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Technology development report

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FOREWORD

The Low Carbon energy Observatory (LCEO) is an internal European Commission Administrative Arrangement being executed by the Joint Research Centre for Directorate General Research and Innovation. It aims to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

Which technologies are covered?

- Wind energy
- Photovoltaics
- Solar thermal electricity
- Solar thermal heating and cooling
- Ocean energy
- Geothermal energy
- Hydropower
- Heat and power from biomass
- Carbon capture, utilisation and storage
- Sustainable advanced biofuels
- Battery storage
- Advanced alternative fuels

How is the analysis done?

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

What are the main outputs?

The project produces the following report series:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Future and Emerging Technology Reports (as well as the FET Database).

How to access the reports

Commission staff can access all the internal LCEO reports on the Connected LCEO page. Public reports are available from the Publications Office, the EU Science Hub and the SETIS website.

1 INTRODUCTION

The purpose of this report is to provide an assessment of the state of the art of ocean energy technology, to identify their development need and barriers and to define areas for further R&D in order to meet announced deployment targets and EU policy goals.

The analysis focuses primarily on tidal and wave energy technology, considering their potential to provide a significant contribution to the European energy mix in the coming years.

In order to undertake the different tasks set out for this report, different approaches have been employed, based primarily on in-depth literature reviews, expert judgements, existing KPIs identified by the sector, employment of technology specific database, collection of techno-economic information and analysis of the information collected to provide an unbiased assessment of the ocean energy sector.

1.1 Literature review and analysis

This report is an update of the LCEO Technology Development Report Ocean Energy 2018 developed by the JRC and focuses on the key progress achieved since the last report.

Chapter 2 provides an in-depth literature review to assess the state of the art of the ocean energy sector. This review is rooted in research and policy support activities undertaken by the JRC on Ocean Energy, such as the 2014 JRC Ocean Energy Status Report [1], the 2016 JRC Ocean Energy Status report [2] and complemented by high level independent reports [3]–[6]. This literature review is complemented by an assessment of ongoing developments in the sector, and where possible validated by the data contained in the JRC Ocean Energy Database JRC [7], [8]. Information has been updated with a review of literature as shown in section 2

From the analysis of the sector's state of the art, sub-technologies were categorised and prioritised, based on their technological advancement (TRL and MRL) and their potential to provide a significant contribution in the short-term period. The definition of TRL employed for the analysis is the one provided by the European Commission Horizon 2020 framework. This analysis was complemented by extended TRL definition provided by the European Commission guidelines in 2017 [9]; which offer a more details assessment of checkmarks for each TRL.

Technology gaps have been identified during the first two steps of this analysis, and coupled with techno-economic data to analyse particular areas (components and sub-components) of the technology that could provide a significant cost-reduction to ocean energy technologies and therefore should become areas for focussed research in the upcoming calls.

1.2 Data sources

The main sources of data for the work are the Cordis web site, the internal Commission Compass tool, the JRC Ocean Energy Database, IEA-OES studies. Techno-economic information was gathered according to the ETRI [10] methodology, and complemented with updated data [11] and information from H2020 project deliverables.

Table 1 presents the data source employed for the 2018 and 2020 analysis.

Table 1 Data sources for the analysis.

Data sources	2020 Update	SOA*	DT**	TE+	BAR++	Trends
Most relevant EU-funded projects (H2020, NER300, ERA-NET)	✓	✓	✓	✓	✓	✓
Compass database	✓	✓	✓		✓	
SETIS (reports from IWGs and Country Members)	✓	✓	✓	✓		✓
EU Member State or regionally co-funded projects (provided to OES)		✓	✓	✓		✓
National projects from major non-EU countries (provided to OES)		✓	✓	✓		✓

* State of the Art, **Development trends,+, Techno-economic projections, ++Technology Barriers

2 TECHNOLOGY STATE OF THE ART

2.1 Introduction

Energy present in oceans and seas can occur in many different forms including waves, tidal range, tidal currents, ocean currents, temperature differences and salinity gradients [12]–[14].

All forms of ocean energy can be used to generate electricity, Salinity gradient and OTEC technologies will be able to produce base-load electricity. Other forms of ocean energy show variable generation, with different predictability [12].

In the EU, the highest resource potential for ocean energy exists along the Atlantic coast, with further localised exploitable potential in the Baltic and Mediterranean seas and in overseas regions (e.g. Reunion, Curacao). The theoretical potential of wave energy in Europe is about 2800 TWh annually, and the potential for tidal current was estimated to be about 50 TWh per year [12], [15]. OTEC offers potential only for the EU overseas islands since its deployment is basically only possible in tropical seas [13].

Given the resources available in the EU, and the advancement of the technologies, it is expected that in the short-to-medium term (up to 2030), ocean energy development in the EU will be largely dependent on the deployment of tidal and wave energy converters. The deployment of OTEC in continental waters is limited, whilst it is not clear how salinity gradient technologies could develop both in terms of technology and market.

Up to 2020, the development of ocean energy in the EU has been linked by the commitment of eight EU Member States that included ocean energy in their 2009 National Renewable Energy Action Plans (NREAP). The target set for 2020 was to reach a total combined tidal and wave energy capacity of 2250 MW. This target has been largely missed, with ocean energy deployments taking place at a slower pace than expected, with only 12 MW of operative tidal energy capacity and 5 MW of wave in 2018. Additionally, it shall be noted that part of the current installed capacity is deployed for demonstration projects, and may be removed once projects end.

In 2019 Member States shared with the European Commission their draft National Energy and Climate Plans (NECPs). In contrast to the 2009 NREAPs, ambitions for the development of ocean energy have been significantly curbed, with only France, Ireland, Portugal and Spain providing provisional figures for ocean energy deployment, which would range between 150 and 450 MW by 2030. At the time of writing, the final version of the NECPs provided by Spain and Portugal hint at respectively 50 MW and 70 MW of operational ocean energy capacity by 2030. These figures indicate that the MSs do not see the development of ocean energy as a utility electricity market technology in this timeframe up to 2030.

More attention to ocean energy is provided in the section dedicated to research, innovation and competitiveness of the NECPs. MSs link the development of ocean energy to the SET Plan, however this link is not provided by all MSs participating in the Ocean Energy Implementation Working Group. Furthermore, no financial commitments towards R&I activities supporting the development of ocean energy technologies is mentioned. The SET Plan Ocean Energy Implementation Plan [16] foresaw circa EUR 400 million of national funds up to 2030 necessary to sustain the 11 actions for the development and deployment of ocean energy, based on the cost-targets outlined in the SET Plan Declaration of intent [17].

Over the past few years one of the critical aspects for the development of ocean energy has been the identification of market pull mechanisms that would encourage the deployment of first-of-a-kind demonstrator farms. The lack of clear national support for ocean energy that emerges from the draft NECPs may undermine further the development of the sector, and reduce the opportunities for Europe to exploits its current technological leadership.

With continued support, JRC-EU-TIMES[1] simulations of the EU energy system indicate that a total capacity ranging from 14.8 GW to 46.6 GW could be expected in the EU27 by 2050, under the assumption of that wave and tidal energy devices meet the cost reduction of the SET plan. Tidal energy could be cost-competitive by 2030 and reach 15.7 GW by 2050. Wave energy could reach 30 GW by 2050, only under the assumption of the SET Plan scenario for cost reduction.

The development and commercial uptake of ocean energy in Europe relies on the ability of developers to identify innovative solutions that could stimulate significant cost-reductions and on R&D activities addressing the key-issue currently undermining technology development. However this quest requires the establishment of support mechanisms that are currently lacking.

2.2 State of the art

The state of the art of ocean energy technologies varies according to the conversion type (wave, tidal, OTEC and salinity gradient) and the different technologies under development.

A wide array of ocean energy technologies has been developed, some with significant differences in terms of principle of operation. For example, according to EMEC, the European Marine Energy Centre, there are 8 different classes of wave energy converters and 7 different classes of tidal energy converters [18], [19].

Similarly, salinity gradient comprises three different conversion technologies: Pressurised Reverse Osmosis (PRO), Reverse Electro-Dialysis (RED) and Hydrocratic Ocean Energy.

In order to provide a relevant overview of the progress made by the ocean energy technologies over the past two years, the state of the art review of this report will be prioritised to reflect the key advances in the sector.

Table 2 presents an overview of the technologies that will be addressed in the Ocean Energy Technology Development Report, because these are considered the most promising device types at the moment.

Table 2 Sub-technologies and priorities

Sub-technology	Priority
Tidal energy	
Horizontal axis turbines, tidal kites	High
Floating technologies	High
Vertical axis turbine	Medium
Wave energy	
Point absorber	High
Oscillating water column	High
Surge converters	High
Others WECs	Low
Ocean thermal energy conversion	Low
Salinity gradient	Low

[1] No support mechanisms are considered within the model.

Over the past two years, technology progression of wave and tidal energy technologies has included innovative development of key components such as the Power Take-off (PTO) and moorings (***Table 3***).

Table 3 Components priority

Area	Priority
WP2	
Power take-off (PTO) optimisation and improvement	High
Moorings and foundations	High
Array dynamics, interactions and optimisation	High
Environmental impacts and monitoring	Medium

Further information on key ocean energy technologies, innovations needs and challenges has been developed as part of the LCEO Future Emerging Technology Work Package [20], which is complimentary to the work presented in this report. It is therefore recommended to consult the report "Workshop on Identification of Future Emerging Technologies in the Ocean Energy Sector" for detailed analysis of innovation possibilities for ocean energy technologies and components.

2.3 Overview

The ocean energy sector is a promising sector, which has significant potential to contribute to the decarbonisation of the EU energy system as well as establishing a new EU-lead industry. The challenges for ocean energy technologies, as identified by the SI Ocean project [21], include providing reliability, survivability and viability.

Over the past three years (2016 to 2019), considerable progress has been achieved in proving different kinds of tidal energy concepts. Turbines developed by Nova Innovation, Atlantis, Andritz Hydro-Hammerfest, Minesto, Orbital Marine[2], Schottel, Sabella, Sustainable Marine Energy, Tocardo have been operational in demonstration and pre-commercial projects in Europe and Canada. The reliability of the devices, and their ability to provide stable input to the grid has been proven beyond initial expectations, with devices achieving higher capacity factors that initially expected[22].

These are the first examples of the technology reaching higher TRLs, and should be considered as demonstration projects, since in many cases the technologies are still being tested for prolonged times and operational strategies are being implemented and improved before commercial roll-out can take place. These demonstration projects have often been made possible by the availability of market access mechanisms, often as Feed-in-Tariffs. The current lack of similar mechanisms in Europe is pushing the deployment of demonstration projects to other countries, such as Canada, where market access instruments are available.

Wave energy technologies are lagging behind tidal energy in terms of performance, especially in terms of electricity generation. The Mutriku power plant, operational since 2011 in Spain, has been most consistent wave energy converter in terms of electricity generation. In recent years, especially from 2017 onwards, a number of single-device demonstrations have been deployed by different technology developers including the Wello Penguin at EMEC[3], the Sea-based projects, Oceantec Marmok, Corpower C3, Wedge W1, Demowave, SinnPower, Nemos and Ecowavepower, In 2019 new devices were deployed including the WaveRoller in Portugal

[2] Formerly Scotrenewables

[3] This device has sunk and is no longer operational.

[23], the OPT Powerbuoy [24] and the ENI/Wave for Energy ISWEC in the Adriatic Sea[25], the upgraded Fred Olsen LifeSaver[26]. The OceanEnergy Buoy was successfully towed to Hawaii and is expected to be deployed in the early months of 2020 [27].

In 2019 the sector was also affected by a number of setbacks, such as the Wello WEC1[28] device sinking and Tocardo[4] turbines filing for bankruptcy, to be later bought by QED Naval[29]. Nevertheless in terms of technology development the ocean energy sector is fertile, and compared to two years ago with a higher than ever number of ocean energy technologies deployed. Furthermore, compared to a few years ago, new industrial players have entered the market such as Enel Green Power, ENI, Saipem and SBM Offshore, all of them bringing experience form the oil and gas industry.

Tidal and wave energy technologies are not yet commercially viable, especially in terms of utility markets. .

The SET Plan declaration of intent for ocean energy [17] has set ambitious targets for wave and tidal energy technologies (***Table 4***). Tidal technologies are expected to reach a levelised cost of energy (LCOE) of 15 cEUR/kWh by 2025 and of 10 cEUR/kWh by 2030. Wave energy technologies are expected to reach the same targets with a five-year delay, 15 cEUR/kWh in 2030, and 10 cEUR/kWh by 2035. In order to meet these targets, technology costs need to be reduced by about 75% from 2016 values [30].

Table 4 SET Plan LCoE targets for wave and tidal energy technologies. Source: (European Commission 2016)

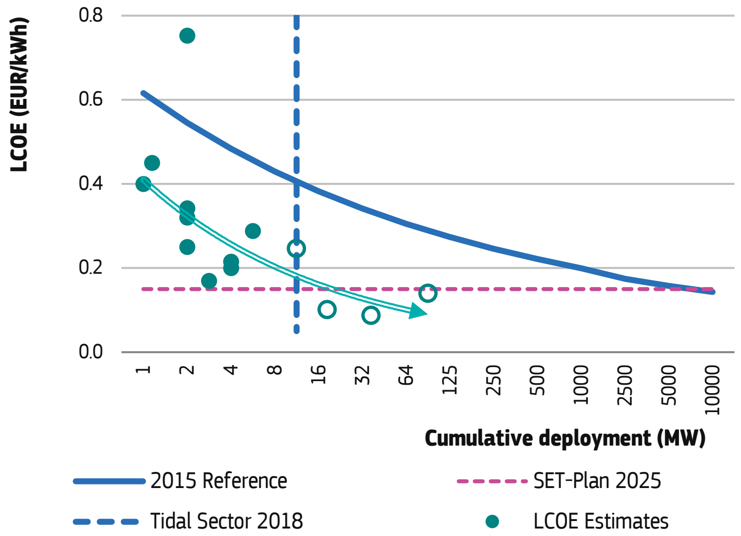
Technology	Year	Target
Tidal energy	2025	15 cEUR/kWh
Tidal energy	2030	10 cEUR/kWh
Wave energy	2025	20 cEUR/kWh
Wave energy	2030	15 cEUR/kWh
Wave energy	2035	10 cEUR/kWh

Technology improvements and steep-cost reductions are still required despite the significant cost-reductions achieved over the past few years, thanks in part to the contribution of Horizon 2020 projects.

Demonstration projects such as FloTEC, Oceang_2G, TIPA and Meygen are showing that cost-reduction is possible. Data from the projects indicate that the LCOE of tidal energy technology ranges between 0.34 and 0.38 EUR/kWh (Figure 1), down from 0.60 EUR/kWh in 2015. This corresponds to reduction of more than 40% in three years. The current value is below the 2015 reference cost-reduction curve, which indicated that LCOE would reach 0.40 EUR/kWh with the current deployed capacity.

[4] Tocardo went into bankruptcy in 2019, however their projects in the Netherlands are still operational and the company was acquired by QED Naval and HydroWing JV https://marineenergy.biz/2020/01/06/qed-naval-and-hydrowing-jv-acquire-tocardo/

Figure 1 Cost-reduction curves for tidal energy and LCOE estimates from ongoing projects. Solid dots represent data from ongoing demo projects, while hollow dots indicate developers' estimates on the basis of technology improvements and increased deployment.



These high cost reductions are related to the increasing reliability of the devices deployed in first-of-a-kind demonstration projects. These technologies are still in pre-commercial phase and operational strategies being implemented, tested and optimised. The ongoing demonstration projects show that it is possible to generate electricity continuously, and that capacity factors of 37% or higher are achievable. Know-how acquired through the deployment of multiple devices is also reducing the capital expenditure through more efficient installation techniques. Optimisation of operation strategies is reducing O&M costs. For wave energy technologies, continued support in Horizon 2020 and Horizon Europe can help generate similar cost-reductions.

Overall, the status of ocean energy development can be seen as a positive, in particular in terms of cost-reduction. Cost-reduction is taking place, and Capex of both wave and tidal energy technologies are lower than expected at this stage of development.

JRC-EU-TIMES scenarios indicate that the total ocean energy capacity that could expected by for 2050 is between 28-46 GW provided that the current rate of development is maintained and that the sector receives sufficient support.

Wave energy technologies, despite a number of demonstration units at TRL7, still have to achieve significant operational hours coupled with a reasonable level of electricity generation. The devices currently deployed are showing increased survivability, operating throughout the year and surviving storms; however the total electricity produced is small, indicating that most devices are still at pre-commercial phase. The proposed targets for LCOE, availability and capacity factor appear to require further improvement in the conversion technologies themselves in order to be met.

As reported in the 2018 version of the Technology Development Report - Ocean Energy, significant technology progression was achieved at low TRLs. In particular, thanks to the contribution of Horizon 2020, ocean energy developers are optimising the design of their devices, in particular in terms of critical components such as power take off and moorings. Through these technological advances, developers have identified ways to reduce costs, in particular:

- Moorings solutions adopted in many floating tidal and wave energy devices have been optimised and cost-effective solutions identified.
- PTO is the focus of many projects. Significant improvements in the efficiency of PTOs of 25% or more are highlighted in many projects.

From a manufacturing perspective, the Manufacturing Readiness Level (MRL) of ocean energy technology ranges between 5-6 [31]. In the prevision edition of this report we considered OpenHydro (Naval Energies) at MRL7; however the company has since ceased operation in the sector. As mentioned earlier in the report, the most significant change to the industrial perspective of the ocean energy sector is the entry in the market, or the reinforcement of their presence, of companies such as ENEL Green Power, ENI, Saipem and SBM Offshore.

Enel Green has signed a memorandum of understanding (MoU) with The European Marine Energy Centre (EMEC)[32], to drive forward ocean energy technology validation and demonstration projects. ENI has launched the MaREnergy Project in collaboration with Ocean Power Technologies[33] to demonstrate the suitability of wave energy technologies for O&G application. ENI is also working on the ISWEC device developed by Wave for Energy, in a project in partnership with Fincantieri (Maritime group), Terna (Transmission network in Italy) and Cassa Depositi Prestiti (Italian Investment Bank) [34]. SBM Offshore have been developing a wave energy technologies, which is expected to be trialled in Monaco in 2021[35]. The company is building on its Oil & Gas experience to deliver economically viable wave energy technologies.

2.4 Tidal energy

The tidal sector has reached a critical phase of development, with a clear focus on deploying demonstration farms and development of systems and strategies for the optimisation of operations and power output.

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.[5] This include both bottom-fixed and floating concepts, with power rating ranging between 100 kW to 2 MW per device. Other technologies that have made considerable progress are enclosed tips turbines and tidal kite devices. Ongoing projects in France, Japan and Canada are expected to prove the commercial viability of ducted turbines developed by Openhydro/Naval Energies. Tidal kite technology has reached TRL 6, with a 10 MW demonstration plant being prepared. Compared to two years ago, a number of companies are now working on vertical axis turbines, which offer the advantage of being developed also in river streams opening a new market segment for the tidal energy sector.

Horizontal axis turbine represents the most advanced category of tidal energy converters. Many of the designs proposed for horizontal axis turbines have reached TRL8, with most demonstration projects located in the UK, France, the Netherlands and Canada.

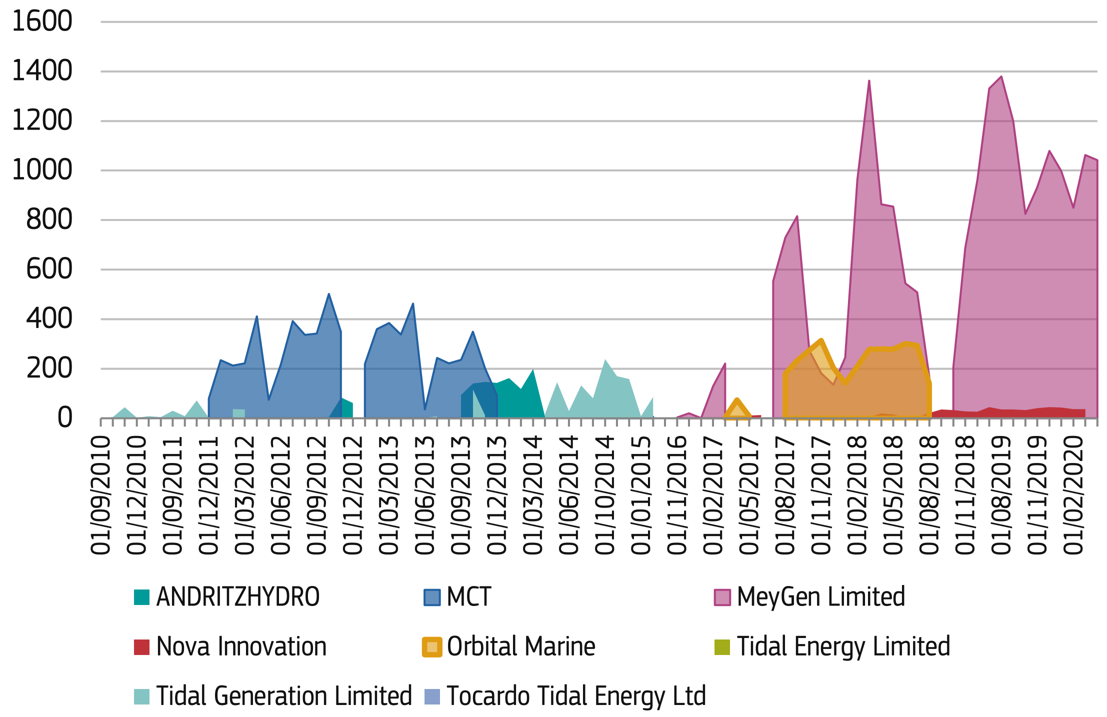
In the UK which is one of the key players in ocean energy development, over 43 000 MWh of electricity generated by ocean energy were fed to the grid since 2008, mostly generated by horizontal-axis tidal devices [36].

[5] 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

Between January and April 2020, 4 GWh have been fed to the grid, qhile the total for 2019 was of 14 GWh. They Meygen project, since its start has delivered almost 22 GWh[6], as shown in *Figure 2*.

The successful and continuous generation of tidal farms such as the Shetland's arrays and the Meygen arrays are proof the reliability that tidal energy converters have reached. Further demo projects could pave the way for significant cost-reductions.

Figure 2 Tidal energy generation in the UK since 2010. Source: [36].



Currently, a number of major tidal deployment projects are ongoing that are mainly at the stage of pre-commercial array demonstration (*Table 6*). Most of them employ HAT devices, demonstrating the higher level of design consensus achieved in tidal energy, yet a number of alternative solutions employing ducted turbines, tidal kites and vertical axis turbines are currently being developed.

Another class of device making significant step forwards towards commercialisation is the tidal kite. A 0.5 MW device was deployed in Wales in 2019 as part of the 10 MW Holyhead Deep project[37]; another 0.1 MW device is operational in the Far Oer Islands[38]. The technology, developed by Minesto, is being tested at TRL7/8. A similar project developed by Sea-Qurrent in the Netherlands is still rated at TRL4-5 [39].

[6] It shall be noted that the reported generation from Meygen and Ocean Energy Europe is of 28 GWh (https://www.rechargenews.com/circuit/recovery-packages-must-make-clean-energy-a-cornerstone-of-the-new-global-economy/2-1-805945). The JRC employs the data available from Ofgem, based on the Renewable Energy Generation certificates, further information can be found at https://www.renewablesandchp.ofgem.gov.uk/Public/ReportManager.aspx?ReportVisibility=1&ReportCategory=0

Vertical axis concepts have been developed by Hydroquest in France, GKinetic and DesignPro in Ireland. Hydroquest deployed a 1 MW device in the second half of 2018 in France, and the device is currently being manufactured in Cherbourg[40]. Verticle Axis turbines are operational in China, installed in a multi-structure. The possibility for employing vertical axis turbines in river streams has opened up the market for these concepts. In terms of technology development, vertical axis turbines are behind HAT devices, with TRL ranging between 4-7.

Table 5 presents an overview of the TRL of tidal energy devices per class.

Table 5 TRL levels of tidal energy devices

Device class	Highest TRL achieved	Highest TRL attempted
Horizontal axis turbine	8	9
Vertical axis turbine	5	8
Oscillating hydrofoil	5	5
Enclosed tips	7	9 (attempted but not validated)
Tidal kite	6	7
Archimedes screw	-	-
Other	-	5

Table 6 Major tidal current pre-commercial and first-of-a-kind demonstration projects. Source project websites and NER300 update reports (confidential).

Project	Country	Location	Capacity	Class	Turbines	Status
MeyGen Phase 1A	UK	Pentland Firth	6 MW	HAT	4 x 1.5 MW (3 Andritz HS1000, 1x Atlantis)	Operational since 2016.
~~Cape Sharp~~	~~Canada~~	~~Bay of Fundy~~	~~4 MW~~	~~Enclosed tips~~	~~2 x Openhydro (2 MW)~~	~~Devices deployed July 2018~~ Device stopped operating following deployment. Company dismissed
Orbital Marine (Scotrenewabless)	UK	EMEC	2 MW	HAT	SR1-2000	Deployed in 2016. X MWh Obrital Marine is now building the new O2 device which is expected to be deployed in 2020.
Sabella D10 Demonstrator	FR	Ushant	2 MW	HAT	D10	Operational (currently under maintenance).
Shetland Array	UK	Shetland	300 kW	HAT	3 x Nova 100 kW tidal turbine	Operational December 2015. Extension to 600 kW in 2020 (ENFAIT project). Company benefitting from technology progression achieved in H2020 Project TiPA.
Plat-I	UK / Canada	Canada	280 kW	HAT	4 Schottel Instream turbine (62 kW each)	Deployed in Canada following UK deployment. Operational since 2018
Eastern Scheldt	NL	Eastern Scheldt	1.25 MW	HAT	5 Torcardo turbines (250 kW each)	Deployed on storm structure in 2015.

Project	Country	Location	Capacity	Class	Turbines	Status
Afsluitdijk	NL	Afsluitdijk	300 kW	HAT	3 Tocardo T1 turbines	Deployed on storm structure in 2015
Texel	NL	Texel	250 kW	HAT	1 Tocardo T2 turbine	Deployed on floating structure in 2016
~~InToTidal~~	~~UK~~	~~EMEC~~	~~1.2 MW~~	~~HAT~~	~~4 Tocardo T2 turbines~~	Project suspended
Ocean2G	UK	EMEC	2 MW	HAT	1 Magallanes contrarotating turbine	Deployed September 2017. Testing ended in May 2019
Holyhead	UK	Holyhead	500 kW	Tidal Kite	1 Minesto Deepgreen	Deployment TRL7
Hydrouqest	FR	N/A	1 MW	VAT	1 Hydroquest	Deployed in July 2019, delivering electricity to the grid since September 2019.
~~Normandie Hydro~~	~~FR~~	~~Raz Blanchard~~	~~14 MW~~	~~Enclosed tips~~	~~7 x Openhydro (2 MW)~~	The project is suspended following Naval Energies decision to stop OpenHydro. SIMEC Atlantis has acquired the rights to develop the project and has formed a partnership with the Normadie Regional Government.
Meygen 1B	UK	Pentland Firth	8 MW	HAT	4 SIMEC Atlantis devices (NER300)	Supported through NER300. Awaiting final investment decision. SIMEC Atlantis developed new turbine.
Holyhead deep	UK	Holyhead	10 MW	Tidal Kite	10 Minesto deep green	Project under development
Sound of Islay	UK	Islay	10 MW	HAT	4 x: Andritz HS1000 (NER300)	Supported through NER300. Awaiting final investment decision.
QED Naval Strangford lock	UK	Strangford Locak	0.150 MW	HAT	3 turbines mounted on SubHub platform	SuHub platform deployed in Strangford lock for testing
Petit Passage	CA	Petit Passage Marine Renewable Energy Area	1.5 MW	HAT	15 Nova 100 Turbines	Array to be developed in 3 phases of 0.5 MW each

2.4.1 Alternative applications

The development of tidal energy technology is taking place both through the development of commercial scale applications (Atlantis, AndritzHydro Hammerfest, Orbital Marine) as well as through the development of smaller, localised projects such as Sabella in France, Nova Innovation in Scotland and Sustainable Marine Energies in the UK and now in Canada.

The predictability of tidal energy coupled with the possibility of ensuring almost 20 hours of generation per day, has led to exploratory projects where electricity that cannot be used by the grid is directed towards the production of hydrogen. The ITEG[7] project, supported by the European Union's Interreg project combines the Orbital Marine O2 2 MW tidal turbine with a custom built hydrogen electrolyser (500 kW, developed by AREVA) and an onshore energy management system to be deployed at EMEC [41]. The project aims to overcome the high costs that is associated with ocean energy demonstrator projects through the integration of hydrogen production solutions. Similarly Sabella and Akuo Energy are developing an integrated renewable energy project intended to provide up to 80% of the island of Ushant power with renewables. The Phares[42] project comprises 2 Sabella tidal turbines rate 500 kW, one 0.9 MW wind turbine, a 500 kW photovoltaic installation and an energy storage systems. Both projects aim to demonstrate the viability of tidal energy for decarbonisation and its potential to provide grid stability, especially in Islands ecosystems. Nova Innovation started the TESS project [43](Tidal Energy Storage System). Their 300 kW tidal array deployed in the Shetland is coupled with a Tesla battery to become effectively the world's first grid-connected 'baseload' tidal power station. Previously, excess electricity from the Nova Innovation turbines was used for the production of ice for the fishing industry.

2.5 Wave energy

Wave energy shows greater design variance compared to tidal energy technologies. In fact, while the horizontal axis turbine is the dominating design for tidal energy converters, there's currently no dominant design in wave energy. The most common types of devices are point absorbers, oscillating wave surge converters (OWSC) and oscillating water column (OWC). In addition, six other distinct device classes can be differentiated, all with specific design and characteristics [44].

Even within a device class there are significant differences based on how devices are operated and on the power conversion system (PTO) employed. For example, some point absorber converters employ a linear direct drive generator (Wedge, Seabased), others use mechanical systems (Corpower, Waves4Power), and some pneumatic systems such, as the Marmok device developed by OceanTEC. Similarly, some OWSC have been designed to employ hydraulic PTOs while others employ mechanical systems.

The lack of design convergence has already been highlighted as one of the drawbacks of wave energy development so far.

Since 2016, the number of wave energy devices deployed and operational has increased significantly. In 2019 the trend was continued with a number of key deployments taking place. Italian O&G company ENI deployed one OPT PB3 Powerbuoy [33] and one ISWEC device as part of their ongoing project to identify valuable solutions for wave energy and apply them also to the decarbonisation of oil and gas rigs. Another OPT buoy was deployed in the North Sea by Premier Oil[45]. Similarly Nemos deployed their device in the North Sea close to Oostend, while AW Energy deployed the 350 kW WaveRoller in Portugal. Ocean Energy (IE) completed the manufacturing of the OceanEnergy Buoy that is expected to be deployed in Hawaii[27]. The Seabased array in Sweden [46] is still in operation and so is the Marmok at Bimep, the Wedge device at Plocan, SinnPower in Crete [47] and the ECO Wave Power projects[48] in Gibraltar and Israel.

[7] https://www.nweurope.eu/projects/project-search/iteg-integrating-tidal-energy-into-the-european-grid/

The Mutriku Wave Power plant (300 kW) in Spain is the most consistent wave energy generator operating since 2011. The OPT Powerbuoy (3 kW) has generated over 2 MWh since being deployed as part of the MaREenergy project launched by ENI[33].

Devices currently deployed are showing the capability to survive wave loadings, however reliability is still to be fully proven. Information regarding the electricity generation from wave energy deployment is limited. Given the lack of open-access electricity generation data, which would help us validate the progress of wave energy technology, we consider most of the current wave energy deployment to be undergoing testing at TRL8, with only the bottom fixed OWC class of device having demonstrated TRL9. It shall be noted that the deployment of Point Absorber to support the decarbonisation of O&G rigs may yield significant technology progression, however these deployments are taking place at a higher costs than those needed for wave energy to enter the utility market.

Table 7 presents an overview of the TRL reached and attempted by wave energy converters. Classes highlighted in red indicate no significant progress or R&D activity in the past two years.

Table 7 TRL levels of wave energy devices

Device class	Highest TRL achieved	Highest TRL attempted
Attenuator	7	7
Point Absorber	8	8*
OWSC	7	7*
OWC	9	9
Overtopping	5	-
Submerged pressure differential	-	6
Rotating Mass	7	7*
Other	3	5
* indicates expected deployment at higher TRL.		

To date the lack of a clear-cut validation of wave energy converters at higher TRL underlines the gap to commercialisation compared to tidal energy: limited electricity generated suggests that designs still need to be optimised and that reliability of the Power Take Offs (PTO) still needs to be validated. As a matter of fact since 2016, R&D support has been granted in Scotland, at EU level and in the US in projects aimed at developing low TRL technologies as well as innovative PTO systems. In the Wave Energy Scotland programme dedicated to PTO 5 out of 17 projects have completed the stage-gate 3 and are likely to enter stage 4 in 2020.

Whilst many wave energy converters are still not ready yet for commercialisation, a number of developers are intensifying their activities in terms of identifying suitable business plans to close the gap to the market. This includes: Corpower, currently working towards a stage 4 deployment of their device; SBM Offshore, preparing for a scaled deployment in 2021; AW Energy, working towards the upgrade of the WaveRoller from 350 kW to 1 MW, Bombora is working ahead on the deployment of a 1.5 MW WEC in Wales[49]; Seabased, with signed contracts for the development of projects in the Caribbean (2x 20MW wave energy parks)[50] and in Ghana (100MW) and lastly EcoWavePower, with a signed PPA in Israel, the Netherlands and Portugal[51].

Some companies have endured difficulties, for example Wello Oy and Carnegie. Wello was expected to deploy a second Penguin WEC2 at EMEC as part of the CEFOW project, however the project was terminated after a series of delays. Wello, together with Saipem, has announced that they are working towards the deployment of the Penguin WCE2 at Bimep in the Basque Country[52]. Carnegie experienced financial difficulties that halted the progress of its CETO WEC [53].

A number of wave demonstration projects are ongoing, with a few devices expect to be installed in farm layout. (*Table 8*). Many of them will be deploying point absorbers.

Table 8 Wave energy demonstration projects. Strikethrough projects are no longer operational

Project	Country	Location	Capacity	Class	Devices	Status
Mutriku	ES	Bay of Biscay	300 kW	OWC	16 Voith turbines. 1 Turbine chamber used for testing new concept	Operational since of 2011. First WEC to surpass 1 GWh generation to the grid.
Sotenäs	SE	Västra Götaland	10 MW	Point absorber	Seabased	3 MW already deployed and operational since 2015.
Ghana	GH	Ada	14 MW	Point absorber	Seabased	First 6 converters (0.4 MW) assembled and grid connection installed since 2016.
~~Perth Project~~	~~AU~~	~~Perth~~	~~0.72~~	~~Point Abosber~~	~~3 x CETO 5 device~~	~~Operational, Sustained hours at sea, technology to be upgraded to CET6~~
Isle of Muck	UK	Isle of Muck	22 kW	Attenuator	Albatern	3 WaveNET unit installed
Marina di Pisa	IT	Pisa	25 kW	OWSC	H24 from 40Southenergy	New transmission currently being installed on device. Upgraded and grid connected in 2018.
Sinn Power Heraklion	EL	Heraklion	2 kW	Point Absorber	SinnPower	Deployed 2nd PA in 2018
Gibraltar	UK	Gibraltar	500 kW	Attenuator	WaveClapper	EcoWavePower looking to expand project to 1 MW
Fred Olsen	US	WETS Hawaii	60 kW	Point Absorber	FredOlsen Bolt Lifesaver	Second deployment (following 2016) to assess ability of device to power autonomously. 3 PTO installed and operating.

Project	Country	Location	Capacity	Class	Devices	Status
Runde	NO	Runde	100 kW	Point Absorber	WavEel	Retrieved in March 2018 due to mooring failures
Marmok	ES	Bimep	30 kW	OWC	Marmok A5	Deployed as part of Opera project. Currently installing new turbine developed by Kymaner
Wedge Global	ES	Canary Island	N/A	Point absorber	Wedge Global	Operational since 2014.
~~CEFOW EMEC~~	~~UK~~	~~EMEC~~	~~3 MW~~	~~Rotating mass~~	~~Penguin~~	~~1st Penguin deployed in 2017 as part of Cefow project~~. 2nd device to be deployed at Bimep following consortium with Saipem
~~C3 @ EMEC~~	~~UK~~	~~EMEC~~	~~N/A~~	~~Point Absorber~~	~~Corpower C3 ¼ scale~~	~~Device installed in benign waters for testing~~. Device retrieved. Preparation for stage 4.
Laminaria	UK	EMEC	N/A	Other	LamWEC	Expected deployment supported by Foresea
Hace	FR	Semrev	N/A	OWC	Hacewave	Deployed in la Rochelle in 2018.Supported by Foresea,
Nemos	BE	North Sea	200 kW	Point Absorber	NEMOS WEC	Deployed near Oostende
MPS Wales	UK	Prembokshire	N/A	Point Absorber	Marine Power Systems	Successful Lscaled- deployment. Company working towards full scale device to be deployed in 2022. Company also exploring wind-wave device.
StringRay	US	WETS - Hawaii	650 kW	Point Absorber	Columbia Power Technology	Company awarded funds from US DOE at the end of 2019 to design next generation WEC.
Life DemoWave	ES	Vigo	N/A	Point Absorber	DemoWave	Deployed in July 2018
OceanEnergy	US	WETS - Hawaii	500 kW	OWC	OceanEnergy Buoy	Manufacturing in US, deployment in US. Expected deployment 1st half 2020.
FOAK WaveRoller	PT	Peniche	350 kW	OSWC	AW Energy Wave Roller	Deployed in November 2019 (originally expected for 2nd half of 2018).
Jaffa Port	IS	Jaffa	100 kW	Attenuator	WaveClapper	EcoWavePower project under construction
Marina di Ravenna	IR	Ravenna	3 kW	PA	OPT PB3	Deployed in 2019 as part of MaREenergy project with ENI. 2 MWh generated
North Sea	UK	Huntington	3 kW	PA	OPT PB3	Deployed together with Premier Oil and Acteon Group.
Marina di Ravenna	IR	Ravenna	100 KW	RM	ISWEC	Deployed as part of MaREnergy / Energy Cradle project.
GEPS @SEMREV	FR	SEMREV	N.A	PA	Wavegem	Testing for 18 months
Cabo Verde	CV	Cabo Verde	N/A	OWSC	Resolute Marine Energy	Wave powered desalination, supported by
São Vicente wave farm	CV	Cabo Verde	42 kW	Point Absorber	21 WECS from Sinn Power	Expected delivery 2019
Swell	PT	Peniche	5.6 MW	OWSC	WaveRoller	Funded by NER 300 (EUR

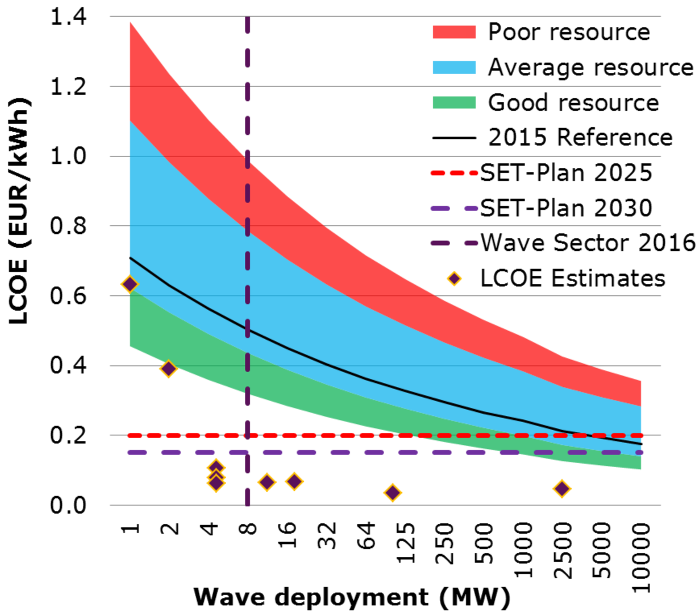
Project	Country	Location	Capacity	Class	Devices	Status
						9.1 million). Initially planned for 2018. Delayed.
Westwave	IE	Killard, Ireland	5 MW	t.b.d.	ESBI currently carrying out due-diligence for identification of suitable WECs	Project funder under NER 300 (EUR 34 million), planned for 2018 A number of developers are carrying out due-diligence to deliver this project including Wello and AW-Energy. Project still expected to be delivered as part of the Irish NECP.

2.5.1 Cost of energy

Compared to the 2018 version of the report, there is no significant update to this section. The cost of energy from wave energy projects is assumed to be in the same range as for 2018. As mentioned in the analysis of the technologies, no significant progress has been made in the generation of electricity from wave energy converters which does not allow for the validation of LCOE. Furthermore for the projects/technologies that are operating for off-grid operations (e.g. OPT) the LCOE is likely to be higher than utility prices, however offsetting either the cost of diesel generators or contributing to the reduction of carbon emissions from O&G rigs.

The cost of energy of wave energy technology provides a good indicator of the development and progression that is required for the technology to meet the SET Plan targets and become competitive in the EU energy system. In 2015, the LCOE of wave energy ranged between 0.47 EUR/kWh and 1.40 EUR/kWh, with a reference value of 0.72 EUR/kWh. In 2018, with addition of 8 MW of capacity, the LCOE is expect to have decreased to 0.56 EUR/kWh, as shown in *Figure 3*. One of the reasons wave energy lags behind tidal energy is also related to the technology being more expensive. Nevertheless, as some of the LCOE estimates in *Figure 3* indicate, several developers see cost of wave energy technology dropping below the 2025 SET Plan targets at a faster rate than expected. Their forecasts, will be de discussed in detail later, are based on unlocking manufacturing potential (Wello and Seabased) as well as improving the performance of their devices (Wello). These improvements could help make a stronger case for wave energy technologies; however, as mentioned earlier, wave energy converters need to show that they can generate electricity reliably to gain the trust of investor and manufacturers to unlock economies of scale cost-reduction.

Figure 3 LCOE predictions for wave arrays. Sources: [11], [54], updated; own analysis.



2.5.2 Other applications

Given wave energy's currently difficulty to compete with market-ready technologies, the sector is investigating the use of the technology for sectors other than the utility-scale electricity market. Possibilities include the desalination market, powering of remote areas (diesel displacement) and powering of offshore oil and gas platforms. The US DOE has undertaken a detailed study of such alternative uses [55].

An example is the Resolute Marine Energy OWSC device (50 kW) developed for desalination (with an ongoing project in Cape Verde), the Squid from Albatern used to power aquaculture farms and the Wedge1 device, which has been designed to operate in island conditions and replace diesel generators.

The deployments of the OPT Power Buoys in conjunction with ENI and Premier Oil highlight the possibilities that wave energy technology offers to provide clean power to stand-alone application such as oil rigs. The interest in developing wave energy technologies for oil and gas applications is reinforced by ENI interested in developing the ISWEC technology forward, by Saipem putting their expertise in offshore engineering to help the commercialisation of the Wello Penguin and by SBM offshore developing in-house a WEC.. The development of wave energy technologies in conjunction with O&G applications may be three-folds. Firstly, it will help reducing carbon emissions form O&G operations which are a key global contributors of greenhouse gases [56]; secondly it helps engaging O&G companies to invest in new energy technologies and act as a catalyst for knowledge-sharing; thirdly act as a bridge between the RD&D development of wave energy and the cost-reductions needed to enter the utility market.

From an economic perspective, evaluating the use of ocean energy converters for alternative uses, offers a development path that is less risky compared to the utility market. The SET Plan targets, for example, expects wave energy costs to be around 20 cEUR/kWh by 2025, whilst in some areas cost of electricity from diesel generators are above 35 cEUR/kWh. Nevertheless, even with favourable economic conditions, wave energy converters designed for alternative application are still required to show that they are value-for-money, or more specifically they would still be required to show that the technology could generate power reliably (or provide sufficient pressure to drive desalination membranes), and to survive storms. The risk for wave energy technology is still similar to the one of the utility market: that alternative technology (such as wind and solar PV) may prove that wind/solar-driven PV is more reliable and therefore preferable.

3 R&D OVERVIEW

A review of policy mechanisms supporting the development of ocean energy technologies is undertaken in order to understand the level of support received by the sector and to identify any gaps that may need to be addressed for the design of specific collaborative actions at European level.

The analysis takes into account EU funds made available through different R&D Framework programmes (FP6, FP7, Horizon 2020), national and regional programmes collected by the JRC and expected 2019 contributions for the period between 2007, the year in which the SET Plan started and 2019. Projects expected to begin 2019 such as NER300 are accounted in the analysis. It shall be noted that the main difference between the previous assessment and the current one is affected by the following factors:

- New ERDF and Interreg projects that have been awarded in 2019 contributing to further demonstration projects
- Variation in funds provided at National level and collected through IEA
- Termination of Horizon 2020 projects that have originally been awarded by the European Commission, but that could not proceed as originally expected.

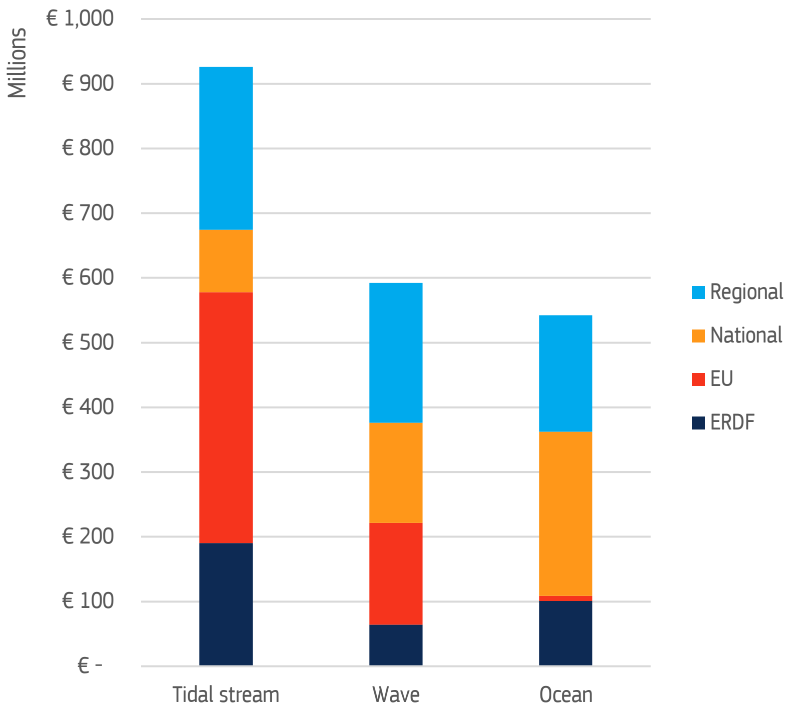
European, ERDF and National programmes have contributed to fund ocean energy projects for EUR 1.726 billion for a total worth of the projects equal to EUR 2.16 billion. It shall be noted however that the termination of a number of IA projects has a strong effect on the funds made available and used by the consortium. The total project costs leveraged by EU-awarded Horizon 2020 projects has fallen from EUR 328 million to EUR 108 million, with the EU contribution being reduced from EUR 163 to 90 million. This is a significant blow to the ambition of the sector, but also highlights the difficulties that project developers are having. A breakdown of the funds and project cost is provided in Table 9, whilst Figure 4 presents the breakdown of funds given to wave and tidal energy technologies

Table 9 Breakdown of funds for ocean energy through European, ERDF and national programmes 2017-2019. Source:JRC analysis

	Funding Contribution	Total Project Costs
ERDF	€253,190,108	€358,746 847
EU	€373,753,790	€631,532,515
Ocean-ERANET	€13,469,842	€18,629,654
National	€504,799,333	€504,799,333
Regional	€578,814,003	€648,114,003
Total	**€1,726,870,711**	**€2,161,822,352**

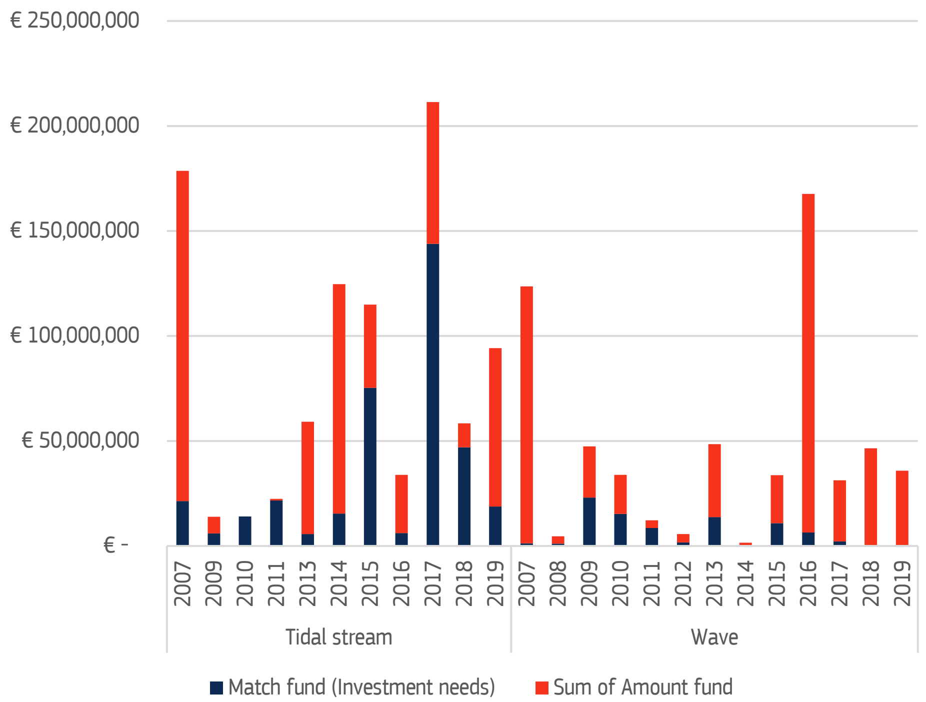
It emerges that EUR 592 million of funds have gone to wave energy R&D and EUR 925 million to tidal energy. About EUR 540 million were directed to other areas of research such as resource modelling, array modelling, and not to one specific technology. In contrast, in the period between 2008 and 2017, the United States Department of Energy has provided USD 327 million (circa EUR 283 million) in funds to ocean energy, of which 77% directed to wave energy R&D. The US DOE has announced that for the financial year 2018, USD 70 million (EUR 60 million) have been allocated for the development of marine hydrokinetic technologies (MHK), mainly focusing to wave energy. A further USD 110 million are being made available for 2020 from the US DOE [57].

Figure 4 Breakdown of funding for wave and tidal energy technology for the period 2007-2019. Projects or programmes on ocean energy in general are not taken into account.



A significant shift in the funding of RD&D projects for wave and tidal energy has taken place since 2014. Up to 2013 the total costs of RD&D projects was comparable for the two technologies (circa EUR 280 million), as were the public funds associated to it (circa EUR 210 million). Since 2014 tidal energy project funding amounts to EUR 640 million (of which EUR 330 million of public funds public funds) against the EUR 316 million for wave energy projects (of which EUR 297 million of public funds). This difference is related in part, to the award of a number of tidal energy demonstrator projects at higher TRL which were also required to leverage private finance.

Figure 5 Yearly breakdown of funds dedicated to wave and tidal energy. It shall be noted that funds allocated to projects such as NER300 (still to be delivered) and to H2020 that have been terminated are still accounted in this figure.

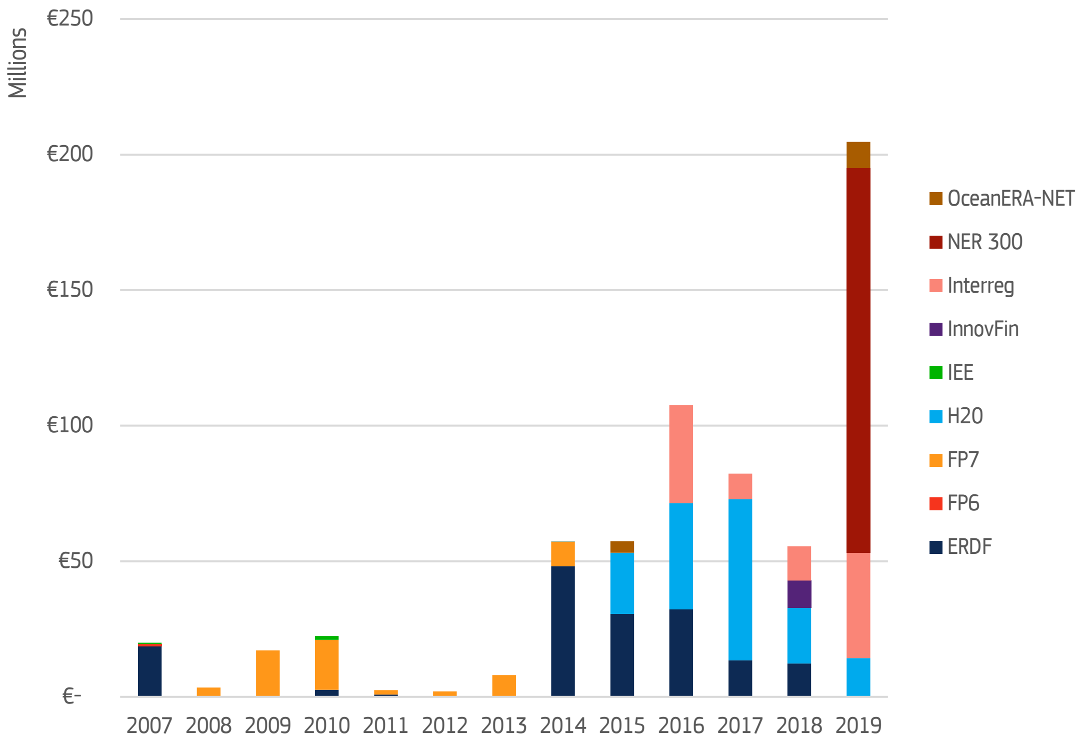


3.1 EU Co-funded Projects.

The European Commission supports different activities addressing the development of ocean energy technologies. In particular, since 2014, the year when the Horizon 2020 (H2020) Framework Programme was launched, the EC has supported 47 projects[8] addressing different technologies at various stages of the development. With the H2020 Framework Programme, the EC has funded EUR 156 million of ocean energy projects, a significant increase from the EUR 60 million directed to ocean energy during the 7th Framework Programme (Figure 6).

[8] Count updated in February 2020. It also accounts for projects launched and later suspended.

Figure 6 Breakdown of EU support for ocean energy in the different framework programmes since 2007.



In total under the Horizon 2020 Framework Programme the EU has supported projects for a total cost of EUR 383 million, funding directly 52% of the funds EUR 199 million, when projects funded under the Life programme are taken into consideration. (*Table 10*).

From *Table 10* it is possible to see that Small-Medium Enterprises (SME) has supported fourteen ocean energy developers, ten at stage one (feasibility) and four at stage two. SME projects aim at helping technology developers to further their business case in order to work on the viability of the company. Marie Skłodowska-Curie Actions (MSCA) support three ocean energy projects, mainly focus on low TRL technologies and explorative research. Coordination and Support Activities (CSA) projects ETIP Ocean, ETIP Ocean 2 and Muses focus on identifying research areas to fill technology gaps and barriers (ETIP Ocean 1 and 2) or to gather information on environmental monitoring and licensing (MUSE). The Era-Net Cofund supports the OceanERA-NET project which involves different National and Regional Agencies supporting ocean energy projects. .

Table 10 Breakdown of EU supported projects for funding categories. Categories in green identify projects were private contribution is expected.

	EU Financial Contribution	Total Project Cost	# Projects
IA	€ 111,307,700	€ 279,980,348	10
Of which terminated	€ 75,021,662	€ 222,974,131	5
Ongoing/successfully concluded	€ 36,286,038	€ 57,006,217	5
RIA	€ 69,436,343	€ 69,436,344	15
ERA-NET-Cofund	€ 5,980,142	€ 18,121,641	1
SME-2	€ 6,328,257	€ 9,153,605	4

	EU Financial Contribution	Total Project Cost	# Projects
CSA	€ 3,578,614	€ 3,584,114	3
Climate	€ 924,871	€ 1,836,788	1
MSCA	€ 1,153,467	€ 1,153,467	3
SME-1	€ 500,000	€ 714,290	10
Grand Total	€ 199,209,394	€ 383,980,597	47

Research, development and deployment projects support by the EU fall mostly under the IA (Innovation Actions), RIA (Research Innovation Actions) and also under Climate actions. Climate actions are taken into account in this analysis since the Life programme is supporting the development of the Life DemoWave WEC in Spain. IA and RIA projects account for the majority of the funds provided by the EU to ocean energy, both in terms of funds (EUR 181 million) and in terms of total project costs (EUR 3499 million). The EU contribution is 100% of project cost for RIA, while IA projects it accounts for about 64% of the total project costs. There is still one ongoing call for H2020 supporting a Pre-Commercial Procurement for Wave Energy deployment with a budget (funds) of EUR 20 million that is not accounted in *Table 10*. As mentioned at the outset of the section, five IA H2020 projects were terminated due to their inability to progress forward with technology development or its demonstration. These projects that were terminated amounted to EUR 75 million in EU contribution and total project costs of EUR 223 million.

In the context of this report, IA and RIA projects are considered more in detail, since they have strong relevance to technology development and to the action of the SET Plan Implementation Plan [16].

3.2 Other EU Programmes

In this section projects and initiative that support the development of ocean energy technologies

3.2.1 Ocean-ERA-NET

Ocean-ERA-NET Cofund is a network of 8 European RTD agencies located in 6 different MS (France, Ireland, Portugal Spain, Sweden, United Kingdom), receiving support from the H2020 programme for the coordination of research projects. The Ocean-ERA-NET Cofund follows up the Ocean-ERA-NET project which consisted of European RTD agencies from 8 different MS (Belgium and Netherlands took part in the first Ocean-ERA-NET).

The Ocean-ERA-NET Cofund project aims to:

- Increase Cooperation between R&D programmes;
- Support industry-led projects;
- Strengthen the EU position in the ocean energy sector.

Under the first Ocean-ERA-NET project 13 R&D projects were support for a total of EUR 11 million of funds made available [58], [59].

Area of research included:

- Moorings: LamWEC, Elasmoor;

- Numerical Modelling: MIDWEST;
- Resource Assessment: Moredata;
- Corrosion: Oceaninc;
- Reliability / Component failure: Recode, Riasor I, Riasor II;
- Novel devices: TupperWave, Se@ports;
- Offshore operations: Kraken;
- PTO Capture, MAT4OEC.

The first call of the Ocean-ERA-NET Cofund project, with a budget of EUR 17 million, aimed at supporting transnational, collaborative projects to demonstrate and validate innovative technologies for ocean energy. Topics included: Ocean energy devices, components and subsystem, grid connection and power systems, materials and structures, installation and O&M, and resource assessment.

10 projects have been selected for funding, for an estimated EUR 10.4 million support, out of 18 projects that met the required standards for the call. Following the contract negotiations, the final amount of funding approved for projects is EUR 7.7 million.

Area of research included (technology developers part of the consortia are mentioned in brackets):

- Tidal turbine blades: Seablade (Eire Composite and Orbital Marine), Topflote (Orbital Marine) ;
- Mooring: Umack (Corpower, Sustainable Marine Energy), TIM(Geps Techno);
- Thermal exchangers (for OTEC): Innotex (Naval Energies);
- Resource Assessment: Resourcecode;
- Foundations: CF2T (Sabella);
- Reliability / Integration / Storage: WEP+ (Wedge Global);
- Novel devices: Sphorcis (Smalle Technologies);

A second OceanERA-NET Cofund call was launched in 2019, the funding approved for the joint call was of EUR 6.8 million. In 2020, four projects have been selected and have received funding to start their activities:

- Sea Snake
- WEC4Ports
- OPTIMOR
- EVOLVE

3.2.2 InnoEnergy

InnoEnergy was established in 2010 and is supported by the European Institute of Innovation and Technology (EIT) as one of a series Knowledge and Innovation Communities (KICs). The InnoEnergy network includes 24 shareholders, as well as more than 360+ associate and project partners. It invests in businesses and helps develop innovative products, services, and solutions. According to the information on its web site, it has invested in two ocean energy technology: Corpower [60] and Minesto. In 2019 the involvement of InnoEnergy has not changed with regards to ocean energy projects.

InnoEnergy has joined Corpower for the HiWave project and Minesto for the DeepGreen 500 project with a EUR 4.5 million investment [61]. Both projects are also supported by Swedish National R&D funds. InnoEnegy supports technology developers via the provision of funds, equity investments and assist developers in developing their business case, like a specialised incubator for innovative energy technologies.

3.2.3 Interreg

Interreg projects aim at fostering transnational cooperation among neighbouring countries, encouraging collaboration to improve economic, social and territorial development of European regions. Since 2016, 16 Interreg projects have supported exclusively or partly ocean energy development for a total of EUR 132 million (Table 11).

Table 11 List of Interreg projects supporting ocean energy development and demonstrations in Europe.

Project Name	Sea Basin	Specific to ocean energy	Total project cost	Start Year
Met-certified	2Seas	YEs	€9,284,697	2016
Intelligent Community Energy (islands)	Channel	No	€8,000,063	2016
Foresea	North West Europe	Yes	€10,750,000	2016
MAESTRALE	MED	No	€2,400,000	2016
PELAGOS	MED	No	€2,400,000	2016
ITEG - Integrating Tidal energy into the European Grid	North West Europe	Yes	€11,790,000	2017
Desal+		No	€2,191,991	2017
MONITOR - Multi-model investigation of tidal energy converter reliability	Atlantic	No	€2,188,839	2017
PROTOATLANTIC - Development and validation of a program for the prototyping and exploitation of innovative ideas.	Atlantic	No	€1,853,895	2017
Renewable energy projects in the countries of north-west Europe next year	North West Europe	No	€5,000,000	2018
Blue-GIFT (Blue Growth and Innovation Fast Tracked)	Atlantic	No	€2,500,000	2018
Marine Energy Alliance	North West Europe	Yes	€6,000,000	2018
OPIN - Ocean Power Innovation Network	North West Europe	Yes	€2,570,000	2018
Tiger	Channel Manche	Yes	€46,800,000	2019
OceanDEMO	North West Europe	Yes	€12,850,000	2019
Ocean Energy Scale-Up Alliance (OESA)	North Sea	Yes	€6,200,000	2019

In 2019 three new projects were launched:

- Tiger, an ambitious EUR 46.8 million (EUR 28 million via ERDF) project whose aim is to drive the growth of tidal stream energy by installing up to 8 MW of new tidal capacity at sites in and around the Channel region, thus driving innovation and the development of new products and services. A list of the deployments is presented in Table 12 [62].

- OceanDEMO [63]who is addressing market failures identified during the FORESEA Interreg by providing market interventions through 3 key elements:
- Prove investibility with investors by demonstrating and de-risking the most promising OE generating technologies in multi-device farm configuration.
- Develop an active supply chain that invests in dedicated OE sub-systems and components.
- Create a supportive policy environment for OE by providing governments with confidence in OE and highlighting OE's economic benefits.
- Ocean Energy Scale-up Alliance [64]that aims to develop new services to support accelerated deployment of ocean energy acting as an innovative Pilot Accelerator Programme to contribute to decarbonisation of the North Sea Region.

Table 12 List of proposed deployments as part of the TIGER project.

Complete consent on three new tidal sites:
Le Raz Blanchard –(1) SIMEC Atlantis (initially 20 MW); (2) CMN (up to 10 MW)
Morbihan –Sabella (up to 10 MW)
Sites re-purposed:
Paimpol-Bréhat –DC to AC outputs, infrastructure for generic fixed bottom turbines
Ramsey Sound –Remove 400 kW Delta Stream turbine, refurbish infrastructure, install new turbine
New tidal turbines installed (c 2.5 MW)
Minesto -DG100, 100-kW power plant at the Paimpol-Bréhat test site
Ramsey Sound –1 x 1 MW generic turbine design
Sabella –2 x 250 kW at Morbihan
Trident –Phase 1 -1 x 12kW demonstrator; Phase 2 –10 x 120 kW at Yarmouth

3.2.4 Infrastructures

One particular areas of research that is addressed by the EU programme is the provision of infrastructure. Horizon 2020 supports the Marinet 2 and Marinerg-I projects, whilst Foresea is supported Interreg. Given the relevance of this topic, these projects are presented in a separate section.

The Foresea project offers project developers access to leading test centres in Europe to support deployment of wave and tidal energy technology at higher TRL. Marinet 2 and Marinerg-I are two projects that provide access to research and infrastructures across Europe.

Marinet 2 brings together 39 partners across Europe, offering access to test facilities ranging from small-scale wave tanks to test-centres (EMEC and Bimep), whilst offering trainings for early researchers and young professionals on thematic such as wave energy modelling, resource assessment and environmental modelling.

The Marinerg-I project bring together 14 EU research and test centres, and works on the implementation of best-practices, guidelines and standers to de-risk investments in ocean energy. The long term aim it to develop and integrated European Research Infrastructure designed to facilitate the growth and development of offshore renewable energies.

There are no significant changes from 2018 in this areas. The Marinerg-I project was concluded at the end of 2019. It has developed a business plan to support ocean energy development research infrastructure and monitoring of projects. Marinet 2 is still ongoing and delivering the expected results.

3.2.5 S3P Marine Renewable Energies

The S3P Smart Specialisation Platform is a project launched by DG ENER and DG REGIO to support regions in areas of excellence. The Interregional partnership on Marine Renewable Energies, which also include offshore wind, pools together regional resources and expertise with the aim to create new business opportunities and growth for the sector.

The S3P partnerships is led by the Basque Country (ES) and Scotland (UK) and comprises fifteen regions with expertise in marine renewables across eleven different countries.

The work of the partnership is focusing on advance manufacturing for energy application in harsh environment, with a key focus on large components manufacturing, corrosion, and monitoring. At the end of 2018 the partnership released report where it highlighted that none of the potential demo projects identified had entered operational phase and the results were limited. No new report is available.

This is results of a prioritisation exercises which assessed regionals strengths and possibilities of the new market (http://s3platform.jrc.ec.europa.eu/marine-renewable-energy).

3.2.6 European Cooperation in Science and Technology (COST)

COST Actions are bottom-up science and technology networks with duration of four years. There is no funding for research itself. Currently, one project addressing ocean energy is supported through COST:

- WECANET (https://www.wecanet.eu/ CA17105) – A pan-European Network for Marine Renewable Energy – which is addressing bottlenecks specific to wave energy to assist the development of wave energy arrays. The action's activities are divided in in 4 main work groups:
- Working group 1: Numerical hydrodynamic modelling for WECs, WEC arrays/farms and wave energy resources;
- Working Group 2: Experimental hydrodynamic modelling and testing of WECs, WEC arrays/farms, PTO systems, and field;
- Working Group 3: Technology of WECs and WEC farms
- Working Group 4: Impacts and economics of wave energy and how they affect decision- and policy-making

The overall aim of the action is to reduce the uncertainties related to the investment decision in wave energy and enhancing investors' confidence in the technology.

3.2.7 NER300

NER 300 is a demonstration programme for CCS and RES projects involving all Member States, using funds from the ETS scheme. The programme aimed to support a wide range of technologies (bioenergy, concentrated solar power, photovoltaics, geothermal, wind, ocean, hydropower, and smart grids). For the period 2021-2030 the Commission has proposed a new programme called the ETS Innovation Fund. Five ocean energy projects have been approved under NER300:

- NEMO – Development of 10 MW OTEC technologies in Martinique. The project is currently suspended due to technical consideration.

- Swell – Development of a 5.6 MW wave energy array in Portugal. The project is currently on track. FID is expected in second half of 208, whilst the First of a kind installation of the Wave Roller devices is expected in summer 2018. Installation of the 5.6 MW array expected between 2019-2020 with operations starting in 2020.
- WestWave – 5 MW wave energy array on the west coast of Ireland. Whilst the identification of viable wave energy technology cannot still be completed (a number of technologies are currently being evaluated including Wello and AW-Roller) the project has obtained planning permission and is undertaking stakeholder consultations
- Sound of Islay – 10 MW tidal farm. There are currently no updates available.
- Stroma – The Stroma NER300 project looks at the development of Meygen 1B (6 MW tidal array). The project is focusing on reaching final investment decision, however, as in the case of the H2020 Demotide, this is yet to be formalised.

Since 2018 there are no public updated about any of the NER300 projects awarded to ocean energy technologies. It can be assumed the FID are still pending. The most notable progress has been achieved by AW Energy that has installed the Wave Roller Device in Peniche [23], however it also show how delayed the project is. SIMEC Atlantis are still working on Meygen Phase 1B[65]; they have developed an updated AR2000 device to be deployed as part of the new project..

3.2.8 InnovFIN Energy Demo Projects

Innovfin EDP is an instrument designed by the European Commission and the European Investment Bank (EIB) to support innovative energy demonstration projects. Support is given in the form of loans, loan guarantees and equity-type finance.

Projects should aim at demonstrating the commercial viability of pre-commercial technologies (TRL8) or enhance the competitiveness of the manufacturing process. In order to receive EIB support, projects need to show reasonable potential for a successful demonstration and the potential to be bankable.

The SWELL project, which was supported also under NER300, has received EUR 10 million from the EIB under this programme (EUR 7 million from Finland and EUR 3 million from Portugal). Project Stroma (also supported under NER300) is under appraisal since 2017 [66].

The EIB requirement to show sufficient prospects for bankability currently poses a hurdle for tidal deployment in the UK. While capital support is often offered, the lack of revenue schemes (feed-in-tariff or alternative) hinders the bankability of the projects given the higher cost of the electricity generated compared to market rates.

There have been no new developments for InnovFIN projects on ocean energy.

3.3 International programmes and developments

Support for the development of ocean energy technologies takes place in many countries at national level, in EU member states and other countries outside of the EU. A quick overview of the schemes in the countries participating in the International Energy Agency (IEA) Ocean Energy Systems (OES) is here presented based on the information provided by the participating country through the OES Annual Report 2019[9] [67].

[99] https://www.ocean-energy-systems.org/documents/49568-oes-annual-report-2019.pdf/

3.3.1 Australia

In 2019, the Blue Economy Cooperative Research Centre (BECRC) was established. BECRC consists of a 10 year partnership between government, industry and research sector to support sustainable growth of Australia's blue economy. The BECRC has received support for 329 mAUD (circa 198 mEUR), and on the five streams of study is dedicated to the investigation of "Offshore Renewable Energy Systems" with an investment of 66 mAUD (40 mEUR), with the aim to identify, develop and demonstrate offshore renewable energy systems capturing generation, storage and control aspects optimised for co-located offshore, off-grid operations [67].

In addition to the BECRC, Arena, the Australia Renewable Energy Agency, has supported the the development of ocean energy technology, funding fourteen different projects from tidal energy resource assessment and the creation of Australia Wave Energy Atlas to supporting the development of ocean energy technologies. Carnegie and Bombora are two Australian developers that have received significant contribution from Arena [67].

Current ARENA's supported project include the Wave Swell project at King Island with ARENA contributing 4.03 mAUD (2.4 mEUR) of the total 12 mAUD (7 mEUR) project costs. Arens is also supporting the AUSTEn project, mapping tidal energy in Australia (TPC 5.85 mAUD [3.5 mEUR], ARENA contributing $2.49M [1.5 mEUR] - [67])

In terms of technology development, the MAKO tidal turbine has completed 6 months of testing, while Wave Swell has begun the construction of their 250 kW device for expected development in 2020. Carnegie is continuing its works on the development of the CETO6 device. Carnegie is continuing its works on the development of the CETO6 device [67].

3.3.2 Canada

Support for ocean energy technology in Canada take places mostly in the form of support scheme for demonstration projects in Nova Scotia, although low TRL research is also supported. The combination of tidal resources available together with the strong support provided by the Nova Scotia government has already attracted many technologies developers to initiate projects in Canada. DP Energy, Sustainable Marine Energy, Minas Tidal, Big Moon Power, Jupiter Hydro, and Nova Innovation are among the technology developers planning deployment in Canada. The Canadian government is supporting directly the deployment of the 9 MW Uisce Tapa project being developed at FORCE, through the 29.7 mCAD (19 m EUR) Emerging Renewable Power Program (ERPP) scheme. The project has been awarder to DP Energy (IE/UK) and foresee the deployment of tidal technologies developed by Andritz Hydro Hammerfest. Other planned deployments including European technology developers include the Petite Passage project (Nova Innovation) and the Sustainable Marine Energy Pempa'q project [67].

In order to support the development of tidal energy, the Nova Scotia government has launched the Marine Renewable Energy Act. The Act foresees that projects that are issued a permit for operation can also receive a Power Purchase Agreement (PPA) for up to 15 years from a local utilities. Two of the projects that have received permit and feed-in-tariff for their deployments at the FORCE test centre have entered in PPA with Nova Scotia Power [67].

Other ongoing demonstrations include Big Moon Power, currently considering deploying a device in the Minas' passage, Jupiter Hydro, ORPC Canada (river deployment in Quebece), Yourbrooke energy and Oneka Technologies, who are developing a wave-powered stand alone desalination system [67].

Further support mechanisms are being developed across Canada with a focus on using ocean energy technologies to power remote communities, especially in British Columbia and Quebec.

3.3.3 China

In 2019 th Chinese government has introduce a feed-in-tariff of roughly 33 cEUR/KWh to support the deployment and demonstration of the LHD tidal platform. The LHD platform is a 1.7 MW system that has been operational since 2016, and has genereat 1.5 GWH since. The system comprises both vertical and horizontal axis turbines [68], and as bee expanded to reach the current capacity in 2018. A second LHD platform is under development and expected to be deployed in 2020 [67].

Other Chinese demonstration projects included the the 260 kW Sharp Eagle WEC (upgraded fron 100 kW) and the Zhejiang University (ZJU) tidal current energy demonstration platform deployed near Zhairuoshan Island. Between 2015 to 2019, 3 different prototypes of 60 kW, 120 kW, 650 kW were deployed for open sea test [67].

Significant focus is being dedicated to the coupling ocean energy technologies with other Blue Economy sector such as powering islans (Sharp Eagle WEC), powering aquaculture farms (Penghu platform 120 kW wave energy converter with 10000 sqm for aquaculture), and for navigation buoys (Ocean-Star Wave -Energy Buoy) [67].

3.3.4 France

The main development that has taken place in France since 2018 is the endorsement of the French regulatory framework designed to facilitate and accelerate the deployment of the entire spectrum of Offshore Renewable Energy (ORE) technologies to support the development of offshore wind energy and ocean energy technologies. A feed-in-tariff of 173 EUR/MWh was awarded to two projects which have not formalised. New consortia are exploring the possibility to review the projects [67].

Public support for the development of the ocean energy technologies in France take places under the supervision of ADEME (Environment and Energy agency) and the ANR (National Research Agency). Between 2010 and 2019 it is estimated that the budget direct to ocean energy is of 69 mEUR, including two projects spport in 2019 the Phares project (see section 2.4.1) and a salinity gradient project to be coupled with desalination plants. For the year 2019 and 2020 4 mEUR have been directed to France Energy Marine for to innovative research and development projects, supporting for public-private collaborative R&D projects helps tackle technological bottlenecks and environmental issues. In total, for the period 2015-2020 16mEUR were directed to ocean energy R&I [67].

3.3.5 Ireland

The development of ocean energy technology has benefitted from two main government lead programmes: The SEAI prototype development fund, which since 2009 has supported 113 projects with more than EUR 18 million funds, and the Pre-commercial technology fund. The latter aims to be a tool to help closing the funding gap for devices and sub-system at TRl>3 supported through the prototype development fund. The OceanEnergy OWC device has benefitted from the Pre-commercial technology fund and it's currently being manufactured for deployment. Other devices being supported are Seapower (wave) and Gkinetic (tidal), and the facilities at National Ocean Test Facility at University College Cork and sea trials in Galway Bay [67].

In 2019 the Irish Government launched the Climate Action Plan, which foresee 3.5 GW of offshore renewable energy capacity to be installed by 2030. This will include wave, tidal and offshore wind technology with dedicated support for emerging technology. Renewable Electricity Support Scheme (RESS) will be developed to support the growth of the marine energy sector, and project awarded through auctions. Cost-competitiveness will be a key requirement for the auctions [67].

3.3.6 Republic of Korea

In 2019 the Ministry of Oceans and Fisheries (MOF) lanched a commercialisation plan for ocean energy systems with the expectation that ocean energy could contribute to the new national renewable by providing 20% of electricity generated by renewable sources by 2030. In order to support the growth of the ocean energy sector MOF has invested 14.9 mEUR in ocean energy systems R&D for 2019, with a similar budget set for 2020. Among the R&D project initiated in 20219, it is important to notice the work on the development of a tidal energy converter combined with Energy Storage System to supply energy to remote off-grid islands, and the development of a 1 MW tidal energy converter. In addition ongoing R&D activities supporting the development of a wave energy test site to be inaugurated in 2020, and of a 1MW OTEC prototype [67].

3.3.7 United Kingdom

In 2019 the UK Government has passed legislation to achieve climate neutrality by 2050. Ocean Energy is expected to contribute to this target, however, the funding policies to support low-carbon technologies has not yet fully published [67].

Wave Energy Scotland, established in 2014, represent the most advance UK scheme to support the development of wave energy technology. WES has since support 90 different research projects for a total of 40 mGBP (45 mEUR), with 7.7 mGBP (8.9 mEUR) awarded in 2019 for the deployment of two wave energy proect to take place in 2020. Research projects focus on wave energy addressing: novel device concepts, new materials, power take off and control system. Wave Energy Scotland is also developing stage-gate metrics approach to ensure that device move to the next stage of funding when performance from testing reaches a required value [67].

Further support in the UK is available in Wales, partly though the European Regional Development Fund (ERDF), to develop ocean energy technology and projects in Wales, including the Minesto project in Holyhead, and a 4.2 mGBP (4.8 mEUR) Wales-Irish project to develop ocean energy in the Irish Sea [67].

The UK government offers market support for renewable energy projects through contract for difference (CfD) schemes. Ocean energy technologies are group together in the 'less established' technologies category as part of the CfD auctions, which also includes offshore wind. Ocean energy technologies are however yet to gain a CfD through the competitive auction process, with Offshore Wind being awarded most of the auctions due to its declining cost. The lack of revenue support for ocean energy technologies has slowed down the development of some tidal energy projects that were looking for final investment decision [67].

3.3.8 United States of America

The United states have supported the development of ocean energy through the MHK (Marine HydroKinetic) programme and the water power programmes supported by the Water Power Technologies Office (WPTO) [67]. Since 2008, USD 322 million have been supporting the development of ocean energy technologies, with a focus in early-stage innovative technologies [69]. In 2019 funds directed to ocean energy research increased to USD 70 million, and the support has increased to USD 110 million for 2020[10] . Support has been directed to four main areas:

- Foundational and crosscutting R&D;
- Technology-specific system design and validation;
- Reducing barriers to testing, and;
- Data sharing and analysis.

In 2019 the Powering the Blue Economy R&D initiative was launched, aiming at understanding the power requirements of emerging coastal and off-grid markets, which can be support the integration of marine renewable energy whilst reliving power constraints and promoting economic growth within the blue economy. This initiative, in line with the Australian Blue Economy Research Centre, the European Commission activities on the Blue Economy and Clean Energy Islands and IRENA SIDS lighthose initiative, aims at supporting the development of ocean energy technology by tapping in different markets segments. One example is the Wave to Water programme, whose goal is to demonstrate small, modular, cost-competitive desalination systems that use the power of ocean waves to provide clean drinking water for disaster recovery and for remote and coastal communities.

3.3.9 IEA-OES Programmes

The Ocean Energy Systems Technology Collaboration Programme (TCP) brings together countries to advance research, development and demonstration of ocean energy technologies.

Currently, OES operates 13 tasks designed to advance the status of ocean energy, addressing different aspects of ocean energy from technology specific tasks on wave, tidal or OTEC technology, to consenting process and environmental monitoring.

- Task 1 – Dissemination;
- Task 2 – Guidelines;
- Task 3 - Grid Integration;
- Task 4 - Environmental Issues;
- Task 5 - Technology Development;
- Task 6 - GIS map;
- Task 7 - Cost of Energy;
- Task 8 - Consenting Processes;
- Task 9 - Technology Roadmap;
- Task 10 - Wave Energy Modelling;
- Task 11 – OTEC;
- Task 12 - Stage Gate Metrics;
- Task 13 - Tidal Energy Modelling.
- Task 14 - Jobs creation

[10] For year 2020, the Water Power Technologies Office has estimated USD 148 million budget for R&D projects, including Hydro Power and Pumped Hydro Storage solutions.

In 2017, new tasks were launched, addressing in particular the development of a common methodology to monitor the evolution of the cost of ocean energy technologies (task 7) and one on the development of stage gate metrics.

The collaborative tasks run by the OES are often high-level tasks, nevertheless they allow for the comparison and homogenisation of best-practises at international level.

In particular, Task 12 on stage gate metrics offers the potential to reach consensus on targets for ocean energy development among different supporting agencies (US, UK and EC); while Task 7 on the Cost of Energy allows comparing how ocean energy technologies are becoming market competitive. A new tasks looking at the potential impacts of ocean energy in terms of job creation was launched in 2019.

3.3.10 IRENA

Irena within the framework of its SIDS Lighthouse initiative[11] is exploring the transformation of the energy systems from a predominantly fossil-based to a renewables-based and resilient energy system.

3.4 Patent analysis

The market for ocean energy is in its infancy, and device deployment is limited to projects with a small number of devices. The consolidation of the supply chain involving OEMs has still to take place. The slow deployment of projects does not allow the assessment of industrial strategies.

In order to better identify the current R&D focus and positioning of EU players, we analysed the companies that have filed patents in ocean energy[12].

Patents for ocean energy technologies are classified in 6 CPC classes as follows:

- Y02E-10/28 - Tidal stream or damless hydropower, e.g. sea flood and ebb, river, stream;
- Y02E-10/30 - Tidal stream;
- Y02E-10/32 - Oscillating water column [OWC];
- Y02E-10/34 - Ocean thermal energy conversion [OTEC];
- Y02E-10/36 - Salinity gradient;
- Y02E-10/38 - Wave energy or tidal swell, e.g. Pelamis-type.

In total, between 2000 and 2015, 838 EU companies in 26 Member States have filed patents or have been involved in the filing of patents related to ocean energy. In the EU 51% of the inventions patented are for wave energy technology, 43% for tidal energy, 2.7% on OWC, and 3% for OTEC. This values are in line with the one of the 2018 report.

When countries outside of the EU are accounted for, the share of wave energy increases to 67%, tidal energy decreases to 27%, OWC drops to 1.4%, OTEC rises to 3.55% and Salinity

[11] http://islands.irena.org/

[12] Complete statistics on patent families are available up to 2014; filings in subsequent years are also considered if they belong to a patent family (or invention) that claims priority in this time period. Patent families are collections of documents referring to the same invention (e.g. filings to different IP offices)

gradient to 0.74%. The 30 most active companies have been classified according to type of activity and positioning in the ocean energy supply chain (Table 13).

Table 13 TOP 30 patenting companies in the field of ocean energy in the EU, and focus on CPC classes.

Company	Country	Patents	CPC Class
ROBERT BOSCH GMBH	DE	45	Predominantly wave
VOITH PATENT GMBH	DE	30	Predominantly tidal
TIDAL GENERATION LIMITED	UK	23	Predominantly tidal
Marine Current Turbines Limited	UK	13	Predominantly tidal
AW ENERGY OY	FI	11	Wave only
OPENHYDRO IP LIMITED	IE	11	Predominantly tidal
ROLLS ROYCE PLC	UK	10	Predominantly tidal
AKTIEBOLAGET SKF	SE	10	Predominantly tidal
INSTITUT FRANCAIS DU PETROLE	FR	10	Predominantly tidal
UNIVERSIDADE DA CORUNA	ES	9	Predominantly tidal
INSTITUTO SUPERIOR TECNICO	PT	8	Wave only
WELLO OY	FI	7	Wave only
DCNS	FR	7	Predominantly tidal
Aquamarine Power Limited	UK	6	Predominantly wave
W4P WAVES4POWER AB	SE	6	Predominantly wave
AWS Ocean Energy Limited	UK	5	Predominantly wave
WAVES RUIZ	FR	5	Wave only
Wavebob Limited	IE	5	Wave only
SEABASED AB	SE	4	Wave only
SIEMENS AKTIENGESELLSCHAFT	DE	4	Predominantly tidal
CMI	FR	4	Predominantly tidal
TIDALSTREAM LIMITED	UK	4	Predominantly tidal
OCEAN HARVESTING TECHNOLOGIES AB	SE	4	Predominantly wave
THE UNIVERSITY OF LANCASTER	UK	4	Predominantly wave
VERDERG LTD	UK	4	Predominantly tidal
ANDRITZ HYDRO HAMMERFEST UK LIMITED	UK	4	Tidal only
OCEAN CURRENT ENERGY LLC	UK	4	Predominantly tidal
NOVO VIDAL MARIA ELENA	ES	4	Wave and tidal
AVIATION ENTERPRISES LIMITED	UK	4	Predominantly tidal
TIDAL ENERGY LIMITED	UK	3	Predominantly tidal

Source: JRC. Methodology: [70]

Figure 7 Number of patent families from EU companies most active in patenting.

Source: JRC*Figure 7* shows the countries with the highest patenting activity, led by the United Kingdom, followed by Germany, France and Sweden, Spain, Ireland and Finland. R&D focus and specialisation differs significantly between countries; some countries show higher shares of component and parts manufacturers (e.g. Germany) and others are more active in turbine and device manufacturing. In general, patent applications show an increasing trend up to

2014. In 2015 and 2016 patenting activity has decreased compared to the period 2008 to 2014.

Figure 7 Number of patent families from EU companies most active in patenting.
Source: JRC

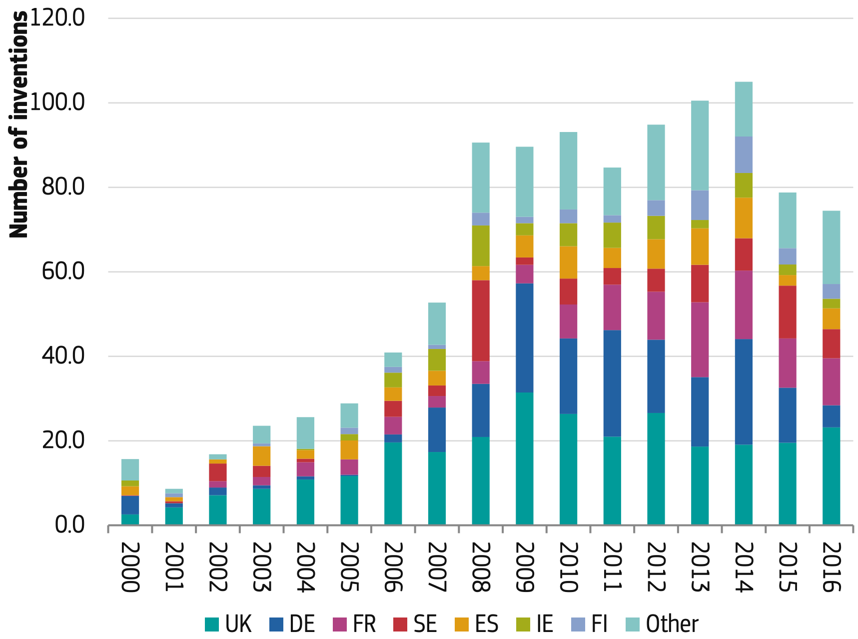
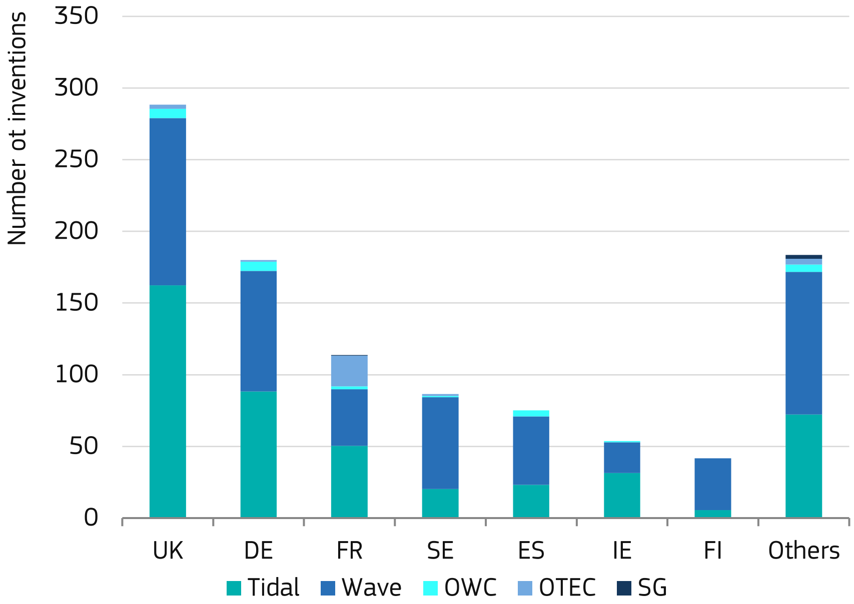


Figure 8 provides details on the total number of EU patent applications by country. The United Kingdom (28%) clearly leads the ranking, followed by Germany (18%), France (11%) and Sweden (9%). These four countries account for 65% of all EU patent applications in the area of ocean energy. Industries and R&D SMEs in Spain (7%), Ireland (5%) and Finland (4%) account for another 16% of patent applications.

Figure 8 Number of the patents families from 2000 to 2014 according to country and CPC classification. *Source: JRC.*



3.4.1 Market protection and competition

The information presented in Figure 9 and Figure 10 indicates that companies in the EU are investing considerably in the development of ocean energy technology.

Since 2000, the EU has been the leader in R&D in ocean energy until 2010. As shown in Figure 9 since 2010 Chinese patenting has increased significantly and has overtaken the EU. Whilst Chinese activity in ocean energy has spiked only a limited part of the inventions patented in China have filed for international protection.

Figure 9 Global ocean energy patents trend from 2000 to 2016. Source: JRC, Patstat

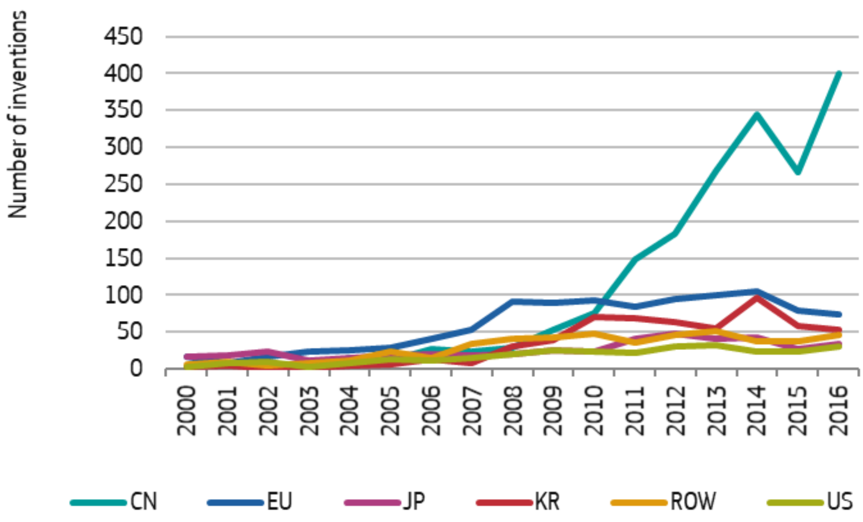
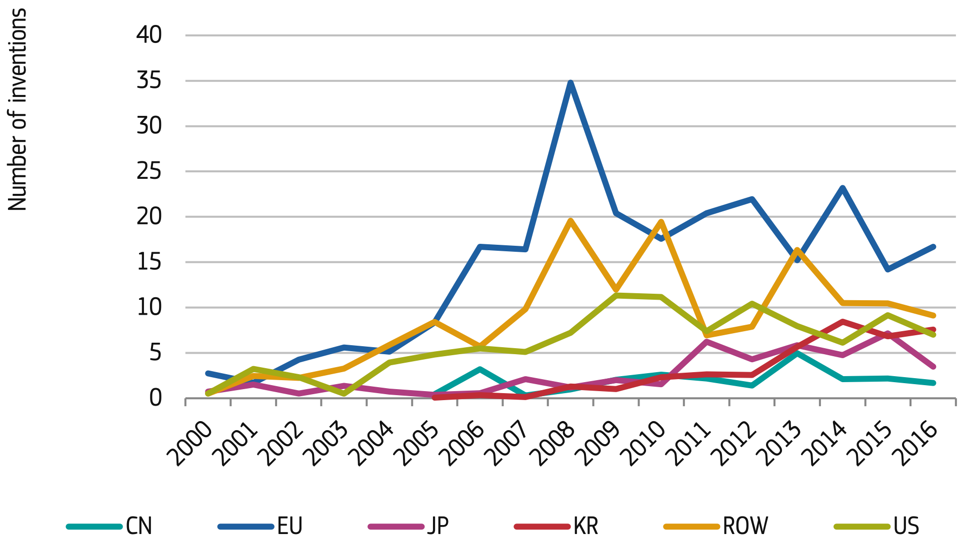


Figure 10 presents the global patent trends for the period 2000-2016, taking into account those High-value inventions. High-value inventions (or high-value patent families) refer to patent families that include patent applications filed in more than one patent office, thus offering IP protection of the technology in multiple markets.

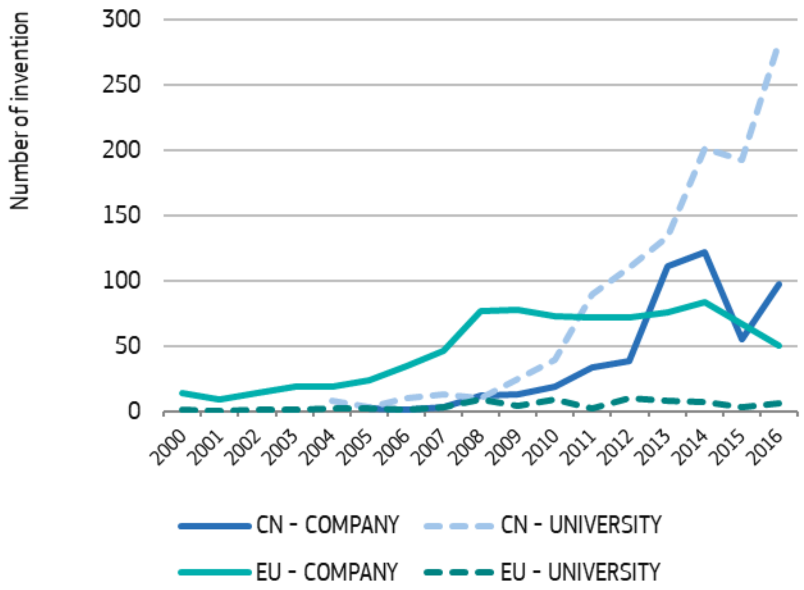
Figure 10 Global High-value inventions ocean energy patents trend, from 2000 to 2016. Source: JRC, Patstat



From Figure 10 one can see that only a few Chinese patents have sought international protection; whilst many EU inventors have sought protections in multiple potential markets.

Furthermore, only a small part of the patents filed in China are filed by private companies, with the majority of the inventions taking place at universities. As shown in Figure 11, most of the EU patents come from private R&D, whilst in the case of China universities play a significant role. This situation is possibly due to the higher intervention of the national government in R&D, but may also be related to the market-maturity of the invention, and the related opportunities for commercialisation.

Figure 11 Trends for private company (solid line) and university (dash) filed patents in China and in the EU. Source: JRC, PATSTAT



From the patent data it is possible to estimate the private R&D investment that has been directed to the development of ocean energy technologies. Figure 12**Error! Reference source not found.** presents the historical trend in Private R&D Investments in the EU. Private investment have decreased steadily from the period 2008-2010 where annual investments were estimated around EUR 300 million to about half of it in 2016 (EUR 158 million). In total since 2003 EUR 2.7 billion of private investments have been directed to ocean energy R&D. Companies based in the UK (EUR 900 million) and in Germany (EUR 475 million) have invested the most in R&D.

Figure 12 Private R&D Investment trend in the EU. Based on patents information. Source and Methodology JRC.

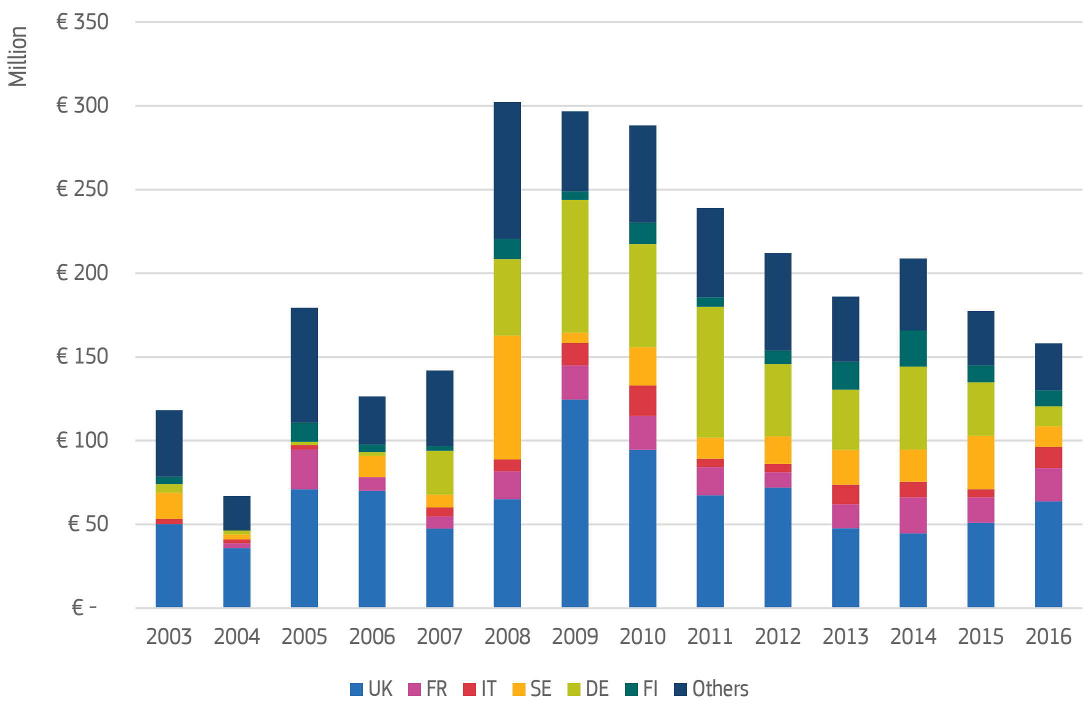
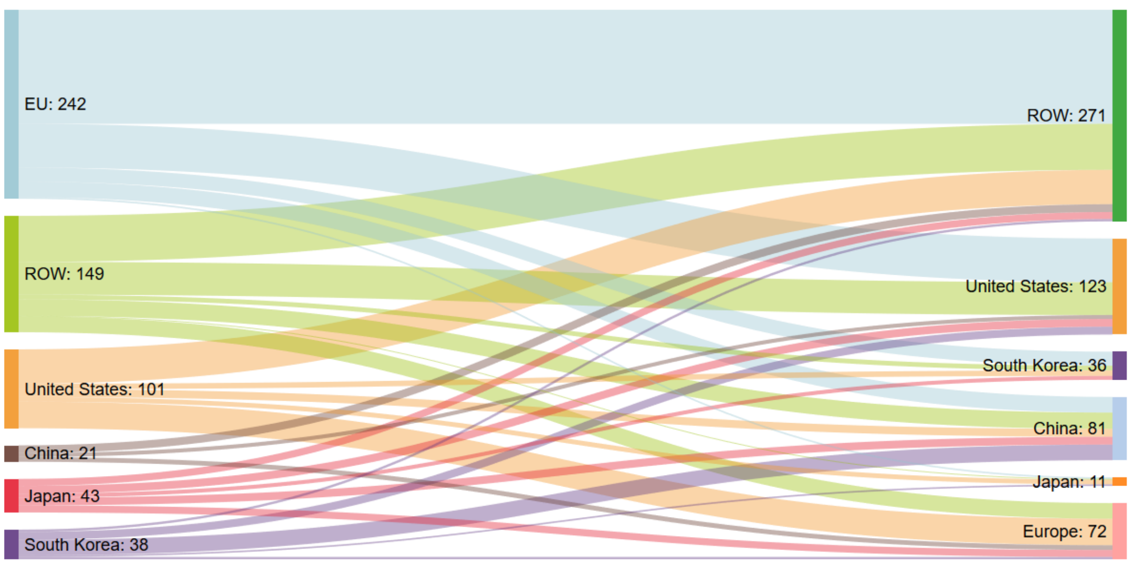


Figure 13 Global patents flow. Intra-market patents are excluded. Source: JRC

Figure 13 presents where protection for inventions is sought, and provides a link to commercialisation plans of technology developers, who seek to protect a commercial avenue in the country of protection. As seen in Figure 13, European developers are exporting their technologies in all the potential key ocean energy markets, such as the US, China, Japan and Korea. On the other hand, only a small share of non-European developers are seeking protection in Europe. Based on patent filings, Europe is the net exporter of ocean energy technology innovation; and European ocean energy developers are well poised to exploit the growth of the ocean energy sector globally.



4 IMPACT ASSESSMENT OF H2020 PROJECTS

In this chapter the contribution of significant EU funded H2020 projects towards the advancement of ocean energy technologies is analysed. The projects are categorised according to the SET Plan actions presented as outlined in the SET Plan Implementation Plan approved in March 2018.

A list of the projects assessed is presented in Table 14. This highlights projects that will be analysed or updated in this report and includes those assessed in previous versions of this report.

The links between each project and the 11 actions of the Ocean Energy SET Plan Implementation Plan [16] is presented in Table 15. The 11 actions of the Ocean Energy SET Plan Implementation Plan are as follows:

Technical Actions:

1. Tidal energy – assist technology development and knowledge building up to TRL 6
2. Tidal energy – support system demonstration in operational environment and knowledge building in the TRL 7-9 categories.
3. Wave energy – support technology development, system demonstration and knowledge building up to TRL 6
4. Wave Energy – encourage and support device and system demonstration at early demonstration array scale up to TRL 7- 9.
5. Collaborate in the areas of installation, logistics and infrastructure.
6. Co-ordinate the development of standards and guidelines for wave technology evaluation and LCoE analysis.

Financial Actions

7. Investigate the potential for creation of an Investment Support Fund for ocean energy farms: EU and National Authorities should collaborate in order to create a Fund providing flexible capital, and enabling further private capital to be leveraged
8. Progress the creation of an EU Insurance and Guarantee Fund to underwrite various project risks: This would be targeted at the first ocean energy projects to cover risks such as availability, performance, unforeseen events, failures, etc. Consider the provision of a common reserve fund available to multiple projects in the initial farm or plant roll-out, to spread the risk and reduce the cost of providing guarantees.
9. Support the development of a collaborative procurement model adaptation of the "Wave Energy Scotland" approach for wave energy development at EU Level using pre commercial procurement or similar.

Environmental Actions

10. Collaboration on the development of certification and safety standards for the development, testing, deployment of ocean energy devices,
11. •Continue the de-risking of environmental consenting through an integrated programme of measures and in particular through promoting open data sharing.

Most of the H2020 projects address the SET Plan technology actions, with only CSA projects addressing (or partly addressing) the other actions. It shall be noted that the technical and financial actions are inter-dependant on each other, especially given the current phase of ocean energy technology development.

Similarly in order to provide further detail to the scope of H2020 funded projects, these are benchmarked against the ETIP Ocean technological challenges. Individual projects may address multiple challenges, especially those at higher TRL. This will be highlighted in the analysis.

ETIP Ocean developed a report highlighting the challenges for the ocean energy sector to develop commercially viable technology. 29 challenges have been identified, of which 14 are considered urgent and to be tackled in the short term, including six technological challenges, as shown in Table 16 [71]. In December 2019 ETIP Ocean released a draft version of the new Strategic Research and Innovation Agenda [72]. Six challenge areas (design and validation of ocean energy devices, balance of plant, logistic and marine operations, and integration in the energy systems, data collection, analysis and modelling tools, cross-cutting challenges) have been identified with 16 corresponding priority actions. Some priority topics have a correspondence with the ones from the 2017 agenda are presented in Table 16. It can be seen that both document focus on technology development as a key area of priority for ocean energy.

Table 14 List and status of the projects considered in the LCEO analysis. The shading of each project indicates the status with respect to the current Technolgy Development report. Green shades indicated projects that will be assessed in more detail in this report (or updated) from 2018 version. Yellow shades indicated project with limited information available (project recently started). White shades refer to project assessed in detail in 2018 and not further discuss in this report. Red shades refers to projects that have been terminated.

Programme	***Project Acronym***	***Developers***	***Project Status***	***LCEO Status***
IA	DTOceanPlus	OceanTEC Corpower Nova Innovation Orbital Marine Sabella	ONG	Project ongoing. 2018 Assessment expanded
IA	EnFAIT	Nova Innovation	ONG	Project ongoing. 2018 Assessment expanded
IA	OCEAN_2G	Magallanes	ENDED	Assessed 2018.
RIA	IMAGINE	Umbra Cuscinetti	ONG	Project ongoing. 2018 Assessment expanded
RIA	MegaRoller	AWENergy	ONG	Project ongoing. 2018 Assessment expanded
RIA	OPERA	OceanTEC	ONG	Project ongoing. 2018 Assessment expanded
RIA	PowerKite	Minesto	CLOSED	Project ongoing. 2018 Assessment expanded
RIA	RealTide	Sabella EnerOcean	ONG	Project ongoing. 2018 Assessment expanded
RIA	SEA-TITAN	Wedge Corpower	ONG	Project ongoing. 2018 Assessment expanded
RIA	TAOIDE	ORPC	ONG	Project ongoing. 2018 Assessment expanded
RIA	TIPA	Nova Innovation	ONG	Project ongoing. 2018 Assessment expanded
RIA	WaveBoost	Corpower	ONG	Project ongoing. 2018 Assessment expanded
CSA	ETIP OCEAN 2		ONG	Project ongoing. 2018 Assessment expanded
CSA	MUSES		CLOSED	Project closed. 2018 Assessment expanded
ERA-NET-Cofund	OCEANERA-NET COFUND		ONG	Project ongoing. Assessment provide in chapter 3
RIA	ELEMENT	Nova Innovation	ONG	Project Launched end 2019. Limited information
RIA	LiftWEC		ONG	Project Launched end 2019. Limited information
RIA	NEMMO	N.A (Blades)	ONG	First analysis
Climate	*LIFE DEMOWAVE*		*ONG*	*No information available*
IA	FloTEC	Orbital O2	ENDED	2018 Assessment completed
RIA	MARINERGI		ENDED	2018 Assessment completed
RIA	MARINET2		ONG	2018 Assessment completed
RIA	WETFEET	Symphony GenericOWC	CLOSED	2018 Assessment completed

Programme	***Project Acronym***	***Developers***	***Project Status***	***LCEO Status***
CSA	ETIP OCEAN		Ended	2018 Assessment completed
MSCA	MoWE		ENDED	2018 Assessment completed
MSCA	OpTiCA		ENDED	2018 Assessment completed
SME-1	BUTTERFLY	Rotary Wave SL	ENDED	2018 Assessment completed
SME-1	Direct Drive TT	NovaInnovation	ENDED	2018 Assessment completed
SME-1	FFITT	Fish Flow Innovation	ENDED	2018 Assessment completed
SME-1	HydroKinetic-25	G Kinetic / Design PRO	ENDED	2018 Assessment completed
SME-1	OHT		ENDED	2018 Assessment completed
SME-1	SEAMETEC	Eire Composite	ENDED	2018 Assessment completed
SME-1	SUBPORT	Current 2 current	ENDED	2018 Assessment completed
SME-1	TidalHealth		ENDED	2018 Assessment completed
SME-1	WATEC		ENDED	2018 Assessment completed
SME-1	Wavepiston		ended	2018 Assessment completed
SME-2	D2T2	Nova Innovation	ONG	2018 Assessment completed
SME-2	DP Renewables	G Kinetic / Design PRO	ONG	2018 Assessment completed
SME-2	eForcis and BeForcis	Smalle Technologies	ONG	2018 Assessment completed
SME-2	POSEIDON	Floating power plant	ENDED	2018 Assessment completed
IA	CEFOW	Wello OY	TERMINATED	Assessed 2018 - Project terminated no updates.
IA	DEMOTIDE	SIMEC Atlantis	TERMINATED	Assessed 2018 - Project terminated no updates.
IA	InToTidal	Tocardo	TERMINATED	Assessed 2018 - Project terminated no updates.
IA	OCTARRAY	OpenHydro	TERMINATED	Assessed 2018 - Project terminated no updates.
IA	OCTTIC	OpenHydro	ONG	Assessed 2018 - Project terminated no updates.
IA	UPWAVE	Wavestar	TERMINATED	Project terminated in 2014. No assessment
MSCA	INNOWAVE		ENDED	Project terminated in 2014. No assessment

Table 15 Classification of H2020 projects according to the SET Plan Implementation Plan actions. ✓Project completed. ●Project Ongoing. ● Project ongoing with some delay. ✱Project interrupted.

	Action	IA	RIA	FTIPilot	SME	CSA	MSCA
Technology Actions	**1 Tidal Energy TRL1-6**		● RealTide (*Sabella, EnerOcean*) ✓ PowerKite (*Minesto*) ✓ Taoide (*ORPC*) ✓ TIPA (*Nova Innovation*) ● Nemmo (tidal blades) ● Element (Nova Innovation) ● ENFait		✓ Direct Drive TT, ✓ D2T2 (*Nova Innovation*) HydroKinetic-25, DP Renewables (*Design Pro*) ✓ SEAMETEC (*EnerOCean*) ✓ SUBPORT (*current2current*)		● OpTICA
	1 Tidal Energy TRL7-9	✱~~Demotide (*Atlantis*)~~ ✱~~Octarray (*Openhydro*)~~ ✓ FloTEC (*ScotsRenewables*) ● EnFAIT (*Nova Innovation*)	✱~~Occtic (*Openhydro*)~~	✱~~InToTidal (*Tocardo*)~~ OCEAN_2G (*Magallanes*)		✓ ETIPOcean	
	3 Wave Energy TRL1-6		● IMAGINE (*UmbraGroupSPA*) ● WETFEET (*Simphony*) ✓ Waveboost (*Corpower*) ✓ Opera (*Oceantec*) ● SEA-TITAN (*Wedge*)		✓ Butterlfy (*Rotary Waves*) ✓ OHT(*Ocean Harvesting* ✓ *Technologies*) ✓ Wavepiston (*Wavepiston*) ✓ eForcis BeForcis (*eForcis*)	● ETIP OCcean 2 ● OCEANERA-NET ● OceanSET	✓ MoWE ✱~~Innowave (*Aquamarine*)~~
	4 Wave Energy TRL 7-9	✱~~Cefow (*Wello*)~~ ✱~~Upwwave~~ LIFE DEMOWAVE (*LIFE*)	● MegaRoller (*WaveRoller*)				
	5 Installation / Logistics			✱~~InToTidal (Tocardo)~~			
	6 Standards and Guidelines	DTOCeanPlus					
Financial actions	**7 Investment Support Fund**						
	8 EU Insurance Guarantee Fund						
	9 Wave Energy Europe						
Environmental and consenting	**10 Certification and Standards**						
	11 Environmental Consenting					✓ MUSES ✓ RICORE	

Table 16 ETIPOcean priority challenges and corresponding challenges from 2019 version. Source: [71], [72].

Category	Challenge in 2017 Version	2019 Technology Challenges	Challenge area 2019
Technology	Developing novel concepts for improved power take-offs (PTOs)	Improvement and Demonstration of PTO and control systems	Design and Validation of Ocean Energy Devices
Technology	Increasing device reliability and survivability	Demonstration of existing ocean energy devices to gain experience in real sea conditions	Design and Validation of Ocean Energy Devices
Technology	Investigating alternative materials and manufacturing processes for device structures	Application of innovative materials from other sectors	Design and Validation of Ocean Energy Devices
Technology	Investigating novel devices before moving towards convergence of design	Development of novel wave energy devices	Design and Validation of Ocean Energy Devices
Technology	Defining and enforcing standards for stage progression through scale testing		
Technology	Developing and implementing optimisation tools	Marine observation modelling and forecasting to optimize design and operation of ocean energy devices	Data Collection and Analysis and Modelling Tools
Financial	Providing warranties and performance guarantees		
	Linking stage-gate development processes to funding decisions		
	Maintaining grant funding for early TRL technologies		
	Establishing long term revenue support		
Environmental and socio-economics	Enhancing social impact and acceptance		
	Minimising negative environmental impacts	Improvement of the environmental and socioeconomic impacts of ocean energy	
	Facilitating knowledge transfer and collaboration	Open-data repository for ocean energy	Data Collection and Analysis and Modelling Tools
	Implementing adaptive management systems		

4.1 Tidal energy R&D

The EU supports the development of low TRL tidal energy technologies through four H2020-LCE projects and six H2020 SMEs projects (**Table 17**).

Table 17 H2020 projects on low TRL tidal energy technologies and related ETIP Challenges

Main Technology	Device Class	Project	ETIP Challenge
M100 (Nova Innovation, UK)	Horizontal Axis turbine	Enfait	Improving costs and efficiency
		Element	Increasing device reliability and survivability (lifetime)
		TIPA	Power Take off, Device reliability Improving costs and efficiency
		D2T2 (SME)	Direct drive PTO
		Direct Drive TT (SME)	Direct drive PTO
ORPC (Ocean Renewable Power Company, US/IE)	Cross Flow Horizontal Axis Turbine	TAOIDE	Power Take off, Device reliability Improving costs and efficiency
Deep Green (Minesto, SE)	Tidal Kite	PowerKite	Power Take off, Device reliability Improving costs and efficiency
D10 (Sabella, FR)	Horizontal Axis Turbine	ReaTide	Implementing suitable condition monitoring systems
Design Pro/GKinetic (IE)	Vertical Axis Turbine	HydroKinetic-25 (SME) DP Renewa-bles (SME)	Power Take off, Device reliability Investigating novel devices
Current2Current	Vertical Axis Turbine	Subport (SEM)	Investigating novel devices

4.1.1 TiPA

TIPA is a project coordinated by Nova Innovation, 7 partners. The aim is to reduce the lifetime cost of NOVA turbines by 20% by developing an innovative drive train. The main goal of the project is to optimise the PTO and doing so by developing a direct-drive wet-gap generator.

4.1.1.1 Expected impacts

- Improved performance of PTO expected to drive LCOE from 400 EUR/MWh to 320 EUR/MWh. Second generation PTO can provide cost reduction of 20-35% (low carbon innovation coordination group)
- Improved reliability, project aims to increase service interval. Reliability can achieve 35-55% cost reduction by 2050 (LCICG) – to be verified
- Demonstrate survivability of device to 20 years through testing.

The TIPA project ended in November 2019. The project was marked successful by the Project Officer. The project achieved five main outcomes:

- Identified way for potential cost-reduction of 29%, higher than expected at the offset of the project.
- Accelerated testing identified promising features such as: the integrated, flexible, modular design; good mechanical-electrical efficiency; excellent thermal performance; excellent improvements in expected reliability leading to significant cost savings; strong potential for new applications in wave energy and other sectors.
- Technology design and test outputs were validated through independent verification.
- PTO optimisation: In-sea testing and dry testing of the PTO were undertaken that helped the optimisation of the PTO.
- Stakeholder consultations have led to design improvements and identification of commercial opportunities.

In terms of commercialisation the project consortium considered the exploration of niche, high value markets for initial commercialisation of technology expanding the commercial outlook for tidal energy technologies.

4.1.2 EnFait

NOVA innovation is also the coordinating partner of the EnFait projects which aims at scaling up the existing 300 kW tidal array located in Shetland in order to reduce cost and improving reliability of turbines. This project is at higher TRL and should be presented together with the other DEMO projects, however it is presented here to offer a complete overview of the projects in which Nova Innovation technology is involved.

The aim is to extend the Shetland array from 300 kW to 600 kW and then 700 kW by adding new 100 kW tidal turbines and test different layout for the optimisation of the power output.

4.1.2.1 Project phases

- Operate existing turbines
- Upgrade turbines
- Manufacture 4th turbine and expand
- Move to array of 6 turbines
- Optimise performance by changing array design
- Use 7th turbine to create/generate improve O&M strategy

4.1.2.2 Expected impacts

- Concept design review
- Technology update review
- 20% OPEX/CAPEX savings

4.1.2.3 Status and updates

The project is making good progress and is expected to meet its goals. In particular in demonstrating the progress in LCOE by making tidal energy technology commercially viable and, bankable.

As part of the EnFait project, the consortium is evaluating a Computerised Maintenance Management System (CMMS) to computerise maintenance management. The implementation of CMMS cold help reduce downtime, improve productivity and yield cost-savings.

4.1.3 Element

In June 2019, the Element project was launched. The project focuses on developing and validating an innovative tidal turbine control system, using the tidal turbine itself as a sensor, to deliver a step change improvement in the performance. The aim is to demonstrate effective lifetime extension in the marine environment for tidal energy with the overarching objecting of taking the EU tidal energy sector to commercial reality. The project will also look at the testing of a floating 50 kW turbine in the estuary of the river Etel in France.

Furthermore the consortium at sharing the learning with other EU projects improve the knowledge base regarding impacts of tidal energy on the environment and local communities and overall increase public support for tidal energy projects.

4.1.3.1 Expected impacts

The Consortium's aim is to reduce LCOE for tidal energy by 17%, driving the EU tidal energy sector to commercial reality. This will be achieved through:

- Reduce fatigue loads experienced by the device by 50% (based on loads experienced by operational Nova M100 turbines.
- Increase energy extraction from the device by 8% based on current yield of NOVA turbines.
- Reduce LCOE of tidal power by 17%.
- Validate the ELEMENT control system to TRL 5 in both a subsea geared device and floating direct drive turbine.
- Reduce the estimated risk of collision with marine fauna by 50%, based on results from NOVA collision risk model.
- Increase estimated lifetime of tidal devices and key components by 25%, based on current estimated lifetime of existing NOVA turbines/components.
- Shared knowledge with a minimum of five EU funded projects relating to offshore renewable energy.
- Deliver a socio-economic and environmental assessment of the potential impact of tidal energy on the local economy (Étel), France, and Europe.
- Deliver a targeted Communications Strategy focussing on the potential societal benefits of tidal energy.
-

4.1.3.2 Innovations

- Optimisation of the control system of a tidal turbine, using behavioural modelling to reduce predicted loads
- Use improved understanding of turbine behaviour to maximise energy yield
- Utilise results to optimise tidal turbine design for world-leading improved performance and reduced cost
- Develop and validate adaptable control technology with a wide range of applications
- Minimise environmental impacts by integrating environmental monitoring into the control system.
- Increased resistance to marine environment & extended lifetime of tidal turbines.

4.1.4 TAOIDE

The Taoide project, similarly to the TiPA projects, focuses on the development of wet-gap drive train for the cross-flow tidal device developed by ORPC. The ORPC device has been developed in the US and has been tested in river flows. SKF, which is involved in the Taoide and Tipa projects, is currently carrying out a trade analysis of seals and bearing for the project.

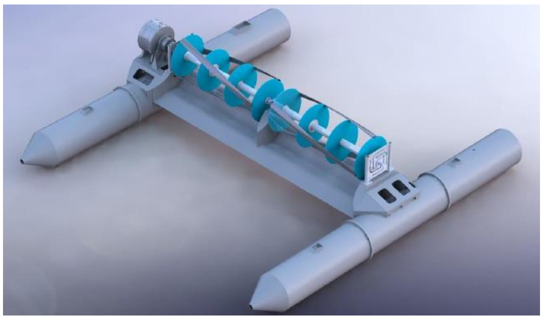
4.1.4.1 Expected impacts

- Develop a 'wet-gap' electrical generator design capable of operating in a fully-seawater flooded condition
- Extended maintenance levels (5 years) – availability of 96%
- Develop bearings and seal designs for hydrokinetic machines
- Develop control system to optimise power output and quality.

4.1.4.2 Innovations

The Taoide project has reached half way. As part of the project, the consortium is developing a synchronous permanent magnet generator rated at 38 kW (max rating 56 kW). During the first part of the project, the design of the RivGen 2.0 generator has been finalised. The generator is designed with a split rotor design where the output shaft rotates, together with the permanent magnet rotor while the inner races of the bearings are supported by a stationary cantilever (*Figure 14*).

Figure 14 RivGen 2.0 Copyright © ORPC



IKM (Norwegian partner) and Sintef have been working on the wet-Gap permanent magnet and on the identification of protection solution for the stator and the generator as a whole. They considered the use of different types of epoxy resin to protect the stator, considering a gap of 5 mm. Design freeze for the generator was reached in April 2018, this will facilitate the identification of the bearings. SKF has been working on the selection of suitable seawater seal for the generator.

4.1.5 PowerKite

The PowerKite project aimes at improving the reliability of the Minesto tidal energy converter. The device is not a horizontal axis turbine, but a tethered kite equipped with a turbine for power conversion. The project concluded at the end of 2018. As part of the project the first Minesto Deep Green500 was deployed in Holyhead in September 2018, and started to deliver electricity to the grid in October 2018 [73].

According to the final project review PowerKite has addressed important aspects of ocean energy such as interaction with the environment, life cycle cost, LCOE analysis, maintenance/serviceability and array configurations. The PowerKite project was run in parallel with the DG500 project, in which Minesto developed and deployed the first commercial scale prototype of the Deep Green technology.

In particular, the project delivered an optimized turbine design, which increases the power output from the tidal power plant. An optimised turbine was developed from the investigation of several turbine design concepts, tested and evaluated in real sea environment.
The core innovation of the PowerKite project resided in the electro-mechanical design of the PTO, including a design for the complete array layout and grid connection allowing the array to be deployed in sites with low velocity currents.

An important take-way that can be applied widely in ocean energy industry are the innovative environmental impact studies performed by the consortium during the lifetime of the project.

4.1.5.1 Achievements

The overall objective of the project was to enhance the structural and power performance of the PTO. Core innovation of the project resides in the electro-mechanical design of the PTO. The project addressed key areas in the Deep Green technology which has the potential to double the tidal power market potential and unlock significant reduction cost of energy and weight per installed MW compared to other tidal energy converters.

Among the key results obtained by the project are:

- New turbine designs with a proved increase in mechanical power output by 31% to 35% compared to the baseline turbine.
- Improvement in terms of power plant energy output against the baseline, in the range of 15% to 21%, stemming from combined effect of the improved turbine design, the improvement of the low-voltage system and the increased drag of the improved tether.
- The life cycle assessment was showed that the impact per kWh produced which is comparable to other marine renewable energy technologies and calculated as 26.2 g CO_2eq/kWh.
- Noise measurements and acoustics modelling indicated that the noise produced during the operation does not significantly impact the local wildlife.
- Increased understanding of cost levels associated with different type of array configurations: Improving the technology (turbine, converter, tether, and similar) leads to improved performance and LCOE levels and unlock news markets for power plants to operate in lower velocity flow conditions.

LCOE is estimated by the developer at 99-121 EUR/MWh for 100 MW cumulative installed capacity.

4.1.6 NEMMO

In April 2019, the NEMMO project was launched. The project aims to create a larger, lighter and more durable composite blade for floating tidal turbines, enabling devices to reach capacities of over 2 MW. The consortium activities will focus on the development of the blades with Magallanes, which has developed a floating 2MW tidal energy device.

4.1.6.1 Expected impacts

The Consortium's aim is to reduce LCOE of 70% through a number of innovations, in particular:

- 50% CapEx reduction related to lower material consumption and 25% lower cost of new composites,
- 2% lower FCR stemming from increased understanding of failure and fatigue mechanisms and more durable composites with 66% higher lifespan.
- 40% reduction in O&M as a result of reduced cavitation wear, bio-fouling and aging.
- 20% increase in AEP thanks to enhanced hydrodynamic performance and higher inlet flow speeds for tidal turbine.

4.1.6.2 Innovations

- Accurate modelling of harsh hydrodynamic and environmental stresses for the development of testing and validation procedures.

- A new test rig for the evaluation of fatigue and cavitation on test probes and downscaled prototypes.
- A testing procedure including bio-fouling and marine environments evaluation in four different real scenarios.
- A development of numerical models for the prediction of lifespan and mechanical properties as function of the materials properties, hydrodynamic loads, time and water composition.
- Novel tidal generator blades designs integrating active control flow, advanced surfaces and new nano-enhanced composites.

As part of the project plan, the consortium has already begun testing of turbine blade panels made from fibreglass and a gel-coat coating, taken from the current Magallanes' turbine blade. The blade's samples will be submerged for six months to determine the level of bio-fouling on the surface, and used as a reference for the development of new blade materials and coatings. The consortium has also developed a numerical model simulating cavitation effects on blades which will be used to identify control mechanisms for the blades' operation and improve the performance of the turbines.

4.1.7 Others

The focus of the SME projects is often directed at understanding the commercial viability of the projects, as indicated earlier in the D2T2 project Nova Innovation undertook a market study for their turbine, similarly DesignPRO developed a market study for their 25 and 60 kW vertical axis turbines designed for riverine applications. The expected cost of the 25 kW turbine is of 167 000 EUR, which could compete with off-grid wind and solar PV applications, in terms of projected LCOE. The company works closely with GKinetic an Irish developer working on floating tidal energy converters with similar design.

Current2Current involved in the Subport project, is developing a subsea unit converting tidal stream and ocean currents into electrical power of Oil and Gas and other remote subsea applications. Their long-term plan is to sell 26 units by 2023 with revenue of EUR 20.8 million. A feasibility study was undertaken to understand the need of the oil and gas sector to allow for market entry of the Current2Current turbines as a replacement of subsea umbilicals.

4.2 Tidal Energy Demonstration

The EU supports 7 tidal energy projects as for technology at TRL 7-9 as shown in *Table 18*. Four projects are dedicated to the demonstration of tidal energy technology, one on optimisation tidal turbines, and two are funded through the FITPlot.

Table 18 H2020 Tidal energy projects at TRL>7p and related ETIP Challenges

Main Technology	Device Class	Project	tStatus
AR1500 (Atlantis, UK)	Horizontal Axis turbine	Demotide	Project terminated (financincal Issues0
Openhydro (IE/FR)	Ducted turbine	Octarray	Project terminated (company folded)
		Occitc	Project stopped,
SR2-2000 (ScotsRenewable, UK)	Horizontal Axis Turbine (Floating)	FloTEC	
M100 (Nova Innovation, UK)	Horizontal Axis Turbine (small size)	Enfait	
S250 (Tocardo, NL)	Horizontal Axis Turbine	InToTidal	
Magallanes (ES)	Horizontal Axis Turbine (Floating)	Ocean_2g	

4.2.1 Demotide

The project aimed at supporting the deployment of the Meygen 1B project. The grant-agreemen was terminated due to the difficulties encountered by the consortium to identify or being granted suitable revenue scheme for the project financing to be completed. As as highlighted in section 3.3.7, the lack of revenue support schemes in the UK specific to ocean energy means that projects participate in the same auctions for CfD against more established technologies such as offshore wind. The termination of the Demotide project reinforces the need to develop support schemes for ocean energy demonstration projects that are critical to unlock further cost reductions.

4.2.2 Occtic and Octarray

As discussed in the 2018 version of this report [74], Naval Energies divested from ocean energy in 2018 to focus on the development of floating wind energy converter. As a consequence the Octarray project, which aimed at deploying a 14 MW tidal array in Normadie was terminated. The Occtic project, related to the same device was not terminated, although no progress is reported since 2018. A new project coordinator has been appointed to see the project through.

4.2.3 FloTEC

The FloTEC is a demonstration project for the 2MW floating tidal energy converter developed by Oribtal Marine. The device was successfully deployed at EMEC and generated over 3 200 MWh of electricity.

The project has already resulted in the re-design of the second generation of the O2 device to be developed. The main features of the new superstructure design are:

- Legs hinged axially to give a 'gull-wing' movement to present nacelles, pitch systems and blades to surface for maintenance
- Legs attached above the waterline to simplify build, maintenance and provide improved cable routing with hull penetrations above the waterline.
- 2 x 20m rotor diameters;
- Optimised for volume manufacture
- Enhanced, lower cost power conversion.

The second O2 device is currently in fabrication and should be deployed in the second half of 2020. The expectation is that the new device is predicted to deliver an LCOE of 200 EUR/MWh in line with project aims.

4.2.4 InToTidal

The InToTidal project was terminated. One of the reasons behind the termination were the financial struggles of Tocardo, the supplier of the tidal energy technology.

4.2.5 Ocean_2G

The Ocean_2G projects aims at the development of a floating tidal platform equipped with 2 contra-rotating turbines developed by Magallanes Renewables. The device was deployed at EMEC in February 2019 for testing and optimisation.

The consortium indicated that the cost of a 2 MW platform is of EUR 3.5 million (EUR 1.75 million/MW) which appears to be competitive with most technologies reviewed so far. No performance data are available to understand capacity factor and potential LCEO. Magallanes plans to produce up to 18 turbines a year by year 2030.

Figure 15 Shape of the Magallanes tidal energy device. Copyright © 2020 Magallanes Renovables

4.2.6 RealTide

The aim of the RealTide project is to identify main failure causes of tidal turbines at sea and to provide a step change in the design of key components, namely the blades and power take-off systems, adapting them more accurately to the complex environmental tidal conditions. Advanced monitoring systems is to be integrated with these identified sub-systems and together with maintenance strategies will be implemented at outset from the design stage to achieve an increased reliability and improved performance over the full tidal turbine life.

4.3 Wave Energy R&D

The EU supports the development of wave energy R&D through four H2020-LCE projects and four H2020 SMEs projects (**Table 19**).

Table 19 H2020 projects on low TRL wave energy technologies and related ETIP Challenges

Main Technology	Device Class	Project	ETIP Challenge	Status
Electro-Mechanical Generator (UmbraGroup, IT)	N/A	IMAGINE	Power Take off and efficiency	
Wedge (ES)	Point Absorber	SEATitan	Power Take off	
C3 (Corpower, SE)	Point Absorber	PowerKite	Power Take off, Device reliability Improving costs and efficiency	
Marmok (Oceantesc ES)	OWC (Point Absorber)	Opera	Power Take off	
Symphony (Teamwork UK/NL)	Point Absorber	WETFEET	Power Take off, Device reliability Investigating novel devices	
Butterlfy (*Rotary Waves, ES*)	Other	Butterfly (SME)		
Infinity WEC (Ocean Harvesting Technologies, NO)	Point Absorber	OHT (MSE)		
Wavepiston (*DK*)	Other	Wavepiston (*SME)*		
eForcis (Smalle Technologies)	Point Absorber	eForcis BeForcis (SME)		

4.3.1 Waveboost

Waveboost is a project working on the optimisation of the Corpower C3 device, focusing on identifying control strategies and developing an innovative braking module with a Cyclic Energy Recovery System (CERS) to increase the energy extraction from the resonant device. The project aimed at increasing in annual energy output by 25% and a reduction LCOE by more than 30% compared to the state of art.

4.3.2 LiftWEC

The LiftWEC project was launched in November 2019 to explore the development of wave energy converters concept based on the exploitation of lift forces generated by wave-induced water velocities. By interacting with lift forces the LiftWEC concept has the advantage that the motion can be unidirectional. In addition, the lift-force can easily be reduced so that the concept can survive storms in the same way that modern wind turbines survive, by stopping turning. The concept proposed by the LiftWEC consortium is different compared to most wave energy converters so far developed since most of these concepts have been based on interacting with the waves using either buoyancy or diffraction forces.

4.3.2.1 Expected impacts

The LiftWEC project is exploring a novel concept of wave energy converters and aims to take it to TRL4.

- To achieve a complete understanding of the LiftWEC concept.
- To identify a viable outline structural design of the LiftWEC concept.
- To identify a viable O&Mstrategy for the LiftWEC concept.
- To achieve a low levelized cost of energy of the LiftWEC concept. The target levelised cost of energy is within an acceptable range (< 0.12 EUR/kWh) to attract commercial interest
- To produce accurate and validated hydrodynamic numerical models of the LiftWEC concept.
- To make all data for the LiftWEC concept publicly available
- To develop the LiftWEC concept with an acceptable social and environmental impact

4.3.3 Opera

OPERA was a research and innovation project at low TRL where a floating OWC device has been deployed in Spanish waters. The project employed the Oceantec Marmok device. The project Opera was successfully concluded in the summer of 2019. The project aimed at reducing the LCOE of 30%, progress the technology from TRL3 to TRL5 and share operational data from open-sea testing.

Different turbines developed by OceanTEC and Kymaner have been tested. Prior to development at sea, the innovative turbines were tested in one of the chambers of the Mutriku power plant. The Marmok device has been deployed at Bimep since December 2016, and has been recently retrieved for monitoring and installation of the 30 kW turbine developed by Kymaner.

4.3.3.1 Achievements

The project showed a significant demonstration and real-sea experience despite being primarily a research and innovation action. The project has achieved results above the initial expectations:

- All the innovations together developed by the project consortium led to a 62% reduction of LCOE (when extrapolating to a 100 MW array), well beyond the initial project targets.
- The biradial turbine in real-sea operation was shown to be more than 55% more efficient than conventional Wells turbine.
- Significant achievement s where obtained in moorings. The tethers developed during the project helped reducing the strain on the system caused by the peak loads.
- The development of advanced control algorithms also contributed to a 30% increase in power production.
- The project has applied the IEC standards and to delivered feedback to the committee,

Based on the operational experience gathered by the Opera project, the industrial experience gathered, it can be expected that the wave energy sector and future wave energy project can access and improve their strategy thanks to the results achieved by the Opera consortium.

4.3.4 Imagine

The Imagine project, launched in March 2018, aims at developing a new Electro-Mechanical Generator (EMG) proposed by Umbragroup S.P.A.. The EMG is designed for wave energy applications, as it could help decreasing CAPEX of current PTO technologies with over 50%, while increasing average efficiency above 70% and lifetime to 20 years. The technology has already received support through the Wave Energy Scotland PTO programme. The working principle of the EMG have been discussed in detail in the LCEO FET report.

4.3.4.1 Expected impacts

- Design, development and fabrication of a 250 kW EMG prototype, with CAPEX reduction of over 50% with respect to current PTO.

4.3.5 Sea-Titan

The SEA-TITAN project aims at designing, building, testing and validating a direct drive PTO solution to be used with multiple types of wave energy converter.

The focus is the development of a new configuration and geometry of a first generation Multitranslator Linear Switched Reluctance Machine employed in the Wedge wave energy converter currently deployed at Plocan in Spain.

The consortium will investigate the application of the new PTO not only to the WEDGE device but also to other WECs. Corpower, is also involved in the project, and collaborating on the identification of control strategies.

4.4 Wave Energy Demonstration

The EU supports 3 wave energy projects as for technology at TRL 7-9 as shown in *Table 20*. One project is dedicated to the demonstration of a wave energy farm, on supported by the Life programme to the demonstration of a novel wave energy converter and one to optimisation and scaling up of the PTO subsystem.

Table 20 H2020 wave energy projects at TRL>7p and related ETIP Challenges

Main Technology	Device Class	Project	ETIP Challenge
Penguin	Rotating Mass	Cefow	
Wave Roller	OWSC	MegaRoller	
Life	Point Absorber	LifeDemoWave	

4.4.1 Cefow

The project CEFOW was terminated in September 2019. The project only deployed 1 of the 3 devices that were originally planned to be deployed at the outset. The project had been hindered by delays in manufacturing, site selection, testing and a number of technical failures. The second Penguin WEC developed as part of the project is likely to be deployed at BIMEP in collaboration with EVE and Saipem.

4.4.2 Megaroller

The Megaroller project, which started in May 2018, aims at developing a 1 MW PTO for the oscillating wave surge converter Megaroller which is based on the WaveRoller energy converter developed by AW-Energy.

4.4.3 Life DemoWave

The Life DemoWave project is a wave energy demonstration project funded through the Life programme of the EU. The main objective of the DemoWave project is to demonstrate the viability of two wave energy converter (WEC) devices from the developer Gelula, which have already been researched and patented, for electricity generation.

The two prototypes, each one scaled at 25 kW, will be manufactured, installed and tested to demonstrate their technical and socio-economic viability, as well as the transferability potential.

4.4.3.1 Expected impacts

- Demonstration of the technical viability and survival capacity of two WEC prototypes
- Demonstration of the energy efficiency, power quality and high generation ratio of the systems.
- Demonstration of the electricity generation potential of these systems in comparison with other solutions.

4.4.3.2 Status and updates

The LIFE DEMOWAVE project demonstrated the technical feasibility of the use of wave power for electric generation to reduce greenhouse gas emissions. Two prototypes for 25 kW wave power generation were designed, constructed, installed and tested in the experimental site of Punta Langosteira (A Coruña) in Spain. One is based on a hydraulic generation system and the other on a mechanical generation system. On the basis of the results obtained regarding energy production, the hydraulic model showed better performance than the mechanical prototype. The prototypes incorporated new technology developed and patented by project consortium members, enabling a reduction in infrastructure and components from current WECs. The prototypes were optimised for high-energy waves and survival. Therefore, the results under experimental conditions for electricity production and CO_2 emissions reduction were lower than expected in the proposal. However, the results were in line with those obtained in other TRL 5 prototypes. Both DEMOWAVE prototypes also had reduced LCA CO_2 emissions and costs compared to other TRL 5 prototypes.

The wave power device developed within the project showed promising results, with high survival behaviour in extreme wave conditions; a compact and non-aggressive anchoring system; low costs in both CAPEX and OPEX (thanks to its ease of access for maintenance and minimal submerged mass); and returns compared to similar technologies for TRL 5

4.5 Ancillary projects

4.5.1 Muses

The MUSES project aimed at exploring the real opportunities for Multi-Use of sea space in Europe, looking at the area for potential innovation within the Blue Growth framework. It presented practical solutions on how to overcome existing barriers and minimise risks associated with MU development. Across five EU sea basins (Baltic Sea, North Sea, Mediterranean Sea, Black Sea and Eastern Atlantic).

The consortium developed an action plan, outlining a number of recommendations addressing the barriers hindering multi-use, on coordination and spatial planning, policies and regulations and future research priorities:

- A much wider range of opportunities for creating positive synergies among different maritime uses exist compared to what has been previously associated with the multi-use concept.
- The shift from a single-sector to a multi-sector approach may unleash a wide scale of new opportunities both for socio-economic development as well as improvement of the environmental status of our oceans.
- Combinations of fishery with tourism or offshore wind farms are already a reality today. Even though such combinations may not substantially impact general economic growth, they may provide other socio-cultural benefits for coastal communities and a shift of perspective on how different uses and users can work together rather than being separate.
- Moreover, new technological solutions such as floating offshore wind farms, hydrogen energy storage or various wave-energy-generation technologies can tap into a wider range of socio-economic and environmental benefits if multi-use solutions are considered in their designs right from the outset, through the application of life-cycle assessment, a systems-design approach or circular-economy principles.
- Multi-use development is not possible everywhere. Lack of suitable geomorphological and environmental conditions, or environmental risks make the development of MUs unsuitable for certain areas.
- Other barriers such as stakeholder perceptions, lack of awareness, as well as multi-use unfriendly policy and regulation, may be overcome through sufficient stakeholder integration in planning and policy processes on all geographical and governance levels.

The project also identified actions to support the development of multi-use system addressing multiple marine renewable energy system, and ocean energy systems together with aquaculture. The latter could provide significant benefit especially in terms of potential reduction in initial investment requirements for both developers due to shared operational and maintenance (O&M) costs throughout the lifetime of the multi-use systems.

4.5.2 DTOceanPlus

The DTOceanPlus project is the follow up of the FP7 DTOcean project that developed a suite of tools for the optimisation of ocean energy array. The projects aims to develop and demonstrate a second generation open source suite of design tools for the selection, development and deployment of ocean energy systems, including sub-systems, energy capture devices and arrays, in order to accelerate the commercialization of such technologies.The project has reached the half way mark in fall 2019, and has focused on the definition of specification of the DTOcean tool to satisfy the needs of the sector, based on results from user-groups consultation, and including functional and technical requirements for the developed tools. The project has also developed key demonstration scenarios for different users of the design tools, considering wave and tidal deployment sites, four technologies, and three tool uses (concept creation, technology development and array deployment).

The projects has engaged with a number of technology developers (e.g. Nova Innovation, see project EnFait) to validate and improve the different modules, including the one of System

Performance and Energy Yield (SPEY). The project is developing a standardised data representation framework in collaboration with OES.

4.6 Key takeaways

EU support is fundamental for ocean energy R&D, supporting a wide range of tidal and wave energy technologies. The outcomes of this support are varied. From the analysis it emerged that High TRL actions and support systems should be re-assessed to avoid that projects are terminated without achieving the expected results.

4.6.1 Tidal energy R&D

Supported tidal energy R&D projects focus primarily on the optimisation of PTO for tidal energy applications. And on other key components such as blades. In terms of PTO there is an increase certain level of convergence between the different projects. Overall, it appears that the supported EU projects have met their targets and contributed to the progression of technology to higher TRL. The R&D undertaken has contributed to develop new components, namely PTO, umbilical and tethers that can assist the cost-reduction of tidal energy technology and drive it towards the targets of the SET Plan.

4.6.2 Tidal energy demos

Since the start of H2020, the EU has not been shy in its commitment in supporting tidal energy demonstration projects. This commitment has yielded significant results for those projects that have been deployed, highlighting that technology costs can be reduced, validating the technology developed and its role in the energy system, and ensuring a steady and balanced support through the innovation cycle.

Nevertheless, the implementation of tidal energy R&D project has not always been successful with 3 projects being terminated before the technology had even being deployed. On the one hand these terminations highlight the difficulties that technology developers encounter in deploying their technology and the struggles in mobilising other viable financing instruments for the projects. The underlying issues may be related to the mismatch between the timelines and duration of the projects imposed by the grant agreements stemming from funding schemes, against the timelines and duration needed for due diligence that investors and financial institutions undertaken before signing a loan and deployment.

Another important aspects that stems from the assessment of tidal energy R&D is that technology developers are looking to deploy their technologies in countries where support mechanisms are available, e.g. Canada and East Asia. As a results it is likely the EU may not reap the fruits from the development of the technology in terms of market creation and associated benefits in terms of supply chain engagement.

4.6.3 Wave energy R&D

The main focus of wave energy R&D is the development of reliable PTO for wave energy conversion. Most projects put significant emphasis on this aspect. Results from TRL 5 experiments indicate that performances are on par or even better than expectation, providing a positive outlook for the development of wave energy technology and their progression to higher TRL.

Significant learnings have been obtained in other aspects, such as survivability and moorings. These learning can offer benefit to the sector and speed-up a much needed convergence in the sector.

4.6.4 Wave energy demo

Three wave energy demonstration projects have been supported by EU funds in H2020 and Life programme. The Gelula device, supported by the Life programme, has shown good survivability and potential. On the other hand, the Cefow project was terminated following a number of delays and failures. Only one out of three devices was deployed as part of the project. As in the case of tidal energy demo, it is clear that there are mismatches in timing between awarding grants for demonstration projects and their implementation, and hindering the overall outcome of the funding programmes and the effectiveness of EU support.

4.6.5 ETIP Priorities

Most of the H2020 projects address one of more ETIP priority challenges. Challenges related to the development of improved PTO and improved reliability and survivability of the device are addressed the most. Other key challenges addressed, although not listed a key priorities, are cost-effective moorings and cost-effective electrical subsystems. As seen in this section considerable progress has been made by the projects in these areas and with solutions validated at TRL 6. It's recommended that the viability of these solutions are explored further. *Table 21* present an overview of ETIP priorities are assessed and recommendations for future support.

Table 21 ETIP challenges and H2020 key lessons. Colour code identifies if priority is addressed in current H2020 projects: green –many projects, yellow – few projects, red - not addressed

Priority	Challenge	Current focus in H2020	Key takeways	Recommendation
A.1	Developing novel concepts for improved power take-offs (PTOs)	●	Key areas of ongoing H2020. Projects Focus mainly at TRL6-7	Maintain support for higher TRLs, possibly in line with priority A.5. Identify way to take the lessons from Waveboost, Opera, Tipa and Powerkite to support action at a higher TRL, maybe with more collaboration between the different developers.
A.2	Increasing device reliability and survivability	●	Focus of many projects, especially IA actions.	Support needed, reliability and survivability issues not solved yet. May require definitions of KPIs
A.3	Investigating alternative materials and manufacturing processes for device structures	●	Number of projects focusing on material will provide clear benefit to the sector.	This is a low TRL topic, developers are investigating the topic for improving their conversion technologies. Low TRL call based on FET/WES study could provide broader results to the sector
A.4	Investigating novel devices before moving towards convergence of design	●	Very few projects address the same technology.	No changes recommended to H2020 calls
A.5	Defining and enforcing standards for stage progression through scale testing	●	There is an ongoing call addressing this item.	Development of Wave Energy Europe and Stage-gate metrics as part of SET Plan implementation plan would address the topic.
A.6	Developing and implementing optimisation tools	●	DTOceanplus project addressing this topcis	

Priority	Challenge	Current focus in H2020	Key takeways	Recommendation
B.1	Building on existing guidelines and standards for third-party verification and testing	●	Not addressed by H2020	There are number of Interreg projects addressing this issues and learning should be extracted from them.
B.2	Developing improved, more cost effective mooring and foundation systems	●	Addressed by few project, significant potential for shared knowledge	There are learning from many of the projects in this context, and it should be taken as one of the main progress obtained from the EU supported proejcts.
B.3	Implementing suitable condition monitoring systems	●	Addressed by few project, significant potential for shared knowledge	Support further R&D on the topic., or coupled with IA projects. Key results may be expected in this area from the Releatide and from the Nemmo project.
B.4	Improving the efficiency and cost-effectiveness of electrical subsystems and power electronics	●	Addressed by few project, significant potential for shared knowledge	Support further R&D on the topicIt presents an area where collaboration or joint projects with wind, or energy systems thems could yield significant learning.
B.5	Optimising offshore operations and maintenance missions	●	Issues is not fully addressed due to delays in getting devices in the water. Demotide and Octarray would have addressed this topic.	Requires more demonstration projects. Currently hindered by lack of projects going in the water.
B.6	Developing dedicated vessels and tools	●	Not addressed by H2020	Requires certain convergence of design and pipeline of projects to be addressed. Might be a R&D project in the transport programme before the commercial roll-out phase.
C.1	Developing expertise related to the manufacture of ocean energy technologies	●	Manufacturing is addressed, blindly in some SME projects and some business cases.	Addressing manufacturing issues requires a design-freeze and project pipeline. May be valuable to explore as a work package part of IA projects.
C.2	Scaling up from single device deployments to arrays	●	Many projects currently focus on single devices.	If projects at TRL6-7 are successful, this topic may need to be explored as a follow-upstage of development of the technologies.Enfait project and deployment of the new Oribtal device will help see progression in this area.

5 TECHNOLOGY DEVELOPMENT OUTLOOK

The development of ocean energy sector requires that significant cost reductions are achieved in order for wave and tidal energy technologies to become competitive with other renewable energy sources. Whilst in the long term expectations are that ocean energy could contribute up to 10% of the EU energy needs. However, in the short term, the sector need to reduce its costs: The targets sets for wave and tidal energy technologies means that the costs of generating electricity from the ocean need to be reduced of 65% by 2025.

Since 2016, ocean energy converters have made stride forwards, with tidal energy technologies showing that cost-reductions and continuous generations are possible.

In the 2018 version of the technology development report and market report for ocean energy the potential deployment of ocean energy in technologies by 2030, 2040 and 2050 was modelled using the JRC-EU-TIMES Model. The JRC-EU-TIMES [75] model offers a tool for assessing the possible impact of technology and cost developments – a note to explain the main features of the model is included in a dedicated annex. It represents the energy system of the EU28 plus Switzerland, Iceland and Norway, with each country constituting one region of the model. It simulates a series of 9 consecutive time periods from 2005 to 2060, with results reported for 2020, 2030, 2040 and 2050. The model was run with three baseline scenarios:

- Baseline: Continuation of current trends; no ambitious carbon policy outside of Europe; only 48 % CO_2 reduction by 2050
- Diversified: Usage of all known supply, efficiency and mitigation options (including CCS and new nuclear plants); 2050 CO_2 reduction target is achieved
- ProRES: 80% CO_2 reduction by 2050; no new nuclear; no CCS. For this analysis we use the scenario employed by Sgobbi et Al, as validated through peer-review [76].
- SET Plan: The SET Plan scenario evaluates the potential deployment of wave and tidal energy technology under the assumption that they meet the 2025, 2030 and 2035 targets. This scenario has been created since with the current conditions no deployment of wave and tidal energy technology is expected in the other scenario aside from the ProRES scenario. Calculations have been based on learning factors employed in [11].

In previous reports the assessment of ocean energy deployment focused on the 3 baseline scenarios and the associated sensitivity runs for the high and low learning rates, considering the EU as a whole. What emerged from previous assessments of the JRC-EU-TIMES Modelling results is that the deployment of ocean energy is dependent on three main aspects: Cost reduction, Policy and flexibility.

5.1 Cost reduction assessment

Current technologies cost are too high and only through significant cost-reduction they will be able to ensure the uptake of ocean energy technologies in the electricity market.

The critical KPI for the assessment of the cost-reductions needs for ocean energy technology is the LCOE. By 2025, LCOE for tidal energy should reach 15 cEUR/kWh against the current reference of 40 cEUR/kWh, whilst for wave energy the target is of 20 cEUR/kWh against the current 60 cEUR/kWh.

Three key parameters affect the LCOE, the capital expenditure (CAPEX) of a project/device expressed in EUR/MW, the operational expenditure (OPEX) expressed in EUR/MW/year, and the annual energy production (AEP) which is dependent on the capacity factor.

As seen in the previous chapter, in some cases LCOE estimates are provided, in other cases AEP and CAPEX estimates are provided. Other factors such as discount rate, are not defined, so in order to allow for comparison of the data we will consider discount rate of 12%, learning rate of 12%, Opex of 5% of CAPEX, and lifetime of 20 years.

It is important to note that the reduction of costs is dependent by the deployment of technology. Thus, the high costs of today's technology are also influenced by limited deployment.

Other factors concur in driving cost reduction[77], [78]:

- Learning by doing, which refers to the learning achieved through methodological improvements, increased efficiency and specialisation.
- Learning by research, as a result of R&D investments and introduction of new materials or components.
- Learning by interaction, achieved through knowledge sharing and knowledge diffusion.
- Learning by upscaling, referring to increase manufacturing capabilities.
- Learning by upsizing of the product, e.g. increased power rating of a turbine.

5.2 Policy support

Cost-reduction and technology deployment go hand-in-hand. It is therefore of primary importance that policies and mechanisms support the deployments of ocean energy demonstration projects. The difficulties encountered by developers in finalising investments for wave and tidal demonstration projects highlight the need to find valuable financing solution for emerging technologies that have achieved high TRL but are still low in the MRL scale.

The review of the NECPs has shown that ocean energy technologies are still considered “emerging” and expected to contribute only in minimal part to the 2030 targets. Therefore most of the policy support is expected to be come under the “Research Innovation and Competitiveness“ umbrella of the NECPs. Yet it is important that the gap between technology R&D and market is filled with policy measure aimed at reducing risk for project developers and investors if ocean energy technologies are to play a significant role in the path to carbon neutrality as indicated in the European Green Deal.

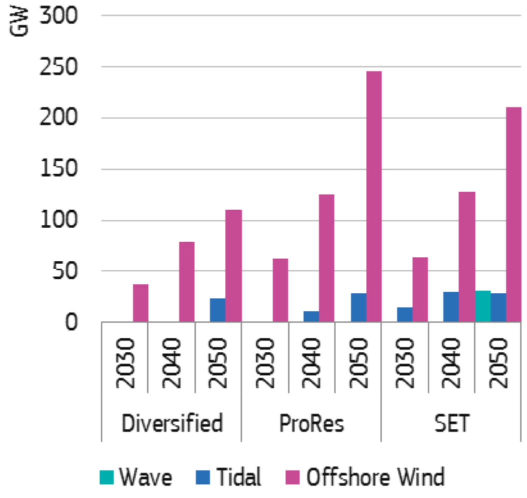
5.3 Flexibility

Ocean energy deployment in the EU energy system as modelled in JRC-EU-TIMES depends not only on the assumptions made for tidal and wave energy cost and performance, but also on the assumptions made for the other energy technologies modelled, and their uptake in the energy system. Since the JRC-EU-TIMES model is an optimisation model, energy technologies are effectively competing one with each other. Figure 16 shows the contribution of ocean energy to the energy system of each MS under different scenarios. Competition with other energy sources, such as wind is minimal. In fact, the share of wind energy in countries such as Ireland and UK is only partly affected by the pronounced deployment of ocean energy under the SET Plan scenario. Furthermore, in countries such as Spain and Portugal both ocean and wind energy increase under the SET Plan scenario. Yet, under the SET Plan scenario, countries with a significant share of tidal energy technologies (UK, France and Ireland) have no uptake of wave energy technologies.

Figure 16 Role of ocean energy technology in the energy system under different scenarios. Source: JRC

A more in-depth look at the deployment of offshore renewable energies under different JRC-EU-Times scenarios is shown in Figure 17. By 2050 the uptake of tidal energy is similar between scenarios, with capacity between 25-28 GW. The uptake of offshore wind energy increases significantly between the diversified and ProRes scenario. However, in the SET Plan scenario, when wave energy enters the market (30 GW by 2050) offshore wind capacity is reduced by about 34 GW, indicating that wave energy and offshore wind technology may, in the long term, be competing for a place in the market.

Figure 17 Modelled deployment of marine renewable energies under the diversified, ProRes and SET scenarios. Source: JRC



While ocean energy technologies are not expected to play a major role in the energy system by 2030, it will be still needed to improve flexibility and predictability. Tidal energy can be considered almost equivalent to a baseload technology, whilst wave energy is more predictable than wind energy. Understanding the role that ocean energy can play in the energy system in terms of flexibility and integration with other renewable sources will strengthen the case for further investment in its development. In particular this will help in shifting the narrative that ocean energy technologies and offshore wind are in competition when they are complimentary in providing the grid with a stable input.

5.4 The role of ocean energy towards Zero Emissions and R&I in supporting ocean energy

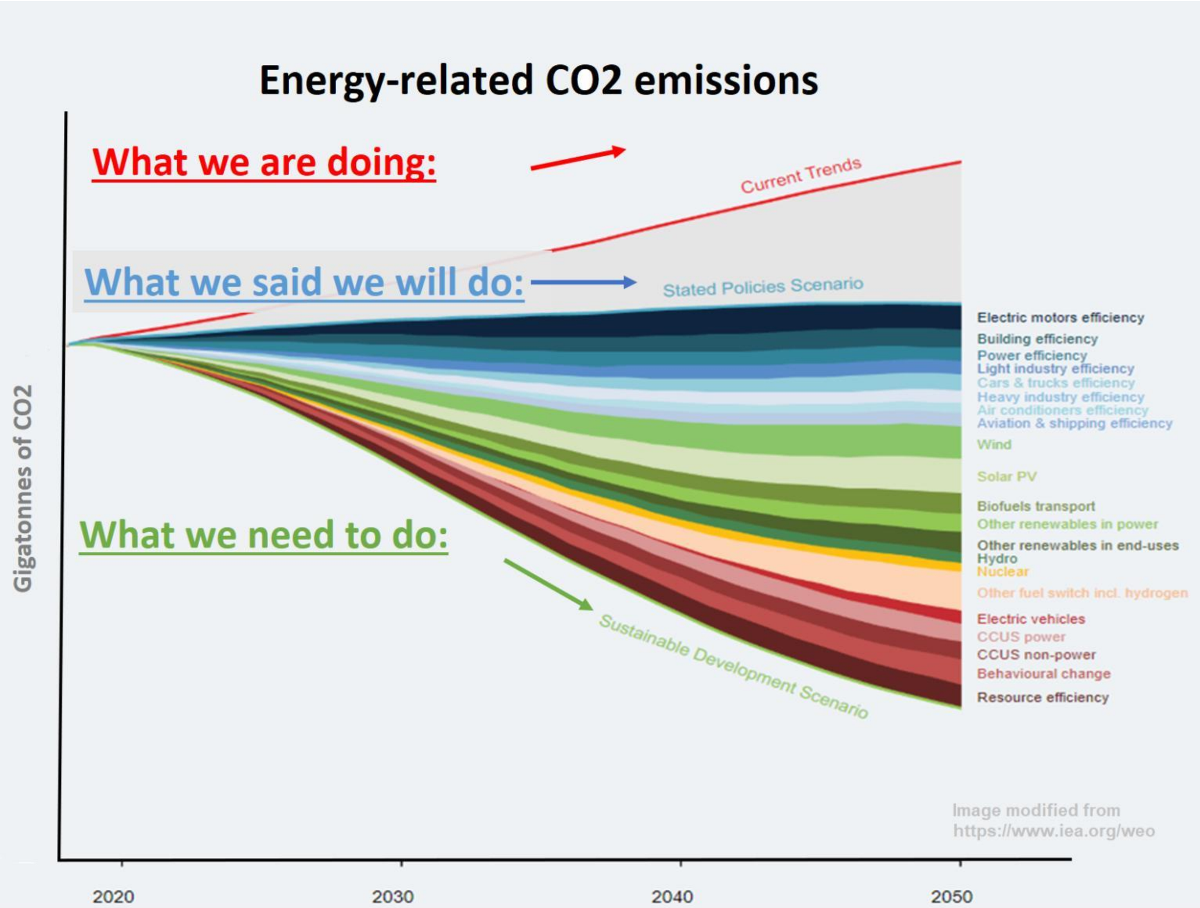
The development and uptake of ocean energy is at critical stage. High technology costs are hindering technology uptake. Whilst technology validation is proving, at least for tidal energy technologies, that they can deliver power reliably to the grid, project developers are having difficult times reaching final investment decisions.

The concrete risk for ocean energy is that public supports fades in favour of other energy technologies, especially offshore wind. Over the past few years offshore wind costs have decreased significantly and many Member States are betting on offshore wind to meet their 2030 decarbonisation targets, as highlighted in the various MS NECPs[13].

Whilst the shift in public support, especially in the short-to-medium term, may have negative consequences for the development of ocean energy technology and the current EU leadership in the sector; the recently released IEA World Energy Outlook [79] report emphasises that beyond Wind, Solar PV and biofuels will be needed to achieve the goals of the Paris deal.

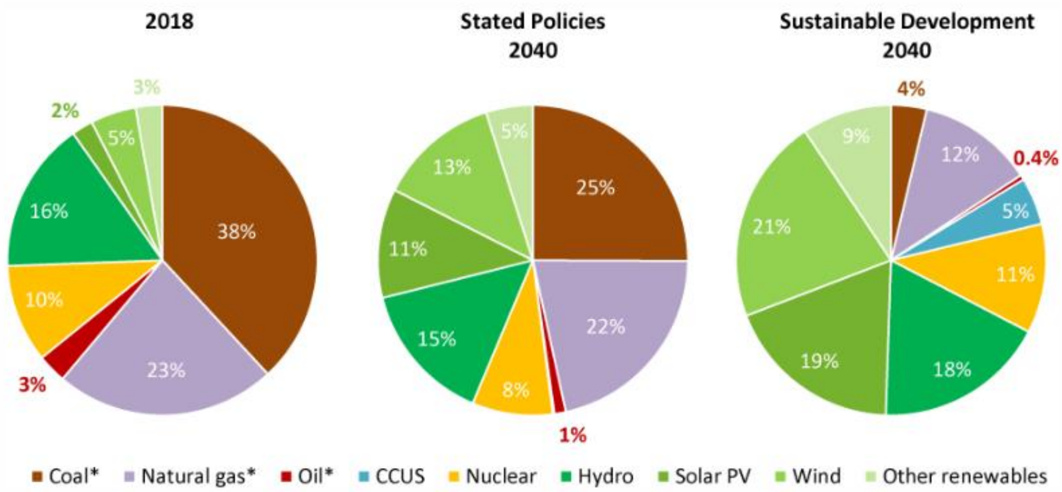
[13] https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en

Figure 18 What is needed to reach the sustainable development scenario. IEA WEO 2019 [79].



In fact, as shown in ***Figure 18***, the path to decarbonisation requires multiple solutions from the development of CCUS, to changes in our behaviour to renewable energy solution. In particular, in the global electricity mix, other renewable will account for up to 9% of the mix by 2040 under the sustainable development scenario (***Figure 19***)[79], including ocean energy deployment.

Figure 19 Global electricity mix – IEA WOE 2019 [79]



In this short note we compare the deployment of ocean energy technology modelled by the IEA with those modelled by the JRC-EU-TIMES model within the context of the Low Carbon Energy Observatory and implication for R&I support for ocean energy.

5.4.1 Assumptions and scenarios

5.4.1.1 IEA assumptions

The IEA [79]considers 3 main scenarios in their WEO:

- Current policy initiative – maintaining the current status of energy policy, leading to an increase of CO_2 emissions (*Figure 18*);
- Stated policies scenario – implementation of policies that have already been announced/implemented to reduced CO_2 emissions, which are expected to leader to a stabilisation of CO_2 emissions (*Figure 18*);
- Sustainable development scenario – actions and technologies needed to meet the Sustainable Development Goals and the Paris Climate deal, towards zero CO_2 emissions.

The IEA results are provided as aggregate for marine energy, including the following technologies:

- Wave energy,
- Tidal stream energy,
- Tidal barrage,
- Ocean thermal energy conversion,
- Salinity gradient.

Results are provided in terms of Generation (TWh), and cumulative installed capacity (GW) at global scale and for Europe. No information is available (yet) on cost assumptions, learning rates.

5.4.1.2 JRC-EU-TIMES assumptions

The JRC-EU-TIMES [80] consider 3 main story-lines/ scenarios:

- Baseline scenario – assume slow renewable deployment, and increase of CO_2 emission from 1990 level – similar to IEA CPI
- Diversified - Assumes moderate RES deployment, with 80% reduction in CO_2 compared to 1990 levels;
- ProRES – assumes high RES deployment with 80% reduction in CO_2

- Further sensitivities have been implemented with the JRC-EU-TIMES model to evaluate particular technology learning and or policy initiatives such as:
- SET Plan – In this assumption energy technologies that are part of the SET Plan meet their cost-reduction targets as presented in the SET Plan declarations of intent. SET Plan targets are applied to all technology. This analysis is a subset of the ProRES scenario.
- NearZERO – assumes the implementation of policies that aim to stimulate the transition towards climate-neutrality/zero CO_2 emissions. This analysis is a subset of the ProRES scenario
- LowLR – low learning rates are applied to RES technologies.

The JRC EU times models wave, tidal stream and tidal range technologies. For each technology costs information have been assessed by the JRC against international values (IEA-OES TCP) and integrated with the information available from H2020 funded projects.

In order to provide comparison between the IEA and the JRC results, the deployment of wave and tidal energy technology has been summed. Data are provided for year 2025, 2030, 2040 and 2050.

5.4.1.3 DG MARE Market Study

In June 2018 DG MARE [81] released a study on ocean energy market developed by Wavec and Cogea. The report provided pessimistic, reference and disruptive deployment scenario for wave, tidal stream, tidal barrage and ocean thermal energy technologies, based on technology progression and project announcement for the period 2018-2030

5.4.2 Results and analysis

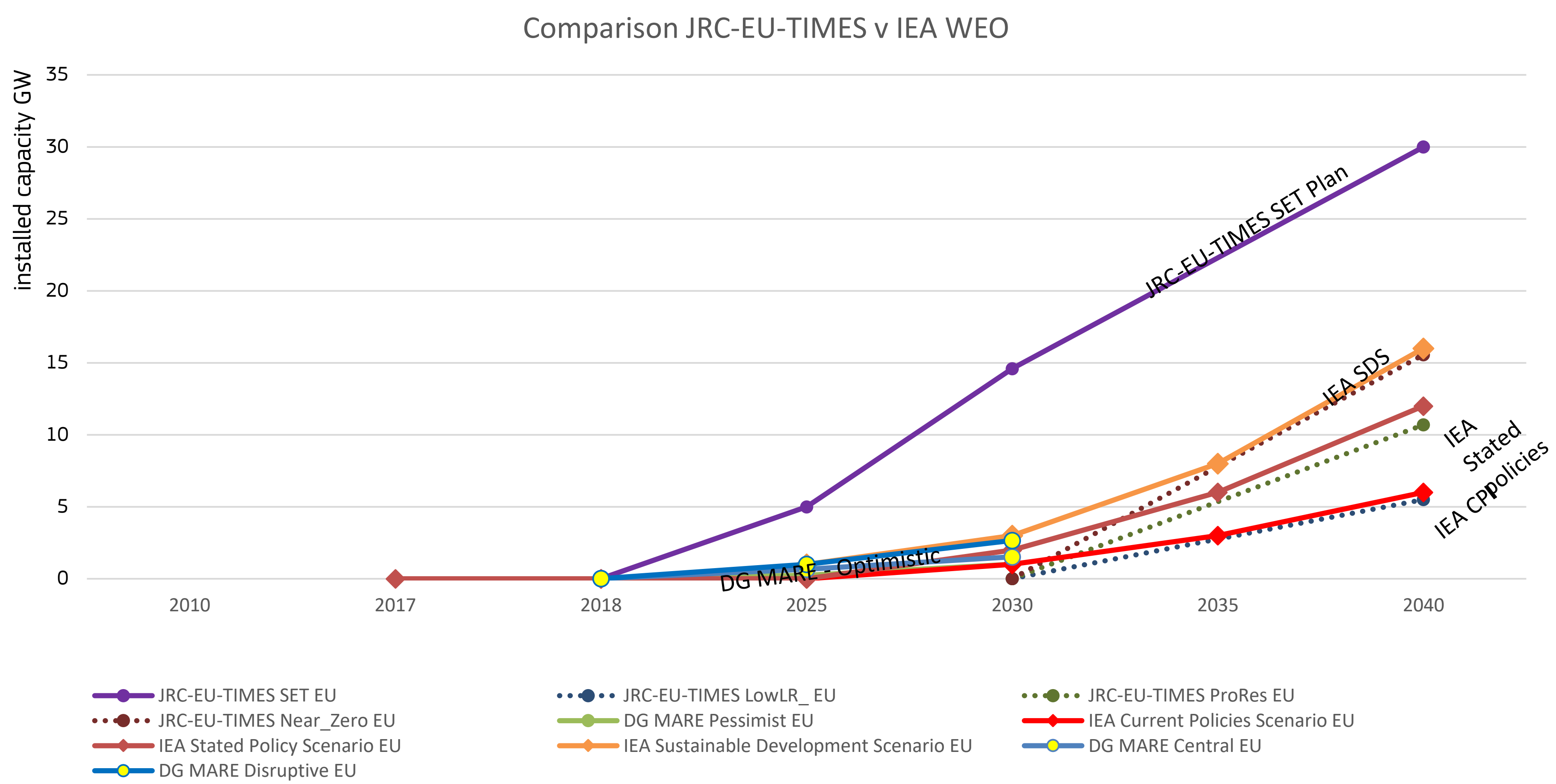
The comparison of the result between the different model and studies is summarised in Figure 20, key takeaways are as follows:

- In all 3 IEA scenario ocean energy plays a marginal role in the energy systems ranging between 5 GW in CPI scenario and 15 GW in the Sustainable development scenario
- In the short term (2025-2030), there is good agreement between the DG MARE disruptive deployment scenario and the IEA SDS scenario.
- In terms of JRC-EU-TIMES vs WEO comparison it can be noticed that by 2040 the results stemming from WEO and those of the JRC indicate similar deployments for ocean energy:
    - The IEA CPI scenario and the JRC-EU-TIMES LowLR indicate a deployment of 5 GW of ocean energy technology by 2040.
    - The IEA-SPS and the JRC-EU-Times ProRES scenario show a deployment of about 11 GW by 2040
    - The IEA SDS and the JRC-EU-TIMES near-zero scenario indicate deployment of more than 15 GW by 2040.
    - Overall it can be said that there's good agreement between the outcomes of the JRC-EU-TIMES and the IEA-WEO, with the IEA providing a smoother trajectory for ocean energy deployment.

The results from the JRC-EU-TIMES scenario assume that the targets of the SET Plan are met, shows however that by 2030 a capacity of up to 14 GW of ocean energy can be reached by 2030 if cost-reduction are achieved sooner.

This highlights the importance of investing and maintaining R&I investments in the sector. The critical point for ocean energy is to match current EU support with national instruments and private finance. In this sense the development of various mechanisms in Europe such as the Innovation Fund, the Blue Invest Fund should take into account the lessons learned from NER300 and identify ways to support emerging technologies.

Figure 20 Comparison of results for ocean energy deployment. Results from JRC-EU-TIMES showing deployed capacity in 2040 are presented with dotted line to represent linear deployment between the 0 deployment in 2030 to the cumulative capacity resulting from the model.



6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The EU is the current leader in ocean energy. Most of the global wave and tidal energy operational capacity is deployed in the EU or employs EU technology. Over the past decade, the EU (Commission and Member states) has supported ocean energy R&D and demonstration projects for a total of EUR 1100 million (including EUR 850 million of MS public funds). This is unmatched globally.

The SET Plan Ocean Energy Implementation Plan indicates that further support to low TRL R&D and to demo projects for wave and tidal energy technology is needed. The review of the H2020 projects indicated that the technologies under investigation at low TRL are meeting their KPIs, whilst demonstration projects are hindered mainly by market-access issues.

More funding has been allocated to ocean energy during H2020 than any previous funding programme. The area where European Commission support has contributed most is for mid-TRL projects focusing on key components such as PTO, moorings and seals. Important steps forward have been made in this area in the ongoing H2020 projects. In particular:

- Moorings solutions adopted in many floating tidal and wave energy devices have been optimised and cost-effective solutions identified.
- Many projects have reported significant improvements in PTO of 25 % or more in efficiency of conversion.

The next step is to build on the progress achieved, often at individual project level, and transform it to a sector-level advance in technology to meet the overall SET Plan targets.

An area where new thinking on EU support instruments is needed, is R&D projects at higher TRLs. Such demonstration projects require significant private investment, and are often hindered by the difficulties in finalising investment decisions. As a result, EU funds allocated in the past either have had limited effects, or were even not used, as is the case when the projects are terminated. There is a clear mismatch between the award of grants and the identification of private financial instruments to support the projects, and this needs to be addressed to ensure funds are put to be used effectively.

Failure in developing appropriate revenue schemes for ocean energy technology may see EU lose is current competitiveness in favours of markets where revenue support is available, with the risks of losing on the potential benefits in terms of manufacturing and employment that can be linked with the industrial uptake of ocean energy technology developed in the EU.

Ocean energy has significant untapped potential for electricity market in the EU. Exploiting the significant pool of knowledge and expertise that has been developed could unlock this potential, which according to the JRC-EU-TIMES energy system mode, can reach 14.8-46 GW of generation capacity by 2050.

6.2 Recommendations

Technology wise – Ocean energy is still an expensive business. Progress is taking place.. Of 9 demonstration projects, 4 have been terminated by the European Commission, and only two have so far provided significant results in terms of technology validation and progress towards the utility market. The lessons learnt from H2020 projects should be shared as widely as possible among the developers, policy makers and other stakeholders.

Technology limitations and the difficulties to unlock financial instruments to support the deployment have hindered the outcome of the projects.

Implementing stage gate metrics and pre-commercial procurement, as indicated in the SET Plan Implementation plan, could lead to proven technology getting funded for higher level deployment. Furthermore, it may be worthwhile to reassess the design of high TRL actions with the implementation of a two-steps assessment for all projects (e.g. as in the case of the EnFait projects) and identify ways to align the grant-based systems of the research framework programme with loan base support (e.g. innovation funds), and/or to re-invest the funds unallocated in other projects in the form of low interest loans (e.g. impact investments where the other indicators aside from the financial performance of projects are evaluated).

Market wise – Despite the steps forwards in technology development and demonstration, the sector faces struggles in the creation of a viable market. National support appears low, as indicated by the draft NECPs and the lack of clear support schemes for demonstration projects is proving hard to manage for ocean energy developers. This limits the possibility of developing a business case, and of identifying viable ways to develop and deploy the technology. Investigating alternative market routes for ocean energy, valorising their capability to provide flexibility to the grid as a highly predictable source and their role for decarbonising small communities/islands, should be given more focus.

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ACRONYMS AND ABBREVIATIONS

ARENA	Australia Renewable Energy Agency
ADEME	French Environment & Energy Management Agency
BECRC	Blue Economy Cooperative Research Centre
CAP	Long-term decarbonisation scenario
CAPEX	Capital Expenditure
CF	Capacity Factor
COP	Coefficient of Performance
COST	Cooperation in Science and Technology
CPI	Current Policy Initiative
DOE	US Department of Energy
DOI	Declaration of Intent
EC	European Commission
EMEC	European Marine Energy Centre
EIB	European Investment Bank
ETIP	Energy Technology Innovation Platform
ETRI	Energy Technology Reference Indicators
EU	European Union
FP6	6th Framework Programme
FP7	7th Framework Programme
HAT	Horizontal Axis Turbine
H2020	Horizon 2020 Programme
IA	Innovation Actions
IEE	Intelligent Energy Europe
IEA-OES	International Energy Agency Ocean Energy Systems
LCOE	Levelised Cost of Energy
MRL	Manufacturing Readiness Level
MS	Member State
MSCA	Marie Skłodowska-Curie Actions
NER300	New Entrants' Reserve
NREAP	National Renewable Energy Action Plan
PA	Point Absorber
PRO	Pressurised Reverse Osmosis
PTO	Power Take Off
OFGEM	Office of Gas and Electricity Markets

OPEX	Operating Expenditure
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column
OWSC	Oscillating Wave Surge Converter
RED	Reverse Electro-Dialysis
RIA	Research Innovation Actions
SET Plan	Strategic Energy Technology Plan
SME	Small-medium Enterprise
TEC	Tidal Energy Converter
TRL	Technology Readiness Level
VAT	Vertical Axis Turbine
WEC	Wave Energy Converter

Units

Throughout the report we use mEUR as an abbreviation of millions of EURO and bEUR for billions of EURO.

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APPENDIX A: LIST OF EC-FUNDED PROJECT AND AREAS OF RESEARCH

Table 22 List of EU co-fund projects identified for the scope of this report. The table presents also which sub-technologies were investigated by the projects, and the specific R&D areas of investigation

Instrument	Project Acronym	Technology Dev	Device 1	Wave	Tidal	Wind	Coordination Activitiv	Standardisation	Demonstration	Testing	Multiplatform	PTO	Device	Structure	Optimisation	Resource	Training	Consenting	Grid
SME	BUTTERFLY	YES	Butterfly (Rotary Waves)	●									●						
IA	**CEFOW**	**YES**	**Wello Penguin**	●					●	●			●						
SME	D2T2	YES	Nova Innovation		●														
IA	**DEMOTIDE**	**YES**	**Atlantis**		●				●			●	●		●				
SME	Direct Drive TT	YES	Nova Innovation		●					●		●							
SME	DP Renewables	YES	Design Pro (River Turbine)							●									
IA	DTOceanPlus	YES	Multple for validation					●	●	●					●				
SME	eForcis and BeForcis	YES	Eforcis	●															
IA	Element	YES	Nova Innovation		●										●				
IA	EnFAIT	YES	Nova Innovation	●									●						
CSA	ETIP OCEAN	NO					●												
SME	FFITT								●	●		●		●	●				
IA	FloTEC	YES	ScotsRenewable		●														
SME	HydroKinetic-25	YES	Design Pro (river)							●									
RIA	IMAGINE	YES	Umbra		●							●							
FTIPilot	**InToTidal**	**YES**	**Tocardo**		●				●			●	●	●					
RIA	LiftWEC	Yes		●									●	●					
RIA	MARINERGI	NO		●	●	●				●		●							
RIA	MARINET2	NO		●	●	●				●		●							
RIA	MegaRoller	YES	Waveroller	●					●	●		●							
MSCA	MoWE	NO		●										●					
CSA	MUSES	NO		●	●													●	
RIA	Nemmo	Yes	Magallanes		●									●					

Instrument	Project Acronym	Technology Dev	Device 1	Wave	Tidal	Wind	Coordination Activitiv	Standardisation	Demonstration	Testing	Multiplatform	PTO	Device	Structure	Optimisation	Resource	Training	Consenting	Grid
FTIPilot	OCEAN_2G	YES	Magallanes	□	●	□	□	□	●	□	□	●	●	□	□	□	□	□	□
CSA	OCEANERA-NET COFUND	NO		□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
IA	**OCTARRAY**	**YES**	**Openhydro**	□	●	□	□	□	●	□	□	□	□	□	□	□	□	□	□
RIA	OCTTIC	YES	Openhydro	□	●	□	□	□	□	●	□	●	□	□	□	□	□	□	□
SME	OHT	YES	Ocean Harvesting Technol-ogies	●	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
RIA	OPERA	YES	OceanTEC	●	□	□	□	□	□	●	□	●	□	□	□	□	□	□	□
MSCA	OpTiCA	NO		□	●	□	□	□	□	□	□	□	□	□	●	□	□	□	□
RIA	PowerKite	YES	Minesto	□	●	□	□	□	●	●	□	●	□	□	□	□	□	□	□
RIA	RealTide	YES	Sabella	□	●	□	□	□	□	□	□	□	□	□	●	●	□	□	□
SME	SEAMETEC	YES	Enerocean	●	●	●	□	□	□	□	□	□	□	●	□	□	□	□	□
RIA	SEA-TITAN	YES	Wedge Global	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
SME	SUBPORT	YES	Current2current	□	●	□	□	□	□	□	□	□	□	□	□	□	□	□	□
	LIFE DEMOWAVE			□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
RIA	TAOIDE	YES	ORPC	□	●	□	□	□	□	●	□	●	●	□	□	□	□	□	□
RIA	TIPA	YES	Nova Innovation	□	●	□	□	□	□	●	□	●	●	□	□	□	□	□	□
SME	WATEC			□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
RIA	WaveBoost	YES	Corpower	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
SME	Wavepiston	YES	Wavepiston	●	□	□	□	□	□	□	□	□	●	□	□	□	□	□	□
RIA	WETFEET	YES	Symphony	●	□	□	□	□	□	□	□	●	●	□	□	□	□	□	□

APPENDIX B: ENTRY TRL OF TECHNOLOGY PROJECTS

Project Acronym	Technology Development	Device 1	Device 2	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9
BUTTERFLY	YES	Butterfly (Rotary Waves)				●	●	●				
CEFOW	YES	Wello Penguin								●		
D2T2	YES	Nova Innovation							●	●	●	
DEMOTIDE	YES	Atlantis									●	●
Direct Drive TT	YES	Nova Innovation						●	●			
DP Renewables	YES	Design Pro (river)						●	●			
eForcis and BeForcis	YES	Eforcis					●	●				
EnFAIT	YES	Nova Innovation									●	●
FFITT		Fish Flow				●	●					
FloTEC	YES	ScotsRenewable									●	●
HydroKinetic-25	YES	Design Pro (river)			●	●						
IMAGINE	YES	Umbra							●	●		
InToTidal	YES	Tocardo								●	●	
MegaRoller	YES	Waveroller								●	●	
OCEAN_2G	YES	Magallanes								●	●	
OCTARRAY	YES	Openhydro									●	●
OCTTIC	YES	Openhydro								●	●	
OHT	YES	Ocean Harvesting Technologies					●	●				
OPERA	YES	OceanTEC						●	●			
OpTiCA	NO											
PowerKite	YES	Minesto							●	●		
RealTide	YES	Sabella								●	●	
SEAMETEC	YES	Enerocean						●				
SEA-TITAN	YES	Wedge Global							●			
SUBPORT	YES	Current2current					●	●				
LIFE DEMOWAVE		Life Demo						●	●			
TAOIDE	YES	ORPC						●	●			
TIPA	YES	Nova Innovation								●	●	
WaveBoost	YES	Corpower						●	●			
Wavepiston	YES	Wavepiston				●	●					
WETFEET	YES	Symphony			●	●						

APPENDIX C : ETIP OCEAN TECH KEY R&I AREAS

Priority	Challenge	Description
A.1	Developing novel concepts for improved power take-offs (PTOs	Work to improve the performance, reliability and cost of PTOs will help maximise energy capture.
A.2	Increasing device reliability and survivability	Improving resilience of devices, e.g. using control systems. Control systems act to optimise power production and reduce stress and fatigue on components by allowing devices to adapt to changing ocean conditions.
A.3	Investigating alternative materials and manufacturing processes for device structures	Alternatives to traditional structural materials such as steel and concrete may overcome the limitations of these materials and offer improvements in cost, performance and survivability.
A.4	Investigating novel devices before moving towards convergence of design	Further investigation of novel device concepts (particularly for wave technologies) is required to provide a step-change before moving towards a consensus on the best concepts to pursue in the longer term.
A.5	Defining and enforcing standards for stage progression through scale testing	Small scale testing in controlled environments allows thorough investigation of specific conditions and underlying physical characteristics before progression to larger scale, more realistic and riskier testing.
A.6	Developing and implementing optimisation tools	Optimisation tools allow the planning of optimal array designs, providing greater certainty of success in an open water environment and a method of assessment and comparison in stage-gate programmes.
B.1	Building on existing guidelines and standards for third-party verification and testing	Third-party verification and testing is required to validate technologies and meet commercial investment criteria. Guidelines and standards allow for comparison between technologies and improved knowledge exchange.
B.2	Developing improved, more cost effective mooring and foundation systems	Mooring and foundation systems (particularly their installation and maintenance) currently represent a very significant portion of overall project costs.
B.3	Implementing suitable condition monitoring systems	Condition monitoring allows for condition based maintenance systems, streamlining O&M and delivering high reliability.
B.4	Improving the efficiency and cost-effectiveness of electrical subsystems and power electronics	The method by which electricity is transmitted throughout an array and then exported to shore is subject to efficiency losses and significant infrastructure costs, both of which stand to be reduced.
B.5	The method by which electricity is transmitted throughout an array and then exported to shore is subject to efficiency losses and significant infrastructure costs, both of which stand to be reduced.	
B.6	Optimising offshore operations and maintenance missions	Manned offshore O&M missions are expensive, risky and time consuming. Periods of suitable weather conditions for O&M missions can be short and infrequent, potentially leading to extended downtime for array components. Remote O&M systems may mitigate such issues.
B.7	Developing dedicated vessels and tools	Tools and vessels tailored to the specific needs of ocean energy O&M missions will allow more optimal use of limited weather windows.
C.1	Developing expertise related to the manufacture of ocean energy technologies	Manufacture of ocean energy array components must move from custom designs to mass production to enable cost reduction, supply chain engagement and sufficient volume output. Increased supply chain engagement presents a significant economic opportunity.
C.2	Scaling up from single device deployments to arrays	Significant cost reductions can be achieved through economies of scale while utility scale developments are of greater commercial appeal.

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