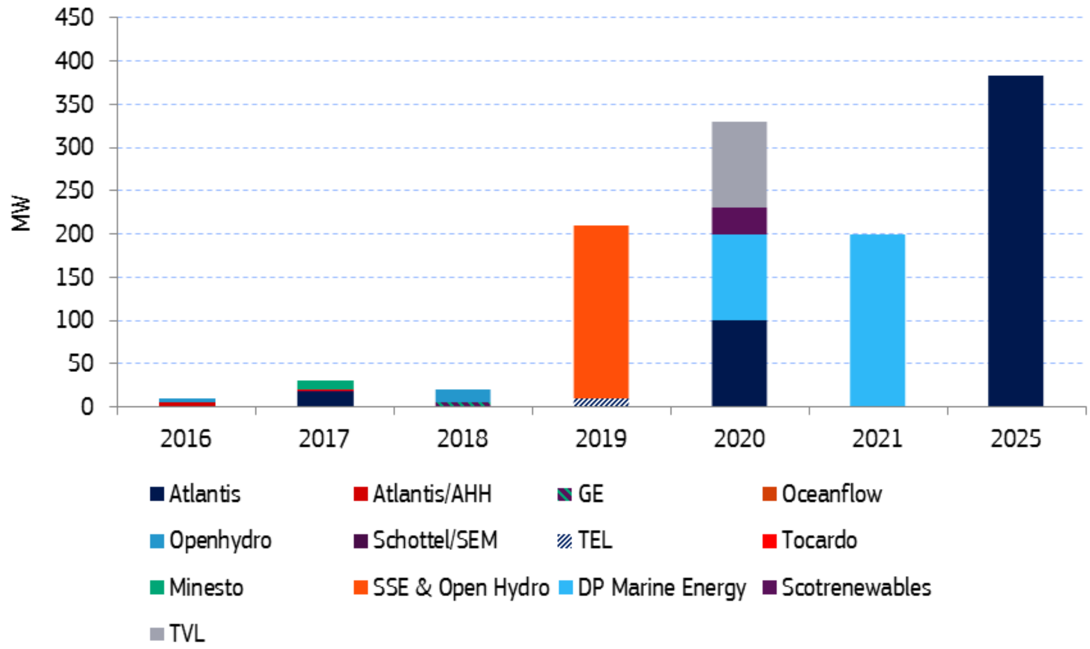

Figure 14. Tidal energy pipeline in the EU

3.2 Wave energy

3.2.1 Companies

Similarly to tidal energy, the majority of companies developing wave energy devices are based in the EU (Figure 15). The United Kingdom has the highest numbers of developers, followed by Denmark. Outside the EU, countries with a larger number of wave energy developers are USA, Australia, and Norway.

Figure 15 presents an overview of the location of European developers in relation to the availability or resources within the EU. As in the case of tidal energy, wave energy developers are spread throughout Europe even in countries with limited resources or no access to the sea.

Globally, about 57 wave energy developers have tested their devices in open waters or will do so in the near future. They are shortlisted in Appendix B.1. The number of shortlisted companies slightly decreased compared to 2014 [Magagna & Uihlein 2015]. As in the case of tidal energy, for some wave energy developers, it is not clear if they still pursue their activities.

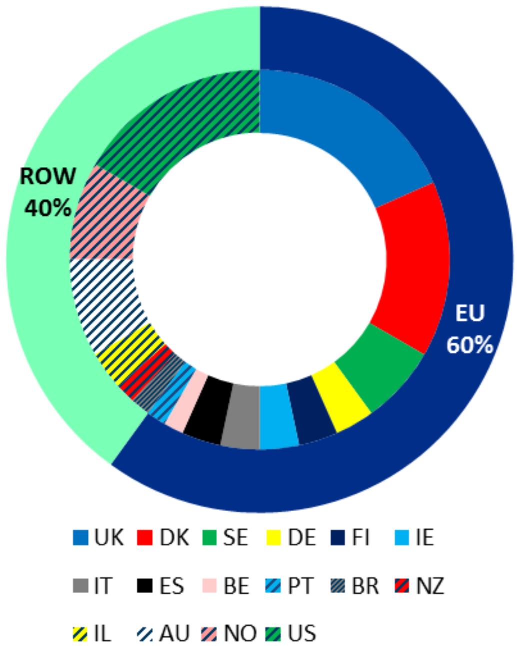

Figure 15. Distribution of wave energy developers in the world
Source: JRC Ocean Energy Database, own analysis

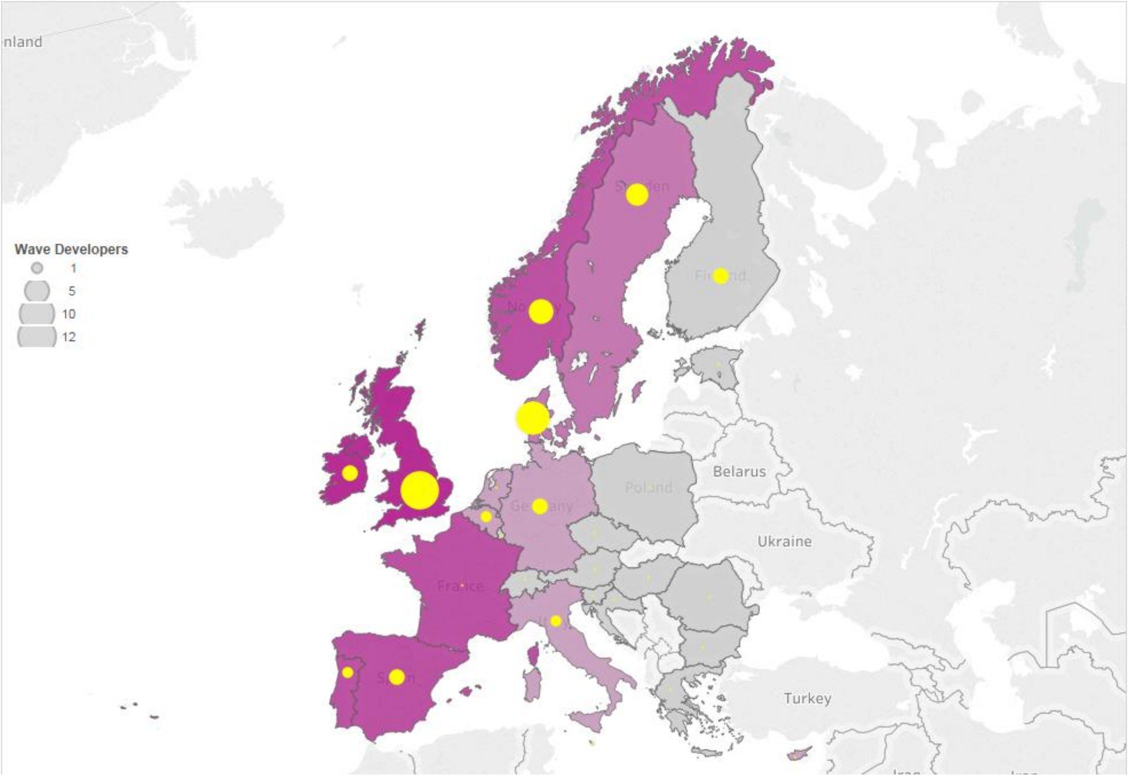

Figure 16. Spread of wave developers (in yellow) and resource availability in Europe. Dark purple areas refer to high resources, and light pink areas indicate limited resources.

Many developers have already performed testing or deployment of their devices at full scale (44 % of all developers) while about one fourth have not gone beyond small scale testing and about 30 % have performed testing on part scale. Most deployments so far have taken place at dedicated ocean energy test centres, while a limited number of projects have also been performed at commercial sites.

When we look at the industrial value chain and suppliers in wave energy, we see some promising developments. Seabased has invested in the manufacturing site at Lysekil and improved the facilities for buoy manufacturing, blastering and painting [Seabased 2015]. The site can now produce about 4 to 5 WEC (25-120 kW each) per week.

The consolidation of the supply chain for wave energy is still somewhat limited, especially compared with tidal energy.

3.2.2 Project pipeline and market outlook

The availability of public funding from programmes directed at low-carbon energy technologies in general has allowed a number of wave energy projects at pre-commercial or demonstration scale to take place (Table 8). Most of these projects are located in the EU, two in Australia, and one in Ghana. The main funding schemes include the NER 300 programme, the European Investment Bank (EIB) InnovFin scheme, and the European Regional Development Fund. (ERDF). At national level, funds to support these wave energy demonstration projects were made available from Swedish Energy Agency and by ARENA, the Australian Renewable Energy Agency. Other national and regional agencies in Belgium, France, Ireland, Netherlands, Portugal, Spain; and the UK are actively supprting wave energy R&D through the Ocean Energy ERA-NET project.

Table 8. List of ongoing wave energy pre-commercial and demonstration projects identified by JRC

Project name	Location and country	Capacity	Companies and devices	Funding	Status
Sotenäs	Västra Götaland, Sweden	10 MW	Seabased & Fortum	139 m SEK from Swedish Energy Agency	Under construction, grid connected, completion expected in 2016
Swell	Peniche, Portugal	5.6 MW	16 x 0.35 kW WaveRoller devices	9.1 m EUR from NER 300	Entry into operation expected in 2020
				10 m EUR from EIB InnovFin	Awarded in July 2016
Westwave	Killard, Ireland	5 MW	ESB, Device to be selected	23.2 m EUR from NER 300, other funding from SEIA	Construction expected in 2016, entry into operation expected in 2018
Carnegie Wave Hub	Wave Hub, Cornwall, UK	1 MW	Carnegie Wave Energy Ceto 6	M 9.55 GBP from ERDF	Awarded in 2016. Commissioning set for 2012
Perth project	Western Australia, Australia	0.72 MW	Carnegie 3 x 0.24 MW CETO5	13.1 m AUD from ARENA and 10 m AUD from LEED	Operational since 2015
Garden Island	Western Australia	t.b.d	Carnegie Multiple 1 MW CETO6	11 m AUD from ARENA and debt facility from CEFC	Commissioning scheduled for 2017
Ghana	Ada, Ghana	14 MW	Seabased	No information available	Installation of generators & switchgear first phase (0.4 MW) started.

Sources: [Marine Renewables Directory 2014, Carnegie 2015a, CEFOW 2015, Seabased 2015, BNEF 2015b, Carnegie 2015b, BNEF 2015c]

The uptake of wave energy technology is limited, and hindered by the lack of technology maturity shown through prototype testing. The expected wave energy installed capacity should have reached 370 MW in 2015 according to NREAPs [Beurskens & Hekkenberg 2011], while it has not reached 10 MW so far. Bloomberg New Energy Finance (BNEF) reduced again their forecasts for wave energy in 2020 from 75 MW (2013) to 21 MW (2014) and now to 19 MW (2015) [BNEF 2015a]. The Ocean Energy Forum expects 10 MW of installed wave energy capacity in Europe by 2020 [Ocean Energy Forum 2016]. In the EU, the pipeline amounts to 65 MW of wave energy projects expected to become operational by 2020 (Figure 17). A more realistic scenario would see 37 MW of wave energy capacity installed by 2020, taking into account projects that have been granted public support (e.g. H2020, NER300 and InnovFin).

A summary of all leased EU wave energy projects identified by the JRC is available in Appendix B.2.

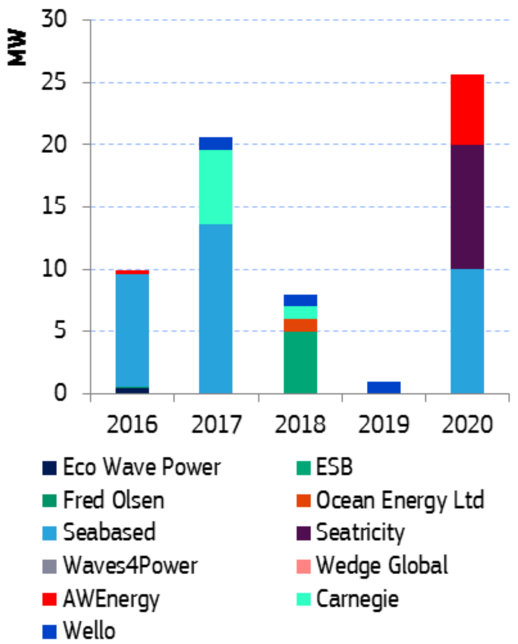

Figure 17. Wave energy pipeline in the EU

Bigger arrays (50 MW to 200 MW) are in early planning stage but far from announcing details on expected dates of entry into operation.

3.3 Supply chain considerations

Current market conditions and technology status of ocean energy converters have affected the consolidation of the supply and value chain of the sector.

Supply chain consolidation is project-driven for technologies that are commercially viable (Figure 18). As witnessed in the wind energy sector, a strong project pipeline ensures that there is sufficient demand for OEMs, and as a result guarantees demand for the manufacturing of components and subcomponents and for the supply of raw materials [FTI Consulting 2015, Magagna et al. 2016]. On the other hand, for technologies that are not yet market-ready, such as ocean energy technology, the consolidation of the supply chain is dependent on the ability of reliability of the technology and its progress to higher TRL.

This demand cycle is presented in Figure 19. Uncertainties in the project-pipeline are amplified throughout the supply chain, with potentially serious implications for the providers of components and raw materials. This can result in both price variation of good and materials, and in limited supply of products.

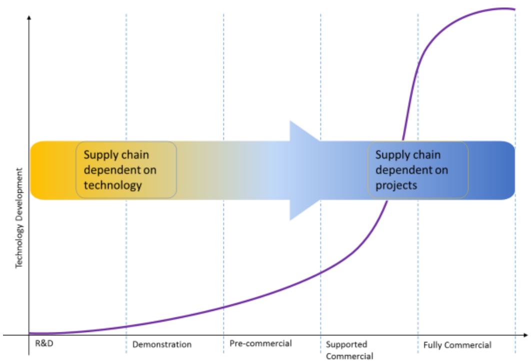

Figure 18. Supply chain consolidation based on market development

The supply chain for ocean energy technology is similar to the one depicted in Figure 20. In this case, the consolidation of the supply chain is dependent on the success of technology developers in delivering viable ocean energy converters. At this stage, a limited number of projects take place in forms of technology demonstrators or first-of-a-kind arrays. Component and sub-component suppliers are engaged on an ad-hoc based, manufacturing few pieces at a higher cost.

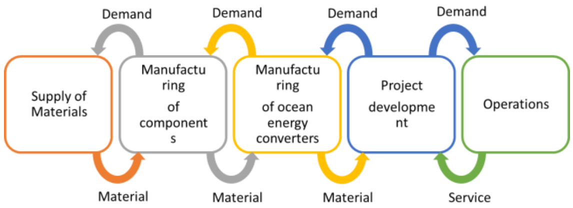

Figure 19. Consolidated supply chain

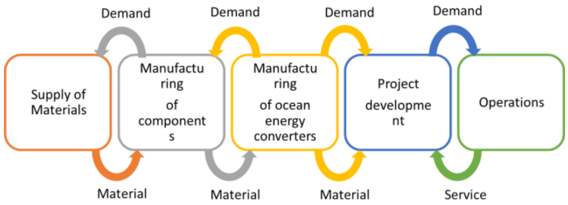

Figure 20. Non-consolidated supply chain

One of the critical issues for the ocean energy sector over the past few years has been the lack of engagement of OEMs. Currently, however, as the separation between tidal and wave energy is more marked, it can be seen that, OEMs are either acquiring or investing tidal energy developers with DCNS, Andritz Hydro-Hammerfest, Lockheed Martin, General Electric despite the early exit of Siemens from the sector. For wave energy however, since 2012 an exodus of OEMs has been witnessed.

The necessity of reducing the cost of ocean energy technology, also through economy of scales, implies that the presence of OEMs with access to large manufacturing facilities could be seen as an indicator of the consolidation of the supply chain.

Table 9 presents a non-exhaustive list of identified companies currently active in the field of ocean energy, ranging from technology developers to component suppliers. The majority of technology developers are based in countries with significant ocean energy resources, many intermediate components suppliers are based across the EU (Germany, Sweden, Finland, Italy, Austria).

Table 9. Non-exhaustive list of main companies identified in the field of ocean energy conversion OEMS are underlined, whilst where companies HQs are outside of the EU these are mentioned.

Developer	Bearings	Brakes	Shaft	Gearbox	Control	Generator	Electrical
Alstom/TGL (NOT-EU)	Wolfgang Preinfalk	Altra Industrial Motions	Invo-tech	David Brown	Schottel	Bosch Rexroth	ABB
Andritz Hydro/ Hammerfest	NKE	James Fisher Defence	Schottel	Siemens	Fraunhofer IWES	Siemens	Metso
Atlantis R.L. (NOT EU)	Hutchinson	Bosch Rexroth	James Fisher Defence	James Fisher Defence	MacArtney	The Switch	KTR Couplings
Lockheed Martin (NOT EU)	Schaeffler		Bosch Rexroth	Bosch Rexroth		ATB Morley	Veo
Nova Innovation			Invo-tech	Orbital2 Wikov		Umbra Cuscinetti	Converteam
DCNS				Siemens			Senergy Econnect
Ocean Flow							ABB
OpenHydro							General Electric (NOT EU)s
Schottel							
Scotrenewables							
Tidal Energy Limited							
40South Energy							
Albatern							
AW Energy							
Carnegie (NOT EU)							
Fred Olsen Ltd							
CorPower							
Seatricity							
Wello OY							
AW Energy							

A full assessment of the involvement of the European industry in the development of ocean energy technology is possible through an analysis of corporate patenting activities in the field. The European Patent office database provides information concerning patents application filed in one of the six ocean energy categories (CPC code, Table 10). Overall, about 550 European companies (including EEA members Norway and Switzerland) have applied for IP protection for ocean energy related inventions in the period between 2008 and 2013.[4] From the data it was possible to separate companies classified as technology developer (e.g. Wello Oy or Nova Innovation), and companies supplying components (such as Bosch Rexroth or SKF). The results of this analysis are presented in Figure 21.

Overall, with reference to Figure 21. it can be said that ocean energy development involves companies throughout the EU. Furthermore only 12 % of the companies identified are technology developers and 88 % are component suppliers.

Table 10. CPC patetnig codes for ocean energy

CPC Code	Definition
Y02E 10/28	Tidal stream or damless hydropower
Y02E 10/30	Energy from sea
Y02E 10/32	Oscillating water column**
Y02E 10/34	Ocean thermal energy conversion
Y02E 10/36	Salinity gradient
Y02E 10/38	Wave energy or tidal swell

[4] Patent data for 2014,2015 and 2016 are not complete. An assessment of patenting activity from 2014 onwards would be inaccurate and therefore was not carried out.

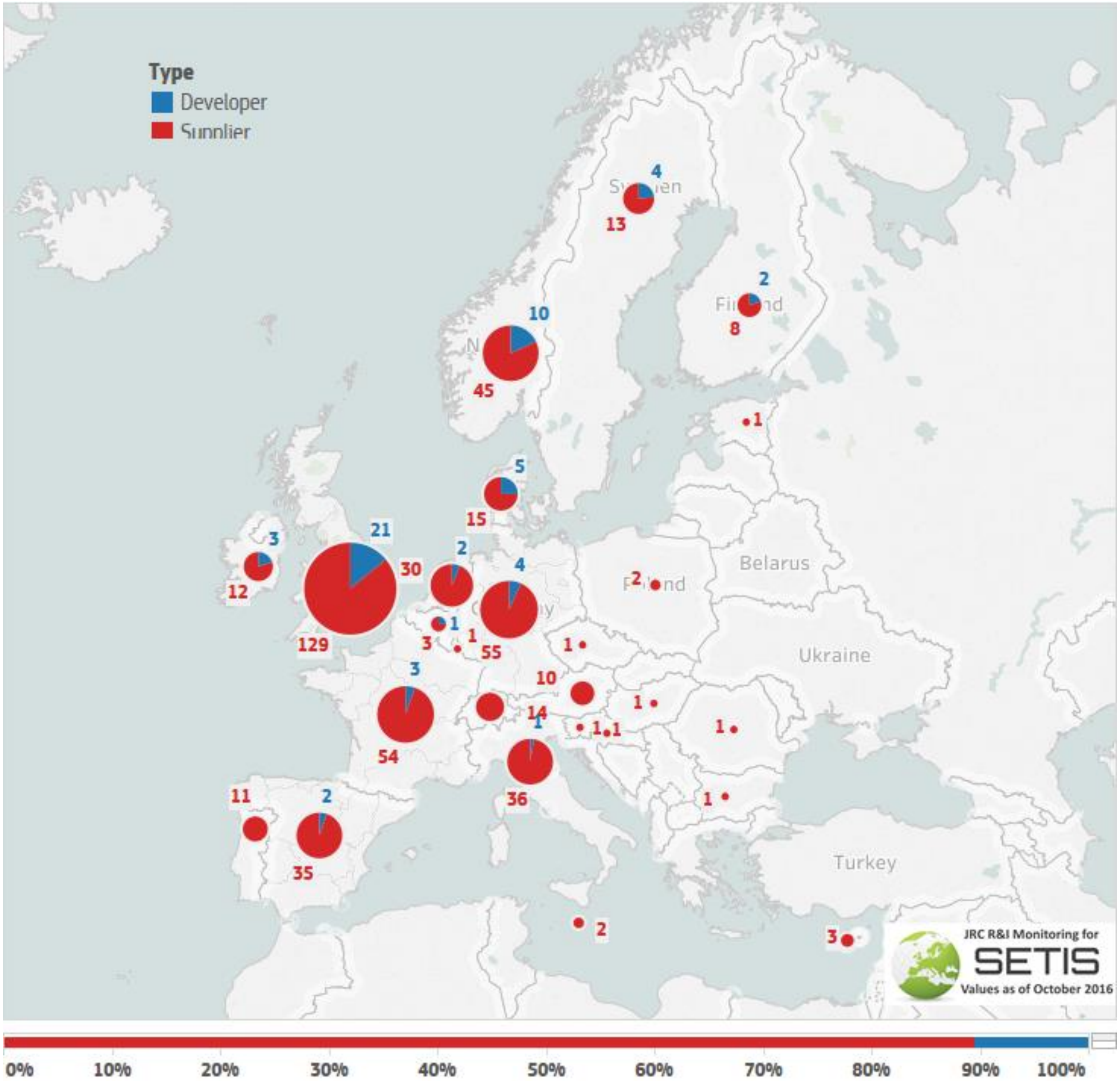

Figure 21. Ocean Energy patenting companies in the EU in 2008-2013 Companies identified as wave and tidal energy developers are represented in blue, supply chain and components manufacturers are classified as suppliers and represented in red. Please note that 2013 is the last year with complete patents data. An assessment of patenting activity from 2014 onwards would be inaccurate and therefore was not carried out.

Source: Eurostat.

4 Policy support and other initiatives

The development of ocean energy is associated with high capital expenditure (CAPEX), high operational expenditure (OPEX), low capacity factors and low reliability of devices. As seen previously, the current electricity generation from ocean energy is small and does not impact significantly on the overall EU electricity production.

Whilst technology issues have been identified as the main immediate problem for the sector [MacGillivray et al. 2013, Magagna & Uihlein 2015], market and infrastructure barriers may still hinder the uptake of the technologies in the mid to long term horizon [Badcock-Broe et al. 2014]. Policy support instruments for ocean energy technology include both push and pull mechanisms such as risk insurance funds, feed-in-tariffs (FIT), feed-in-premiums (FIP), tradable certificates, tendering, and soft loans. Table 11 gives an overview of current pull mechanisms implemented in the EU supporting ocean energy. Most often, they are feed-in tariffs, but also feed-in premium models exist, and rates (subsidies) range between 3 cEUR/kWh and 30 cEUR/kWh.

Table 11. Pull mechanisms for ocean energy in the EU

Country	Rate and eligibility
Denmark	Maximum tariff of 0.08 EUR/kWh for all renewables including ocean energy.
France	Feed-in Tariff for renewable electricity. Currently 15 cEUR/kWh for ocean energy.
Germany	Feed-in Tariff for ocean energy between EUR 0.035 and 0.125 depending on installed capacity
Germany	Feed-in Tariff for electricity from hydro power, wave and tidal at least 7.67 c EUR/kWh
Ireland	Market support tariff for ocean energy set at €260/MWh and strictly limited to 30 MW
Italy	0.34 EUR/kWh tariff (capacity installed until 2012)
Italy (from 2012)	For projects until 5 MW 0.3 EUR/kWh For projects >5 MW 0.194 EUR/kWh
The Netherlands	The SDE+ (feed-in premium) supports ocean energy with a base support of 0.15 EUR/kWh minus the average market price of electricity in the Netherlands (support is given for a 15 year period). Total budget for SDE+ capped (EUR 8 billion in 2016)
United Kingdom	Renewable Obligation (RO) Scheme. Renewable Obligation Certificates (ROCs) price set to 44.33 GBP in 2015/16. Will be replaced by a Contract for Difference (CfD) scheme in 2017. Wave and tidal energy technologies will be allowed to bid for CfDs, however they are currently expected to compete with other technologies (e.g. Offshore Wind) to access CFDs.
Source	NREAPs update reports

As can be seen, only a few member states have dedicated pull mechanisms to support the development of ocean energy. Countries such as Finland, Portugal and Spain have included the technology in their NREAPs, but have no dedicated market support system.

Four member states have also implemented push mechanisms to favour the development of ocean energy. Push mechanisms tend to provide upfront capital for the deployment of pilot projects. Table 12 provides an overview of the push mechanisms provided across Europe. It can be seen that funds made available range from EUR 26 million in Ireland to more than about EUR 285 million in the United Kingdom. Availability of push mechanisms is restricted to four member states, with the United Kingdom being the most proactive.

Nevertheless, as summarised in Figure 22 the current availability of support mechanisms in terms of technology push and market pull does not cover fully the market development trajectory of technologies. At EU level, efforts are being stepped up to support first-of-a-kind industrial demonstration projects. In June 2015, the European Commission and the European Investment Bank launched the Energy Demo Projects Risk Finance Facility as a thematic finance instrument under the existing InnovFin programme. The objective is to bridge the gap from demonstration projects to commercialisation and helping the further rollout of renewable energy and hydrogen and fuel cell technologies to the market. InnovFin Energy Demo has been designed to address a higher level of risk than what is currently covered under InnovFin, allowing projects that are currently unviable to benefit from the risk finance envelope.

Table 12. Push mechanisms for ocean energy in the EU

Country	Rate and eligibility
France	Two projects awarded funding: Normandie Hydro (EUR 52 million funding) and Nepthyd (EUR 51 million).
Ireland	SEAI Prototype Development Fund, dedicated to ocean energy. Total amount available not discolde
Ireland	Ocean Energy Development Budget increased to EUR 26 million.
Portugal	Fundo de Apoio à Inovação (FAI) for renewable energies, 76 m EUR total
United Kingdom	Renewable Energy Investment Fund (REIF) Scotland, 103 m GBP.
United Kingdom	Marine Energy Array Demonstrator (MEAD), 20 m GBP.
United Kingdom	Energy Technologies Institute (ETI), 32 m GBP for wave and tidal projects.
United Kingdom	Marine Renewables Commercialisation Fund (MRCF) Scotland, 18 m GBP.
United Kingdom	Marine Renewables Proving Fund (MRPF), 22.5 m GBP.
United Kingdom	Saltire Prize, Scotland, 10 m GBP. For first device delivering > 100 GWh for two years
United Kingdom	Wave Energy Scotland funding, GBP 14.3 million until end of 2016
Source	NREAPs update reports

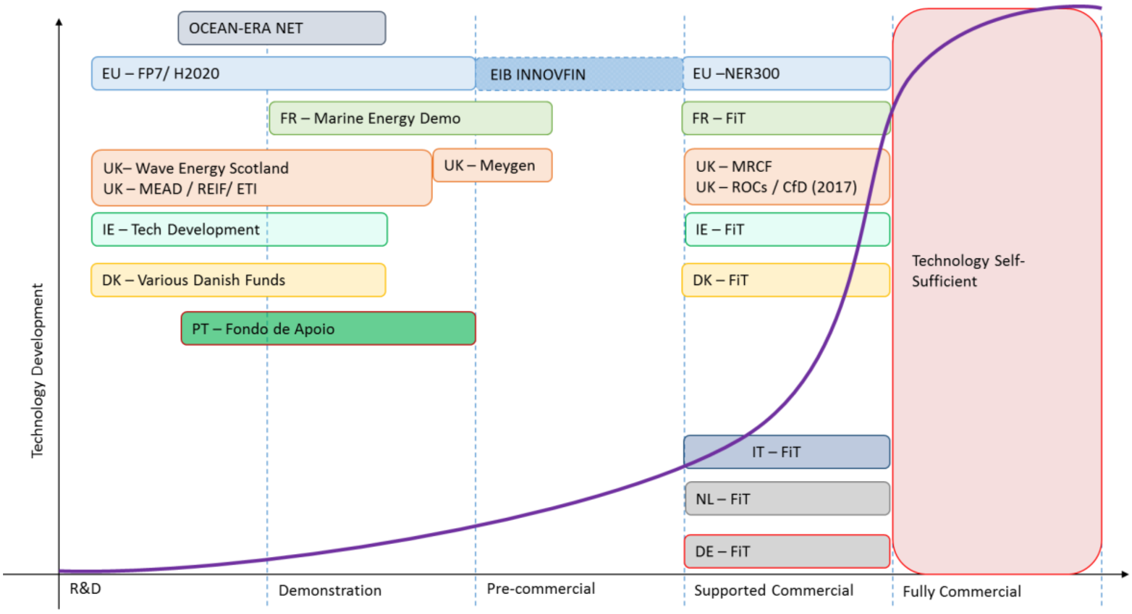

Figure 22. Summary of market push and pull mechanisms for ocean energy in the EU based on Carbon Trust deployment scenarios [Vantoch-Wood 2016]*. Supported commercial indicates technologies that have a market but receive support such as FITs, whilst the term fully commercial refers to energy technologies (not necessarily RES) that do not require FITs or other support schemes, and are thus self-sufficient.*

4.1 Regional collaboration

Within the framework of the Smart Specialisation Platform on Energy (S3PEnergy[5]) initiative launched by the European Commission, ocean energy was identified as one key area for collaboration at regional level [Jiménez Navarro & Uihlein 2016].

The S3PEnergy initiative is designed to harmonise the regional effort in the development of ocean energy. It facilitates collaboration by matching research and innovation strengths with business needs; with the aim to identified address emerging op-

[5] http://s3platform.jrc.ec.europa.eu/s3p-energy

portunities and market developments in a coherent manner.

A regional partnership for regional collaboration on ocean energy was established in 2016 under the S3P umbrella, with a number of key European regions already participating in the initiative.

Further collaboration at regional level is facilitated by the Ocean-ERA project, which coordinates activities between European Countries and regions to support RDI activities for the development of ocean energy technology.

5 Outlook and concluding remarks

2016 has been an important year for the ocean energy sector. Significant developments have taken place in the EU and Canada, with the deployment of the first tidal energy demonstration farms, a major milestone for the creation of the ocean energy market.

Europe's technological leadership in the sector has been strengthened. Europe accounts for 52 % of tidal stream and 60 % of wave energy developers.

In 2016, Europe has reinforced its commitment to the development of ocean energy technology. The SET-Plan Declaration of Intent has set out ambitious targets for the ocean energy industry, and ensures the support of the EU through research, demonstration and innovation actions.

The roadmaps developed by the Ocean Energy Forum and by the European Technology and Innovation Platform for ocean energy have identified key actions for making ocean energy a commercial reality in the EU and on a global stage.

The newly formed[6] European Technology and Innovation Platform on Ocean Energy (ETIP Ocean)[7] will be tasked to ensure a unified stakeholders input for the implementation of the SET Plan actions 1 & 2:

1. Sustaining technological leadership by developing highly performant renewable technologies and their integration in the EU's energy system;
2. Reducing the cost of key technologies.

ETIP Ocean will act as a bridge between the actions identified by the Ocean Energy Forum and activities to be implemented within the SET-Plan, in the context of the 5th pillar of the Energy Union under its first priority "Being n°1 in renewables". The scope of ETIP Ocean covers the whole innovation chain as well as bringing technologies to the market by for instance identifying innovation bottlenecks.

Strong mechanisms at European level are in place to support the development of technology from early stage prototypes through commercialisation. The H2020 programme alone has been funding over EUR 60 million of R&D projects in wave and tidal energy in two years. NER 300, EIB-InnovFin and ERDF mechanisms are helping supporting the deployment of demonstration projects. Collaboration initiatives at regional level are catalysing the formation of marine energy cluster to consolidate the European supply chain.

There are still technical, financial and environmental barriers, preventing large-scale ocean energy uptake in the EU. The cost of tidal and wave energy technology has to be reduced by 75 % and 85 % to meet the targets agreed in the SET-Plan.

Financial instruments need to be established to help reduce the risk associated with demonstration farms, hindering in particular the progression of tidal energy technology.

R&D mechanisms are needed to support the technological development of ocean energy technology. Concerted actions are taking place for the implementation of stage-gate metrics. These are expected to help assess the success of technology progressing through the TRL, aligning it with available funds.

In terms of market creation, the aim of the sector, as reported in the ocean energy roadmap, is to reach 100 MW of installed tidal energy capacity and 10 MW of wave energy capacity by 2020.

[6] The industrial platforms of the initial SET Plan governance structure were simplified in 2016 following the COM (2015) 6317 final "Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation". The 6 European Industrial Initiatives have been merged with the 8 European Technology Platforms to form 9 distinct entities called the European Technology and Innovation Platforms (ETIPs). These ETIPs are recognised as key industry-led communities for the implementation of SET Plan priorities along the innovation chain. They have been directly involved in the 2016 target setting process.

[7] http://www.oceanenergy-europe.eu/

Currently over 600 MW of tidal energy projects have been announced in the EU with expected operation to start by 2020 and the wave energy pipeline accounts for 65 MW.

Announced ocean energy projects that have obtained support through the different funding streams (e.g. H2020, NER 300 and InnovFin) and that are expected to be operational by 2020 account for 71 MW of tidal and 37 MW of wave energy capacity.

In 2016, the ocean energy sector showed encouraging signs for its development. The successful progression towards commercialisation could play a key role in the decarbonisation of the EU energy system, and help ensuring a competitive advantage for European businesses involved in ocean energy development.

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APPENDIX A Tidal Energy

Appendix A.1 Developers

Shortlist of tidal energy developers identified by JRC

Company name	Model family	Testing	Country	Website
Alstom[a]	Oceade	Full scale	USA	www.alstomenergy.gepower.co
Andritz Hydro Hammerfest	HS Series	Full scale	Norway	www.hammerfeststrom.com
Aqua Energy Solution[b]	AES	Part scale	Norway	www.aquaenergy.no
Atlantis Resources	AK, AR, AS, AN Series	Full scale	UK	www.atlantisresourcesltd.com
BioPower System	bioSTREAM	Full scale	Australia	www.biopowersystems.com
Bluewater	BlueTEC	Part scale	Netherlands	/www.bluewater.com
Deepwater Energy	Oryon Watermill	Part scale	Netherlands	www.oryonwatermill.com
EEL Energy	EEL membrane	Small scale	France	www.eel-energy.fr
Elemental Energy Techn.[c]	MAKO turbine	Small scale	Australia	www.makoturbines.com
Flumill[b]	Flumill	Part scale	Norway	www.flumill.com
Straum	Hydra Tidal	Full scale	Norway	www.straumgroup.com
Hyundai Heavy Industries	HHI Tidal	Part scale	South Korea	www.hhiir.com/en
IHC Tidal Energy[d]	OceanMill	Part scale	Netherlands	www.ihctidalenergy.com
Kawasaki Heavy Industries	KHI Tidal Turbine	Full scale	South Korea	www.khi.co.jp
Marine Current Turbines[e]	SeaGen	Full scale	UK	www.marineturbines.com
Magallanes	Atir	Part scale	Spain	www.magallanesrenovables.com
Minesto	Deep Green Series	Full scale	Sweden	www.minesto.com
Nautricity	CorMaT	Full scale	UK	www.nautricity.com
New Energy Corporation.	EnCurrent	Full scale	Canada	www.newenergycorp.ca
Nova Innovation	NOVA series	Full scale	UK	www.novainnovation.co.uk
Ocean Renewable Power Company	TidGen	Full scale	USA	www.orpc.co
Oceana Energy Company	Oceana Marine Turbines	Small scale	USA	www.oceanaenergy.com
Oceanflow Energy	Evopod	Part scale	UK	www.oceanflowenergy.com
OpenHydro (DCNS)	Open-Centre Turbine	Full scale	Ireland	www.openhydro.com
Pulse Tidal[b]	Pulse-Stream Series	Part scale	UK	www.pulsetidal.com
Sabella	D series	Full scale	France	www.sabella.fr
SCHOTTEL group	SIT Instream	Full scale	Germany	www.schottel.de
Scotrenewables	SR Series	Full scale	UK	www.scotrenewables.com
Tidal Energy	DeltaStream Series	Part scale	UK	www.tidalenergyltd.com
Tidalys	Electrimar series	Part scale	France	www.tidalys.com
Tocardo	T series	Full scale	Netherlands	www.tocardo.com
Verdant Power	KHPS series	Full scale	USA	www.verdantpower.com
Voith Hydro[b]	HyTide	Full scale	Germany	www.voith.com
Vortex Hydro Energy	VIVACE series	Small scale	USA	www.vortexhydroenergy.com

[a] acquired by GE; [b] last news from 2013, current status unclear; [c] now MAKO turbines, before SeaUrchin; [d] acquired by Tocardo; [e] acquired by Atlantis Resources; [f] acquired by Voith

Appendix A.2 Projects

List of ongoing leased EU tidal energy projects identified by JRC

Project name	Location and country	Capacity (MW)	Companies and devices	Status	Comment
Brims	Brough Ness, Orkney Islands, United Kingdom	100	Atlantis Resources (MCT)	In planning	Construction expected to begin during 2016, entry into operation 2017, entire project commissioned by end 2020
Cantick Head	Pentland Firth, Orkney Islands, United Kingdom	200	SSE & OpenHydro	In planning	In planning, Construction to begin in 2019
Fair Head	Antrim, Northern Ireland, United Kingdom	100	DP Marine Energy & Bluepower	In planning	Construction of first phase (10 MW) expected to start in 2017
Holyhead Deep	Anglesey, Wales, United Kingdom	10	Minesto 3x 1.5 MW Deep Green for first phase	In planning	First 0. 5 MW turbine to be deployed in 2017
Isle of Islay	Islay, Scotland, United Kingdom	30	DP Marine Energy 30x 1 MW turbines	In planning	Construction expected to start in 2015
Lashy Sound	Orkney Islands, United Kingdom	30	Scotrenewables Tidal Power	In planning	Construction of first phase (10 MW) expected to start in 2017
MeyGen	Pentland Firth, Orkney Islands, United Kingdom	398	Atlantis Resources	In planning	Phase 1A (6 MW) operational in 2016. Phase 1B (8 MW) in 2017
Mull of Kintyre	Scotland, United Kingdom	3	Argyll Tidal 6x 500 kW Nautricity Cormat	In planning	No information available
Nepthyd	Normandie, France	5.6	GDF & Alstom 4 x 1.4 MW Oceade 18	In planning	Entry into operation expected in 2017
Ness of Duncansby	Pentland Firth, Orkney Islands, United Kingdom	30	ScottishPower Renewables	In planning	No information available
Normandie Hydro	Normandie, France	14	EDF & DCNS 7x 2 MW OpenHydro	In planning	Entry into operation expected in 2018
Ramsey Sound	Pembrokeshire, Wales, United Kingdom	1.2	TEL 1x DeltaStream	In planning	Device being commissioned
Sound of Islay	Islay, Scotland, United Kingdom	10	ScottishPower Renewables	In planning	No information available
St David's Head	Pembrokeshire, Wales, United Kingdom	10	TEL and Eco2 9x DeltaStream	In planning	Construction expected to begin in 2017
Tidal Ventures	Antrim, Northern Ireland, United Kingdom	100	TVL (Open Hydro & Brookfield Renewable Energy Grou)	In planning	Construction of first phase (30 MW) expected to start in 2017, full completion expected in 2020

Project name	Location and country	Capacity (MW)	Companies and devices	Status	Comment
Westray South	Westray Firth, Orkney Islands, United Kingdom	200	DP Marine Energy	In planning	No information available
Fromveur	Bretagne, France	1	Sabella 1 MW D10 turbine	In construction	Turbine deployment ongoing
Shetland Tidal Array	Shetland, United Kingdom	0.5	Nova International 5x100 kW Nova M100 devices	In construction	Subsea cable and onshore connection completed. Entry into operation expected in 2015
Sanda Sound	Sanda Island, Scotland, United Kingdom	0.035	Oceanflow Energy 1x35 kW E35 Evopod	In construction	Grid connection expected in 2015
Den Oever TTC Pilot	Afsluitdijk, The Netherlands	0.3	Tocardo 3x 100 kW T1 turbines	Commissioned	Entry into operation in 2015
Nova 30 demonstrator	Shetland, United Kingdom	0.03	1x 30 kW Nova 30 turbine	Commissioned	Entry into operation in 2014
Strangford Lough	Northern Ireland, United Kingdom	2	Atlantis (MCT) 2 MW Sea Gen S	Commissioned	Entry into operation in 2008
Strangford Lough	Northern Ireland, United Kingdom	0.5	Minesto 1x Deep Green	Commissioned	Entry into operation in 2013
Texel Tidal Project	Texel, The Netherlands	0.2	Bluewater 1x 200 kW Tocardo T2	Commissioned	Entry into operation in 2015

Sources: [Fair Head Tidal 2014, MCT 2015a, Minesto 2015, Nautricity 2015, Nova Innovation 2015a, Oceanflow 2015, Pentland Firth Renewables 2015, ScottishPower Renewables 2015a, Tidal Energy 2015a, Tidal Energy Today 2015, Tidal Ventures 2015, MCT 2015b, Nova Innovation 2015b, ScottishPower Renewables 2015b, Tidal Energy 2015b, Wales Online 2015b], own analysis

Appendix A.3 Techno-economic data

2015 Techno-economic data for tidal energy

Parameter	Unit	2010	2020	2030	2040	2050
Net electrical power	MWe	10	10-20	20-30	30-40	50-400
Max. capacity factor	%	36.3	45.2	47.1	47.1	50.0
Avg. capacity factor	%	29.0	33.0	40.0	42.0	45.0
Technical lifetime	Years	20	20	20	20	20
CAPEX reference	EUR/kWe	10668	5010	3100	2585	1897
CAPEX low	EUR/kWe	9304	3678	3024	2030	1701
CAPEX high	EUR/kWe	12281	6834	3400	3262	2454
CAPEX learning rate	%	12	12	12	12	12
FOM	% of CAPEX	6.2	6.5	5.6	6.3	4.9
FOM learning rate	%	3	3	3	3	3

APPENDIX B Wave Energy

Appendix B.1 Developers

Shortlist of wave energy developers identified by JRC

Company name	Model family	Testing	Country	Website
40 South Energy	R115, Y series	Full scale	UK	www.40southenergy.com
Albatern	Squid	Part scale	UK	www.albatern.co.uk
AquaGen Technologies	RigDrive, SurgeDrive	Small scale	Australia	www.aquagen.com.au
Aquamarine Power[a]	Oyster	Full scale	UK	www.aquamarinepower.com
Atargis[b]	CycWEC	Small scale	USA	www.atargis.com
AW Energy	WaveRoller	Full scale	Finland	www.aw-energy.com
AWS Ocean Energy	AWS III, Waveswing	Full scale	UK	www.awsocean.com
BioPower Systems	bioWave	Small scale	Australia	www.biopowersystems.com
Bombora WavePower	Bombora WEC	Small scale	Australia	www.bomborawavepower.com.au
Carnegie Wave Energy	CETO	Full scale	Australia	www.carnegiewave.com
Columbia Power Technologies	StingRay	Part scale	USA	www.columbiapwr.com
COPPE Subsea Technology Laboratory		Part scale	Brazil	www.lts.coppe.ufrj.br
DexaWave	DexaWave	Small scale	Denmark	www.dexawave.com
Eco Wave Power	Wave Clapper, Power Wing	Part scale	Israel	www.ecowavepower.com
Floating Power Plant	P37, P80	Part scale	Denmark	www.floatingpowerplant.com
Fred Olsen Ltd	Bolt Lifesaver	Full scale	Norway	www.fredolsen-renewables.com
Intentium[c]	iowec, iswec	Full scale	Norway	www.intentium.com
Langlee Wave Power	Robusto	Full scale	Norway	www.langlee.no
LEANCON Wave Energy		Small scale	Denmark	www.leancon.com
Neptune Wave Power[c]	Model 3.1	Part scale	USA	www.neptunewavepower.com
Ocean Energy Ltd	OE Buoy	Part scale	Ireland	www.oceanenergy.ie
Ocean Harvesting Technologies	OHT	Full scale	Sweden	www.oceanharvesting.com
Ocean Power Technologies	PowerBuoy	Full scale	USA	www.oceanpowertechnologies.com
Oceantec	Oceantec WEC	Small scale	Spain	www.oceantecenergy.com
Offshore Wave Energy	OWEL WEC	Small scale	UK	www.owel.co.uk
Oscilla Power	Triton	Small scale	USA	www.oscillapower.com
Perpetuwave	Wave Harvester	Part scale	Australia	www.perpetuwavepower.com
RESEN Waves	LOPF Buoy	Small scale	Denmark	www.resenwaves.com
Resolute Marine Energy	SurgeWEC	Full scale	USA	www.resolutemarine.com
SDE Energy[d]	Sea Wave Power Plants	Full scale	Israel	www.sdeglobal.com
Seabased	Seabased	Full scale	Sweden	www.seabased.com
Seatricity	Oceanus	Full scale	UK	www.seatricity.net
Spindrift Energy	Spindrift	Small scale	USA	www.spindriftenergy.com
Straum	OWC Power	Full scale	Norway	www.straumgroup.com
Trident Energy Ltd	PowerPod	Full scale	UK	www.tridentenergy.co.uk
Wave Dragon	Wave Dragon	Part scale	Denmark	www.wavedragon.net
WavEC	Pico Plant OWC	Full scale	Portugal	www.pico-owc.net
Wave Rider Energy	Wave Rider platform	Part scale	Australia	www.waveriderenergy.com.au
Wave Star Energy	Wave Star	Part scale	Denmark	www.wavestarenergy.com
Wedge Global		Part scale	Spain	www.wedgeglobal.com

Company name	Model family	Testing	Country	Website
Wello	Penguin	Full scale	Finland	www.wello.fi
Weptos	WEPTOS WEC	Part scale	Denmark	www.weptos.com
Werpo	SDE WECs	Full scale	USA	www.werpo.us

[a] went into administration in 2015; [b] last news from 2012, current status unclear; [c] last news from 2013, current status unclear; d acquired by Werpo

Appendix B.2 Projects

List of ongoing leased EU wave energy projects identified by JRC

Project name	Location and country	Capacity (MW)	Companies and devices	Status	Comment
Costa Head	Pentland Firth, Orkney Islands, United Kingdom	200 MW	SSE & Alstom	In planning	Status unclear
Marwick Head	Pentland Firth, Orkney Islands, United Kingdom	50 MW	ScottishPower Renewables	In planning	Scoping report ready
Brittany	La Bretagne, France	1.5 MW	Fortum & DCNS WaveRoller devices	In planning	Development agreement signed
Gibraltar	Gibraltar, United Kingdom	0.5 MW	Eco Wave Power	In construction	PPA signed, construction started in 2015
Sotenäs	Västra Götaland, Sweden	10 MW	Seabased & Fortum	In construction	Completion expected in 2016
Swell	Peniche, Portugal	5.6 MW	16 x 0.35 kW WaveRoller devices	In planning	Entry into operation expected in 2020
Westwave	Killard, Ireland	5 MW	ESB, Device to be selected	In planning	Construction expected in 2016, entry into operation expected in 2018
CEFOW	Wave Hub, Cornwall, UK	3 MW	Fortum Wello Penguin	In planning	Project awarded funding in 2015
Limpet	Island of Islay, Scotland, United Kingdom	0.5 MW	Voith Hydro Wavegen	Commissioned	Current status unclear
Mutriku	Masque Country, Spain	0.3 MW	Ente Vasco de la Energia & Voith Hydro Wavegen	Commissioned	Running as foreseen
Pico	Azores, Portugal	0.4 MW	WavEC	Commissioned	Plant has deteriorated, unclear if still producing electricity
WaveStar 1:2	Hanstholm, Denmark	0.6 MW	Wave Star A/S	Commissioned	Currently under rebuilt
Wello	EMEC, Orkney Islands, United Kingdom	0.5 MW	Wallo Oy Penguin	Commissioned	First deployed in 2012 and after upgrades performed, returned in 2013
Peniche	Peniche, Portugal	0.3 MW	AW Energy WaveRoller	In construction	Installation of first device scheduled for 2015

Sources: [JRC 2014, Eco Wave Power 2015, Fortum 2015, BNEF 2015d]; own analysis

Appendix B.3 Techno-economic data

2015 Techno-economic data for wave energy

Parameter	Unit	2010	2020	2030	2040	2050
Net electrical power	MWe	1-3	3-10	10	40	75
Max. capacity factor	%	34	41	43	43	46
Avg. capacity factor	%	25	28	31	34	0
Technical lifetime	Years	20	20	20	20	20
CAPEX reference	EUR/kWe	10500	6636	5267	2650	2300
CAPEX low	EUR/kWe	7680	4582	3620	2624	2050
CAPEX high	EUR/kWe	14000	8834	7526	7082	2560
CAPEX learning rate	%	12	12	12	12	12
FOM	% of CAPEX	4.0	4.3	4.2	5.0	5.5
FOM learning rate	%	1-3	3-10	10	40	75

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