TKI WIND OP ZEE

TKI Wind op Zee

Dutch Wave & Tidal energy sector

Status, challenges and roadmap

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Note This report was commissioned by the TKI Wind op Zee (TKI Offshore Wind). The opinions expressed in this report are entirely those of the authors (MET-Support) and do not necessarily reflect the views of the TKI Wind op Zee, and the TKI Wind op Zee is not liable for the accuracy of the information provided or responsible for any use of the content.

Management summary

This study, commissioned by TKI Offshore Wind, provides an overview of the Dutch tidal and wave energy sector, its needs and challenges. As part the study a stakeholder survey was carried out. Based on the results and literature, recommendations are made to accelerate the development of marine energy in the Netherlands. The findings are summarised in a Roadmap for the industry with specific targets.

While there is only 12MW capacity tidal stream and wave energy installed worldwide, an estimated 60GW is expected to be installed by 2050. The Netherlands has 0,5MW is installed, while the Dutch extractable resource is estimate to be between 20MW and 120MW depending on the future availability of existing dams and barriers for energy generation, such as Oosterschelde and Brouwersdam.

There are twelve Dutch companies developing tidal energy technologies and seven working on wave energy conversion. According to the EC Joint Research Centre, the Netherlands is the number 3 country worldwide in terms of tidal energy activities. A wide variety of research institutes and supply chain companies are working with the technology developers, such as offshore companies, installation contractors, blade manufactures etc. Currently there are around ten funded collaborative R&D projects in progress worth over 35mEUR. Dutch organisations participate in at least three focussed marine energy networks (EWA, EIP Action Group and IEA-OES).

The Dutch industry has a competitive advantage in the field of offshore know-how, installation, operations and maintenance, which is also the area where the highest impact for cost reduction can be expected. It is a recommendation that the involvement of such companies should be a priority in policy making.

Recommendations are made for R&D calls with sufficient levels of funding to match the project needs and an adequate feed-in system to support the implementation phase of innovative technologies. There is a need to expand and improve the access to testing infrastructure, which will also attract international developers. The involvement of Dutch stakeholders in developing standards and certification schemes for marine energy convertors should be promoted, since this will increase investor's confidence and enhance market uptake for wave and tidal power array projects. Consenting could be streamlined by introducing a single point of contact expert who works at the consenting authorities level on behalf of all different permits. Finally there is need to increase the international cooperation and dissemination via existing networks. The recommendations are summarised in a Roadmap for the sector.

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1 Background to the study

TKI Offshore Wind (TKI Wind op Zee) commissioned this study to gain an understanding of the status and needs of the Dutch wave and tidal sector. The results of this study may be used to make specific recommendations to the Dutch TKI Innovation Agendas for 2016 and beyond where the TKI Offshore Wind cooperates with the TKI Maritime in this area.

The Dutch government defined nine so-called Top sectors in which the Netherlands excels globally and are thus a government priority. Currently there is little focus on “energy from water” defined in the Top sectors, although references are made to sustainable dams and infrastructures as part of the Delta Technology cluster under Top sector Water.

Late 2014, a call for crossover projects was announced, for innovations that contribute to the Dutch ambitions for both Top Sectors Energy and Water. As a results, the ministries of Economic Affairs and Infrastructure and Environment, together with Innovation Quarter, then commissioned a study into the potential of energy and water technologies. The report, by Ecofys, indicated favourable conditions for various Dutch innovations and specifically for Salinity Gradient, Thermal storage and tidal energy innovations. This report builds on those findings in order to create a roadmap for the sector (with a focus on wave and tidal energy) and to formulate specific recommendations that can be used to make policy.

2 State of the Industry

2.1 Global Developments

The marine energy industry has entered a critical phase with important ups and downs. Never before was there such a sharp increase in sites either consented or consent applied. Site development is taking place especially in France, Canada and UK, with the first tidal array having reached financial close (Meygen), which is planned to be installed in 2016. This was a positive response to the recent implementation of adequate and attractive feed-inn schemes. An increasing number of governments are actively developing policies in support of marine renewable energy, such as Japan, South of Korea, Philippines, Chile and Argentina.

In 2014 the worldwide marine energy generating installed capacity was 12 MW (of which 7MW tidal stream and 5 MW wave energy). While 500MW of tidal barrage capacity is currently in operation. Of all installed tidal stream and wave energy devices, 75% of the capacity is installed in the UK. The outlook is optimistic with a pipeline of 400MW of consented tidal stream projects and 100MW for wave energy. Although the highest energy potential can be found in wave energy conversion (WEC), most progress has been made so far in tidal applications. Whilst the developers in the WEC field are still innovating on new concepts and working solutions, Tidal Energy Conversion (TEC) solutions are already looking to cut down installation and operating costs in preparation for the first small arrays.

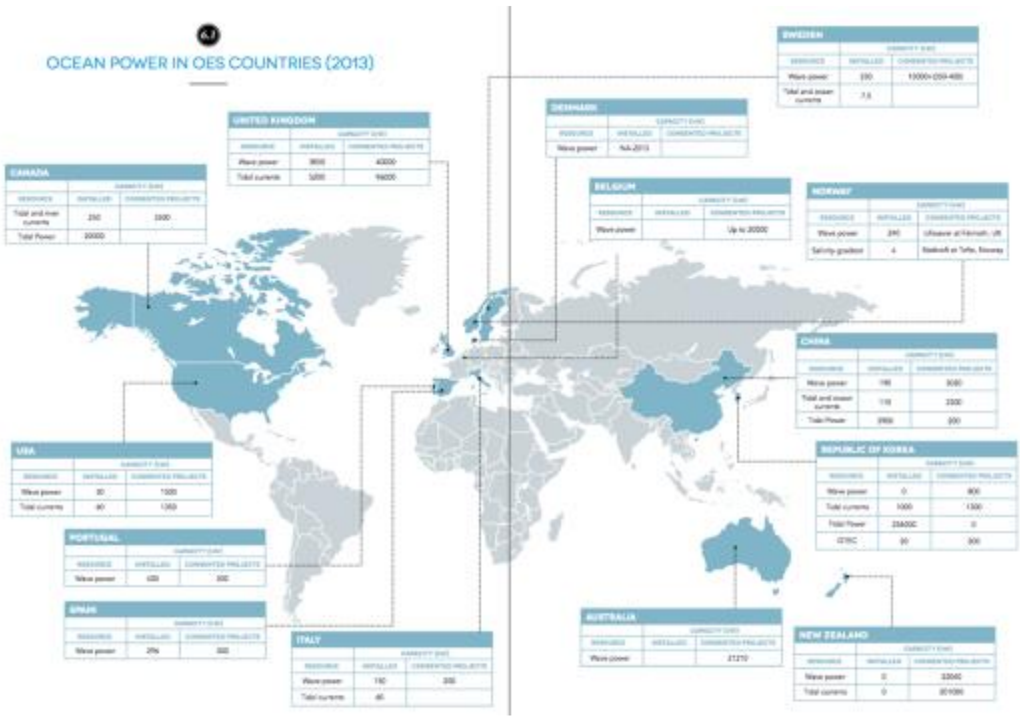


Figure 1 Overview of installed marine energy capacity and consented project worldwide, IEA-OES annual report 2013

The latest report from the European Commission (JRC 2015) confirms the increased interest in developing and commercialising ocean energy technologies on a global scale. For example, the European Commission launched the Ocean Energy Forum in April 2014 to ensure a coherent integrated approach to overcoming existing barriers; Chile and Australia are supporting the sector with ad-hoc grants and incentives; Canada and the USA established concentrated hubs of research; Japan, China and South-Korea are increasingly cooperating internationally to develop policies to develop and implement technologies.

Ocean energy has reached the stage at which technology developers must prove that they can reduce the costs of their technology whilst increasing the reliability and performances of the devices in order to tap into a potentially large market. There is little activity in South America (apart from Chile), Africa, Russia (apart from the noteworthy Kislaya Guba experimental tidal caisson project) although all have significant wave and tidal resources to be developed in the future.

Europe is leading the way in the development of wave and tidal technologies, with the strong lead of the UK, followed by the US. According to a recent study published by JRC, the Netherlands is the third EU country with more tidal developers while in wave energy it has a non-leading position. However, it should be noted that most of the Dutch wave energy inventions were not included in the assessment (see section 4 on current activities in the Netherlands).

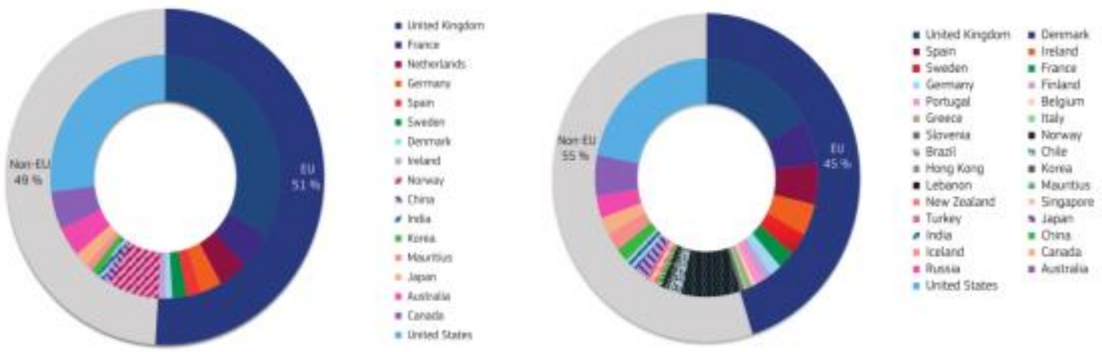


Figure 2 Distribution of tidal (left) and wave (right) companies in the world (JRC 2015)

However, in terms of technology development, the last two years have been convulsive. The Energy Technologies Institute (ETI, UK) indicates that tidal technology is in a demonstrable route to making tidal stream energy competitive with other low carbon technologies, with the potential to be a material part of the future UK energy system. The sector has transitioned in recent years from small-scale prototype devices, through to full-scale demonstration and early commercial arrays are now in development. ETI report indicates that the cost of energy from tidal stream arrays can compete with other low-carbon sources. To achieve that, significant cost reduction will require a coordinated investment in supply chain innovation, processes and people. Also array and device design integration is vital (ETI 2015).

While some tidal technologies are moving towards the demonstration of first small arrays (eg. Andritz/Hammerfest, Alstom/TGL, DCNS/OpenHydro, Tocardo), this period has also seen a number of companies being sold or scaled down. Siemens decided, after strategic review, to sell off Marine Current Turbines as well as the German hydropower giant Voith, who is selling off her direct drive turbine HyTide, rated at 1 MW. Both companies indicated non-technical reasons (tidal energy seen as “niche” for such big companies).

ETI report indicates that unlike tidal, wave energy requires radical innovative thinking rather than incremental cost reduction through deployment of the current family of technologies. It states that current devices such as Pelamis (the technology which followed a diligent development path over a period of 16 years and recently went into administration) is unlikely to make a significant contribution to the UK energy system in the coming decades even with aggressive cost reduction and innovation activities. There is now a need to reconsider some of the fundamental wave extraction and conversion system approaches to establish whether alternative methods are plausible to deliver lower cost solutions in the longer term (ETI 2015b).

Other leading wave energy companies such as Oceanlinx and Wavebob went out of business, Wavegen was folded back into parent company Voith, AWS Ocean Energy scaled back its activities, and Ocean Power Technologies cancelled two of its main projects. Aquamarine Power is downsizing.

This can be seen as part of the natural selection process. It is also interesting to see how some of the emerging technologies follow a different path focusing at demonstrating arrays of smaller scale devices in the short term, before scaling-up to MW scale devices (e.g. Schottel, Plat-O, 40 South Energy, Albatern, Tocardo, etc.). Note that this same evolution was the successful path that the Danish Wind Industry followed in the 70-80s focusing at kW scale turbines, when competing with the American Wind Industry developing MW scale.

More detailed information on the status of marine energy technology is provided in the Annexes, including: classification, TRLs, list of leading technology developers, projects and suppliers.

3 Potential

3.1 Global Potential Market

Wave and tidal have a large potential in terms of total available resource, although not as large as other renewables such as solar or wind, which represent the largest renewable energy sources. According to the IPCC, the theoretical potential for wave energy is expected to be around 32.000 TWh per year, while tidal energy potential is expected to be around 17.500 TWh (IPCC 2011), of which only around 765 TWh is related to tidal currents (Black & Veatch & Carbon Trust 2005).

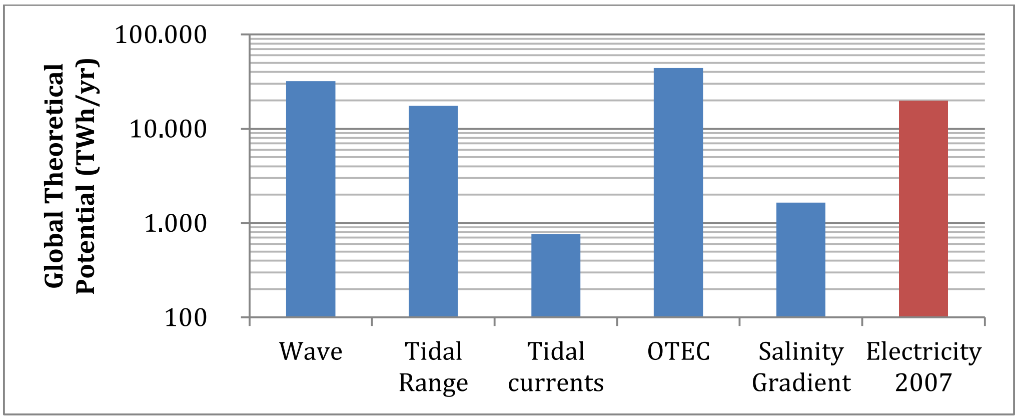


Figure 3 Global Ocean Energy Theoretical Potentials compared to global 2007 Electricity Demand (IPCC 2011)(Black & Veatch & Carbon Trust 2005; IEA 2009)

As can be observed from the figure above, the global theoretical potential for wave energy is significant. In the case of tidal currents, although the total potential is more limited, it is concentrated in very specific areas where it is very intense and potentially leading to low competitive LCOE (compared for example to OTEC which has a larger global potential, but is much more diffuse and difficult to extract). Still the tidal current potential represents around 4% of the global electricity demand (note that wind energy contributed to only to 0,2% of primary energy demand or 1,6% of electricity demand in 2007, according to IPCC).

Of course only a share of the theoretical potential can be technically extracted and will be developed in practical terms, taking into account regulatory, economical and environmental considerations. A realistic estimate of the global installed capacity for wave and tidal in 2050 is around 60GW, although some studies are considerably more optimistic (see reference in the table below).

Region	Wave (GW)	Tidal Current (GW)	Ocean (GW)	Comments	Source
Global	46,5	12,5	59	W&T	(Carbon Trust 2011)
Global			303-748	All ocean	(IEA-OES 2011)
Global		100	>100	Global market	(Alstom 2014)
EU			100	W&T	(SI Ocean 2014)
UK	16	7	23	W&T	(Carbon Trust 2011)
UK	4-19	8-38	23	W&T	(ETI 2015a; ETI 2015b)[1]
US	23-138		>23-138	Only wave	(Revision 2012)

Table 1 Published market size in 2050 for ocean energy in different regions

[1] ETI reports indicate a potential contribution of 20-100TWh for tidal and 10-50TWh for wave. It has been converted to GW assuming 30% capacity factor for both technologies.

In the short term, a number of deployments are foreseen in Europe. The JRC latest report indicates that in 2018 the capacity for tidal and wave energy could be 40 MW and 26 MW respectively, shaping the start of the deployment curve.

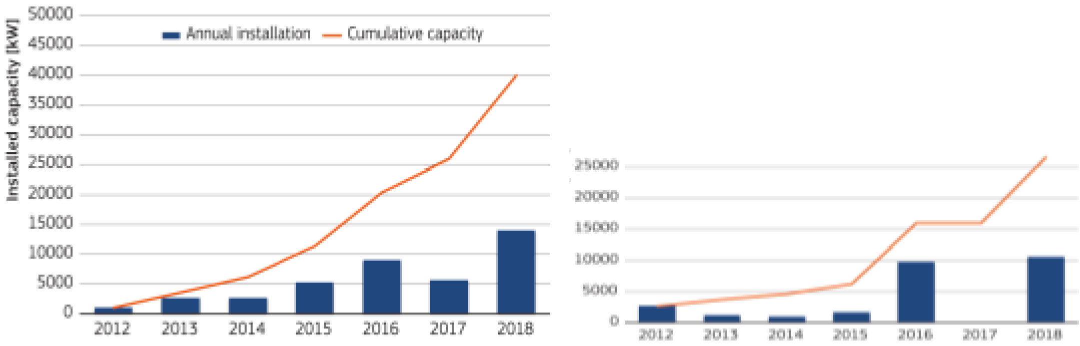


Figure 4 EU foreseen installed capacity for tidal (left) and wave (right). (JRC 2015)

3.2 Tidal and wave energy potential in the Netherlands

Figure 55 shows that tidal sites are located at or near constricted waterways, in dams, rivers, and around the Wadden Sea Islands. The technically feasible wave and tidal energy potential of the Netherlands is estimated to be between 20MW (low estimate) and 130MW (optimistic estimate).

Figure 5 Map of Netherlands with tidal sites with interesting potential

	Potential kW (low estimate)	Potential kW (high estimate)	Installed capacity kW	Technology	Status
Westerschelde	500	5000	30	tidal stream	Permit for 5 years
Water Dunen	1000	2000		stream/low-head	in ontwikkeling
Oosterschelde Stormvloedkering	3000	60000		tidal stream	2 permits (15 years)
Brouwersdam opening	5000	40000		stream/low-head	Tender preparation
Grevelingendam tidal test centre	1000	3000		stream/low-head	Permitting started
Stevinsluizen	2250	4500			
Kornwerderzand	1500	3000	400	tidal stream	partly permitted
Marsdiep offshore locatie	200	500	100	tidal stream	Permit for 5 years
Wadden	5000	10000		tidal stream	
Totals (MW)	**20**	**128**			

Table 2 List of locations in the Netherlands with tidal stream of tidal difference potential

Due to the relatively sheltered coastline of the Netherlands, the North Sea waves are not as energetic as the Atlantic coastline. While average energy densities of 40 to 80 kW per meter wave are normal along many Atlantic coast sites, the North Sea only has 4kW/m average energy density near shore and reaching peaks of around 13kW/m in the middle of the North Sea between Netherlands and UK (at K13 platform). It is therefore highly unlikely that MW-size wave energy convertors can be deployed economically in the North Sea. Even with optimistic assumptions, a 1MW wave energy device would have to stretch over a width of a couple of hundred meters in order absorb enough energy!

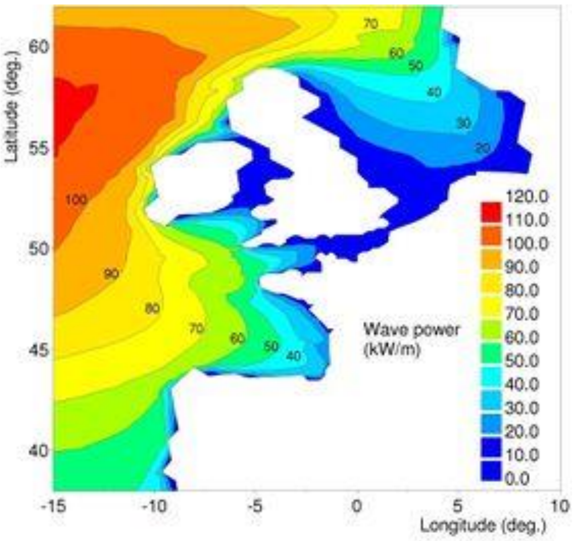


Figure 6 Chart of wave energy densities along Atlantic and North Sea coastal regions. Clearly the North Sea is sheltered by the UK limiting the wave energy density to below 10kW/m wave width.

4 Activities in the Netherlands

Despite some of the failures across the sector there are also numerous success stories to be told, with a noteworthy position for the Netherlands. A first of its kind floating tidal turbine platform was installed in 2015 at the offshore test site of the Tidal Testing Centre in the Marsdiep. The consortium led by Bluewater, includes Van Oord, Damen shipyards, TKF, NIOZ and Vryhof Anchors and will test various tidal turbines supplied by Schottel and Tocardo. The latter will also install a unique array of three turbines using an innovative dam-integrated solution in the Afsluitdijk this year: a finger exercise for the 3 MW project in the Eastern Scheldt Storm Surge barrier in Zeeland. In the summer of 2015 the Dutch government intends start a public tendering process for opening up the Brouwersdam to improve the water quality. Bidders will be encouraged to consider integrating tidal energy in their scope. Below an overview is given of the main technology developers and R&D projects that are currently active in the Netherlands.

4.1 Dutch tidal energy developers

4.1.1 Tocardo

Tocardo has over five years of operational experience with a grid connected pre-commercial T1 demo in the Stevin Sluice gates at the Afsluitdijk. The rotor is a fixed pitch rotor. The blades can flip (passively) about their own axis in order to handle a change in flow direction (patented Tocardo bi-blade technology). Tocardo carried out sea trials in 2013 with its turbine in the Waddenzee and had the turbine performance verified collaboration with MARIN & ECN. The turbine blades have undergone full lifetime fatigue tests at WMC. Since 2012, Tocardo started series production of turbines. By mid-2015 Tocardo will have built seven T1 production turbines. Production of proposed T2 turbine type for the Brouwersdam project started in Q4 2014 and is expected to be operational in 2015 at a floating offshore test site in the Marsdiep, near Texel. Tocardo also expects to realize a 1MW project in the Eastern Scheldt storm surge barrier in 2015.

Figure 7 Tocardo T1 turbine during push tests in the Wadden Sea in 2013, Tocardo T1 turbine mounted under the BlueTEC platform before installation in the Marsdiep and an array of three Tocardo turbines in the Afsluitdijk

In 2014, Tocardo acquired the Wave Rotor technology from IHC, who had previously acquired the technology from Ecofys and dubbed it OceanMill and later Blue Turbines. The technology is based on the vertical axis Darrieus type turbine. Ecofys developed a grid-connected demo unit of the Wave Rotor technology in the Westerschelde near Borselle, named the C-Energy project. Based on the results a larger 1,5MW project was prepared in the Eastern Scheldt Storm Surge barrier together with a strong consortium of local partners.

Figure 8 C-Energy project in the Westerschelde (2009), a 30kWp grid-connected vertical axis tidal turbine at a jetty of Zealand Refinaries near Borselle.

4.1.2 Schottel Tidal Turbines

Although strictly a German company, Schottel has offices in Zoetermeer and employs a Dutch business developer for the technologies. Schottel has a track record with the design, manufacturing and sales of submerged electrical ship propulsion systems. The Schottel hydrokinetic tidal turbine is a spin-out of this technology. The turbine was first tested in front of a tugboat in the harbour of Rotterdam. In 2014 performance tests were carried out at the Queens University Belfast test site in Northern Ireland. Two turbines were also used mounted on the Plat-O submerged platform in a test in the Solent (UK). Later this year a Schottel turbine is expected to be tested under the Bluewater BlueTEC platform near Texel. The turbines feature a rated electrical power of 63 and 72. Each turbine comprises a three-bladed rotor, planetary gearbox and asynchronous generator, both cooled by ambient water.

Figure 9 Left: Schottel 3m turbine being tested at the test site of Queen University Belfast in Strangford Lough, Northern Ireland, Right: two Schottel turbines mounted on the Plat-O platform before deployment in the Solent (near Isle of Wight, UK)

4.1.3 Tidalys

Dutch Expansion Capital from Eindhoven is an investor in a Dutch-French development called Tidalys. The concept uses a counter-rotating turbine suspended from a floating trimaran. A scale model was tested twice at IFREMER France in 2012 and 2013.

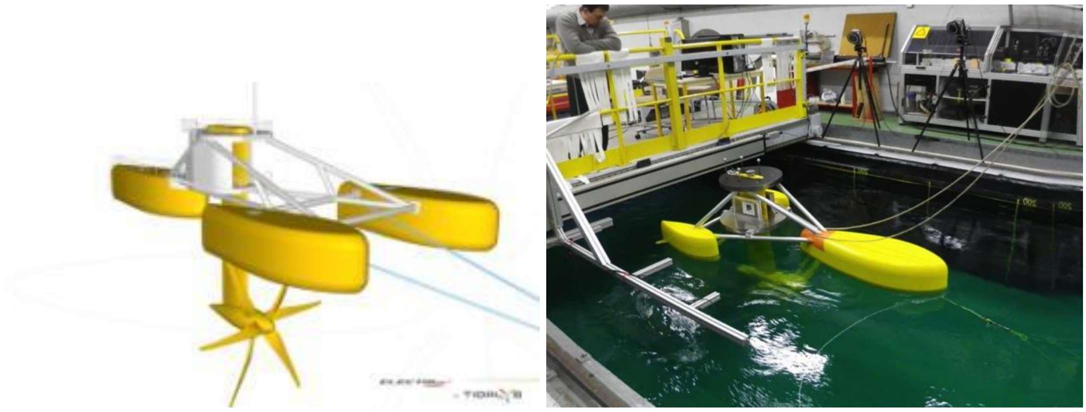


Figure 10 Tidalys counter-rotating turbine. Right: tests at IFREMER, Boulogne sur Mer, France.

The team has executed the preparations for the prototype in 2014 while additional investment rounds are now finalized to build a large demonstration in 2015. The focus of Tidalys will change towards a stronger collaboration with industrial partners in order to increase market traction.

4.1.4 Nyhuis-Pentair Pompen

Nyhuis-Pentair are a pump manufacturer, who re-engineered a pump into a fish friendly bulb turbine that can be used for low head tidal barrage systems. Outdoor tests have been done in 2014 to determine fish mortality rates. Nyhuis have been closely involved in the Brouwersdam and DTP Power consortium to integrate their turbines as part the total concept.

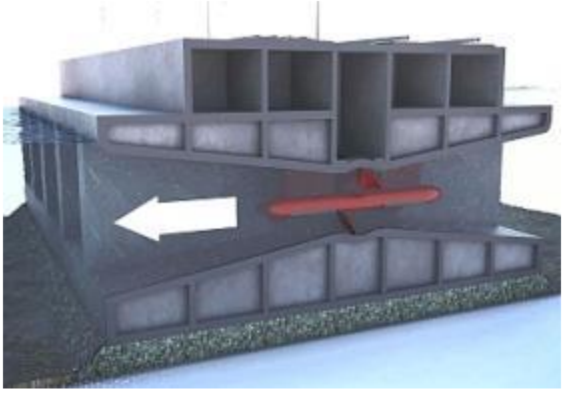


Figure 11 Nyhuis fish friendly turbine

4.1.5 Fish Flow Innovations

Fish Flow Innovations are currently building a prototype of a free stream ducted turbine.

Figure 12 Fish Flow Innovations

4.1.6 Flowserve

Flowserve are, like Nyhuis-Pentair a manufacturer of pumps. They have made designs of a bulb type tidal turbine for integration in dams with a view of application in the Brouwersdam. It is not clear if Flowserve have build any prototypes.

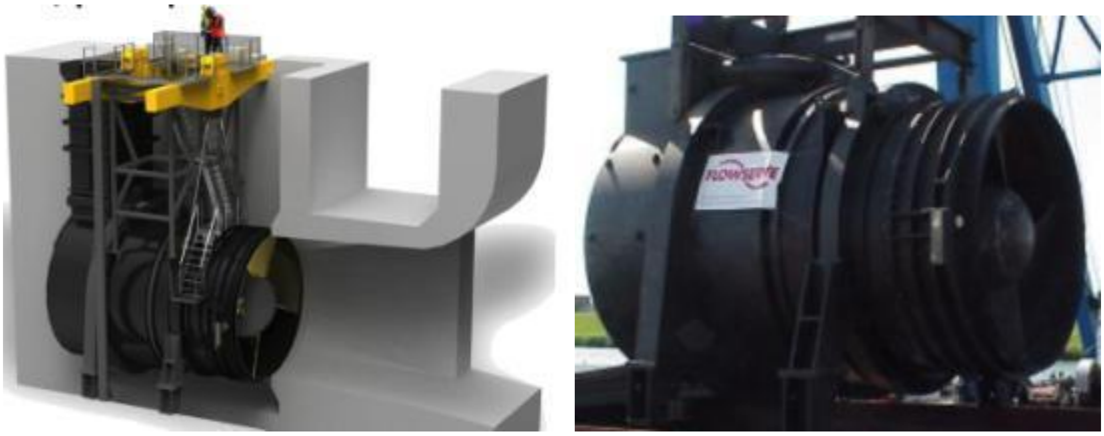


Figure 13 Left: Flowserve bulb turbine design, right: typical Flowserve pump

4.1.7 Water2energy

Water2Energy is a company set-up by two entrepreneurs with a background in shipbuilding. They are developing a vertical axis, pitch controlled turbine. Early 2014 a device was tested in the Lek and late 2014 in the Scheldt river near Temse near Antwerp. For practical reasons an existing Darrieus turbine was procured from Canadian supplier New Energy Corporation. This turbine was adjusted to incorporate the mechanical pitch control system.

Figure 14 Water2Energy being towed in the Scheldt river near Temse for testing as part of the Pro-Tide R&D project.

4.1.8 Oryon Watermill

Deepwater-Energy BV is developing the Oryon Watermill. It is a vertical axis drag turbine with moving blades that can vane during the upstream movement of the turbine to minimise hydrodynamic drag. A venturi construction increases to local velocity through the turbine. A floating prototype was demonstrated in Tolkamer in the Rhine. A fixed turbine was installed in the sluice gate in Ulft in the Oude IJssel. Deepwater-Energy has also been contracted to supply turbines for the Doesburg hydropower scheme (max 300kW) and have expressed interest to test turbines under tidal conditions in the Grevelingen low head tidal test site.

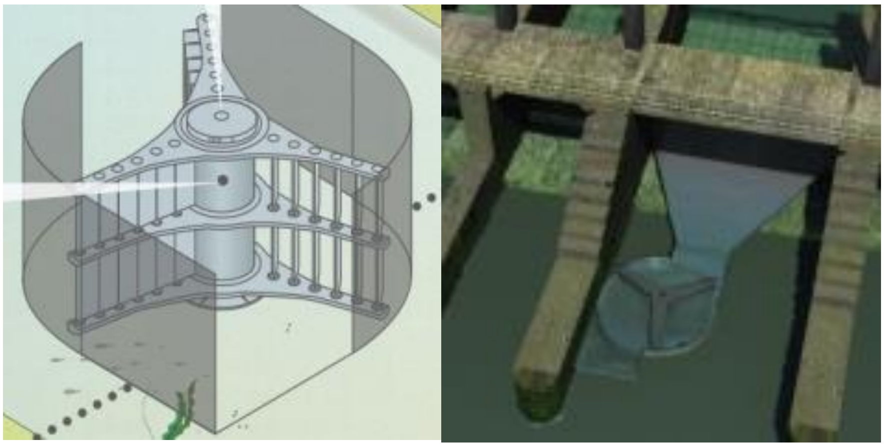


Figure 15 Left: Schematic of the Oryon Watermill, and right: installed in the sluice gate in Ulft, in the Oude IJssel

4.1.9 Bluewater Energy Services

Bluewater is developing the BlueTEC system: a generic floating structure to support tidal stream turbines. A pilot project is currently being prepared for near the island of Texel with a consortium of Dutch supply chain companies (Van Oord, DAMEN, Vryhof, TKF, TTC, NIOZ and others). Bluewater also has berth rights at the European Marine Energy Centre on Orkney and is working on a project at FORCE, Canada for the large 2MW device.

Figure 16 Single turbine floater (200kW) for autonomous power supply for coastal communities recently installed at the Tidal Testing Centre offshore pilot zone near Texel.

4.1.10 Ronamic

Ronamic are developing a Tidal Energy Convertor based on the Positive Displacement principle that can also be found in cars as fuel pump. Besides developing the turbine technology, Ronamic's vision is a multi-functional / hybrid solution that also generates energy from waves (by moving back and forth) and provide a foundation for wind turbines. In a farm, each unit will also be equipped with a hybrid compressed air energy storage system.

Figure 17 Ronamic

Ronamic are currently in the process of going through a due diligence process for potential investment by a Shell investment venture.

4.1.11 Hydromine

Hydromine Holland is developing an innovative Archimedes type rotor comprising a series of flexible-screw elements mounted on a flexible shaft, allowing the turbine to flex with the current. In 2014 an extensive test programme was carried out by MARIN to verify the performance. Hydromine Holland has a UK partner in the development. The next steps envisaged are to proof the total concept including power take off at an open water site, preferably in the Netherlands. Systems can be deployed in river-estuaries in coastal areas all over the world both on the seabed and suspended from existing infrastructure.

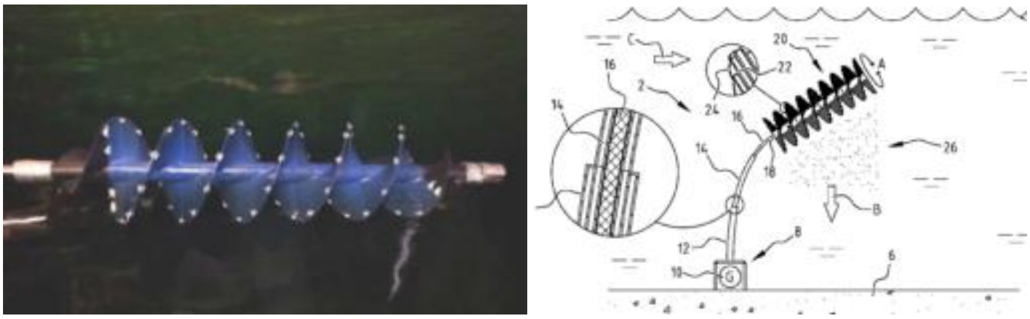


Figure 18 Hydromine model tested at MARIN in 2014 and illustration for seabed mounted solution.

4.1.12 Innovative Input

Innovative Input is an offshore construction company specialised in the design and engineering of heavy lift equipment. The owner and director of the company is inventor behind an oscillating foil concept, mimicking the movement of a whale tail. The movement of the blade is controlled through innovative hydraulic actuators to optimise the angle of attack during the motions. As part of the MaRINET funded programme, a scale model was tested in 2014 at the circulation tank of IFREMER, France.

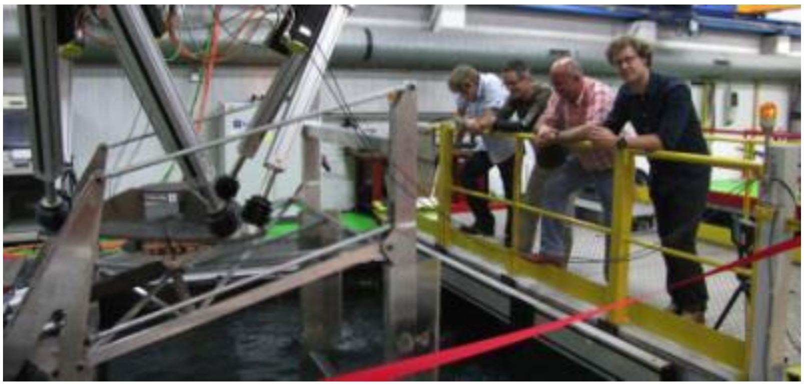


Figure 19 Innovative Input oscillating hydrofoil

4.2 Dutch wave energy developers

4.2.1 SlowMill

SlowMill is an invention by Erwin Croughs. The device comprises a number of horizontal, conically shaped blades connected with wires to a float on the surface. The wires connect to a seabed-mounted winch which is connected to a motor/generator. During the upward stroke, energy is produced. The motor is used to pull the system back again.

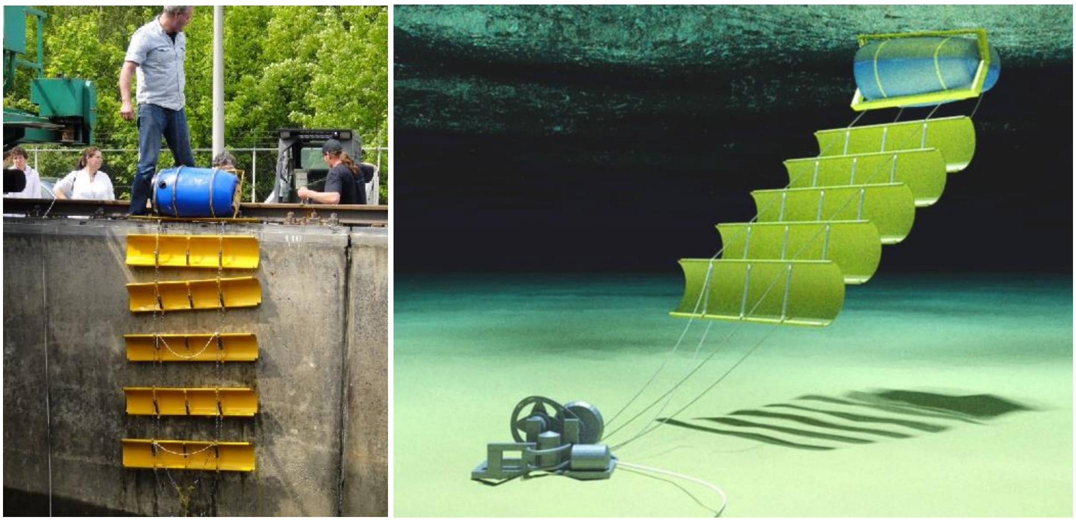


Figure 20 Slowmill being tested at the Delta flume facility of Deltares in 2011

In 2013 several attempts were made to deploy a pilot near the pier of Scheveningen. A suction anchor was successfully installed, but for various reasons the device has not yet been hooked up to date.

4.2.2 OceanGrazer

The basic mechanism of the OceanGrazer, developed at University of Groningen, is a ‘floater blanket’, with small absorbers that rise with the wave. As each absorber rises, it pumps water into an elevated basin for temporary storage. The water flows back to a lower basin through a turbine. A 230-meter-high circular platform is envisaged with a diameter of 400m. Most of this will be under water, with the upper basin 80 meters below surface.

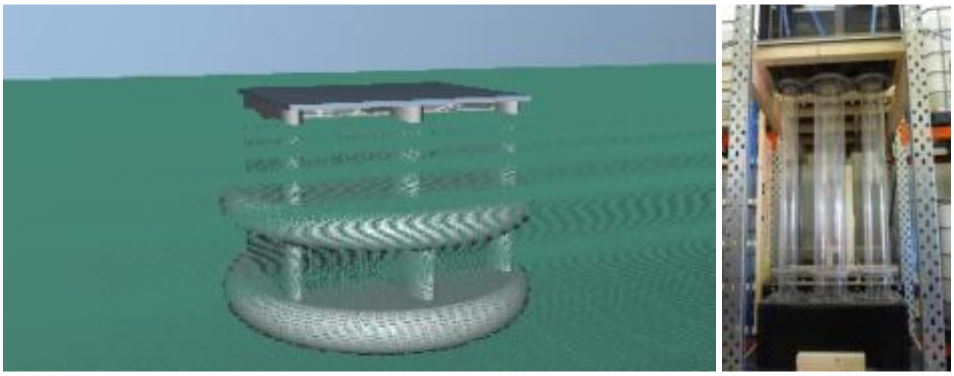


Figure 21 Artist impression and lab model of the OceanGrazer, as being developed by Dr. Prins from University of Groningen.

4.2.3 Ocean Movement

The Ocean Movement Wave Turbine is an invention by Bennie Olde Heuvel. The turbine consists of a number of chambers mounted on a long cylinder. It floats parallel to the direction of the waves. When a wave passes by, chambers fill up with water through the lower part of the chambers, forcing the air out through an air valve. The gravitational force working on the water in the chambers then causes a rotational force when the wave decreases. At the low point of the wave, valves open and release the water. The subsequent wave causes the same motion, keeping a constant rotation going. Increasing waves cause an upward force on empty chambers.

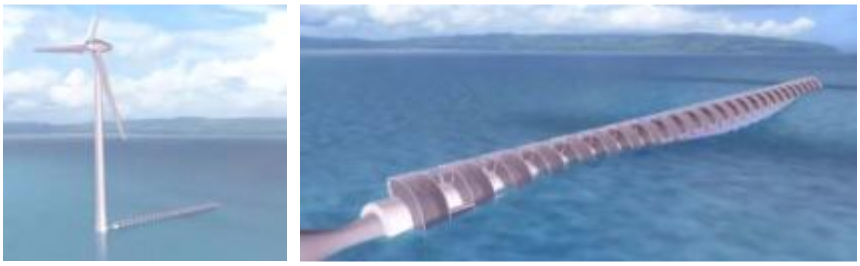


Figure 22 Inventor Bennie Olde Heuvel explaining the principle of the Ocean Movement wave turbine to students

Scale-model tests proved that 33% of the wave energy could be converted into mechanical power. The development is on hold until an investor is found.

4.2.4 Symphony Wave Power

Symphony is a development based on the Archimedes Wave Swing technology, which was developed by Teamwork Technology (1998-2006). The basic principle of operation is still the same, only the internal power take off comprise new systems. A recent EU subsidy application under the Horizon programme was awarded to develop and test the concept in laboratory conditions.

Figure 23 Symphony looks like the Archimedes Wave Swing, but houses an innovative linear power take off system using an air pressure chamber and sliding bellow frames.

4.2.5 Wave Collector

Delta Power Consulting is developing the "Wave Collector": a near shore, top wave, energy convertor. The floating device transforms both kinetic and static energy from sea wave into a rotating movement. A direct drive generator attached to the main shaft converts the mechanical energy into high voltage electrical energy, a subsea power line to the shore can directly be connected to the nearest electrical network.

Figure 24 Wave Collector by Delta Power Consulting

4.2.6 KNSWING

Kim Nielsen and his company KN Ocean Energy Science & Development are developing the KNSWING project. Although the inventor is Danish, he lives and works in the Netherlands. KNSWING is an attenuator wave energy converter (WEC). The ship like structure incorporates 20 oscillating water column chambers on each side. The project was given access to be tested under MaRINET in the Wave Basin at Beaufort Research (HMRC) in Ireland in May 2013 – in scale 1:50.

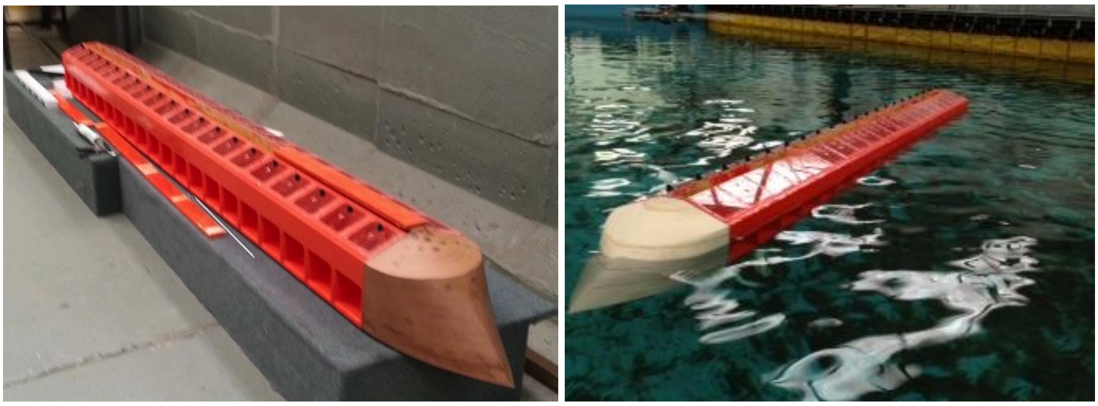


Figure 25 KNSwing being tested at the Hydrodynamic Marine Research Centre Cork (HMRCC), Ireland as part of the MaRINET programme.

4.2.7 CWEC

The CWEC is a combination of the buoy and the flap principle in order to capture both the vertical and the horizontal motion of waves. CWEC is an invention by Wient Mulder.

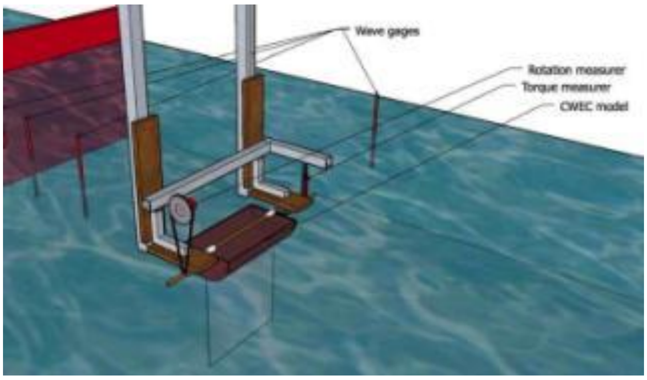


Figure 26 Schematic overview of the test set-up of CWEC at the Aalborg wave basin in 2013

4.3 Collaborative R&D projects

Currently Dutch companies and institutes are involved in a wide number of collaborative R&D projects worth over 35mEUR with activities taking place in the period from 2011 to 2018. Three coordinated networks (EWA, EIP Action Group and IEA-OES) in the field of marine renewable energy are in existence with a (Dutch) member base of over 50 organisations and connections to over 20 countries. The table below lists the projects. Some projects are still in the application phase.

R&D project / Network	Programme	Dutch (Lead) partner	Total Project budget	Start	End
Grevelingen Tidal Testing Centre	EFRO OP-ZUID	Provincie Zeeland / AnteaGroup	10mEUR	2015	2018
DMEC, a Dutch virtual network of marine expertise	EFRO Kansen voor West	PWC/TTC	3mEUR	2015	2018

Certification of Marine Energy Technologies	INTERREG 2SEAS Concept Note stage	TTC NL/	6-8mEUR	2015	2019
Pro-Tide – low head, low stream tidal solutions	INTERREG IV-b	Provincie Zeeland / RWS	3mEUR	2011	2015
Offshore Tidal Farms	EFRO Kansen voor West	TTC NL	3mEUR	2011	2015
Pilot floating Tidal Turbines Texel	Waddenfonds	Bluewater Energy Services	4mEUR	2015	2017
Energising Delta's	EFRO Kansen voor West	TTC NL	2mEUR	2013	2015
FP7 SEAFRONT	EU FP7 Ocean of Tomorrow	Bluewater, TUD, TUE, DPI, AKZO	12mEUR	2014	
OCEANERA-NET	EU FP7	9 countries, RVO	unknown	2013	2017
EIP Action Group on Energy from Water Works	European Innovation Partnership on Water	16 members	not funded	2014	
IEA-Ocean Energy Systems (OES)	International Energy Agency	21 countries, RVO / Ministry of Econ. Affairs	membership fees	2001	
IEC TC 114 committee on standardisation	International Electro-technical Committee	21 countries NEN	membership fees	2010	
Dutch Energy from Water Association	network	26 members	membership fees	2009	

Table 3 List of Dutch R&D projects and networks

4.4 Supply Chain

There is a wide scope of activities required to bring marine energy to the markets, which is best compared to the relatively young Offshore Wind industry and the established Offshore Oil & Gas industry. There will be a significant potential for existing industries to provide services and supplies to the marine energy sector. This new market will attract keen interest from contractors and suppliers from the Oil & Gas sector as their activities may show a gradual decline in the coming decades. The expertise available from this industry is valuable to the success of the marine energy sector. There is a gradual building of interest from experienced suppliers and contractors from these two industries to be involved and to support the marine energy business.

Various companies are starting to develop tailor-made services for the marine energy sector. One such example is Bluewater Energy Services BV from the Netherlands, a global leading offshore mooring systems contractor, who has developed an open architecture floating platform to which various developers can mount their turbines. Other such services relate to component suppliers, environmental permitting, project development, offshore installation, operation & maintenance services, project management & engineering and system certification.

4.5 Standardisation and certification

Currently there is no internationally recognised certification scheme for marine energy technologies. The IECRE group has recently set-up committees to develop such schemes for and by the sector. The scheme uses a number of dedicated technical specifications for marine energy convertors that are being developed in parallel as part of the TC114 committee of the International Electro-technical Committee IEC. Dutch member body NEN is a formal party to the IEC and IECRE. Via membership of NEN, Dutch experts and companies can participate in this development and thus be informed ahead of publication and influence the process. Certification is key to increasing confidence of investors, insurers and consenting bodies and will ensure the market uptake of insurable and therefore bankable marine energy array projects. Considering the Dutch tidal projects (Brouwersdam) and export opportunities, it would be advantageous for the Dutch sector to be involved in this international process to keep a competitive advantage.

5 Survey amongst Dutch Wave & Tidal sector

As part of this study, some 65 stakeholders in the Dutch wave and tidal sector were invited to respond to an online survey. Over 40 stakeholders responded. Below a summary of the replies is given in the charts.

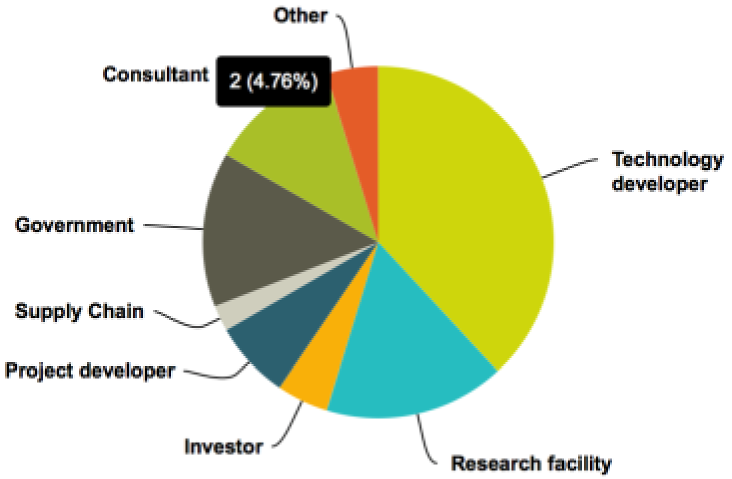


Figure 27 Spread of respondents, mostly Technology developers, Research Facilities, Government and Consultants

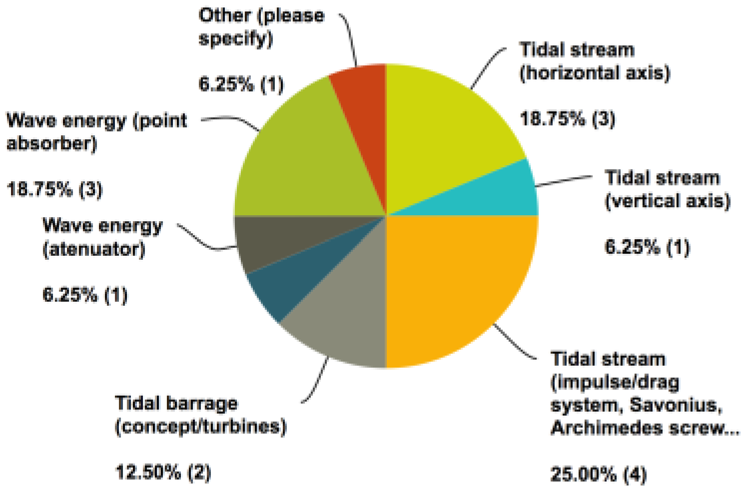


Figure 28 Type of technologies being developed by Dutch companies: majority works on tidal energy, good mix of different type of technological principles.

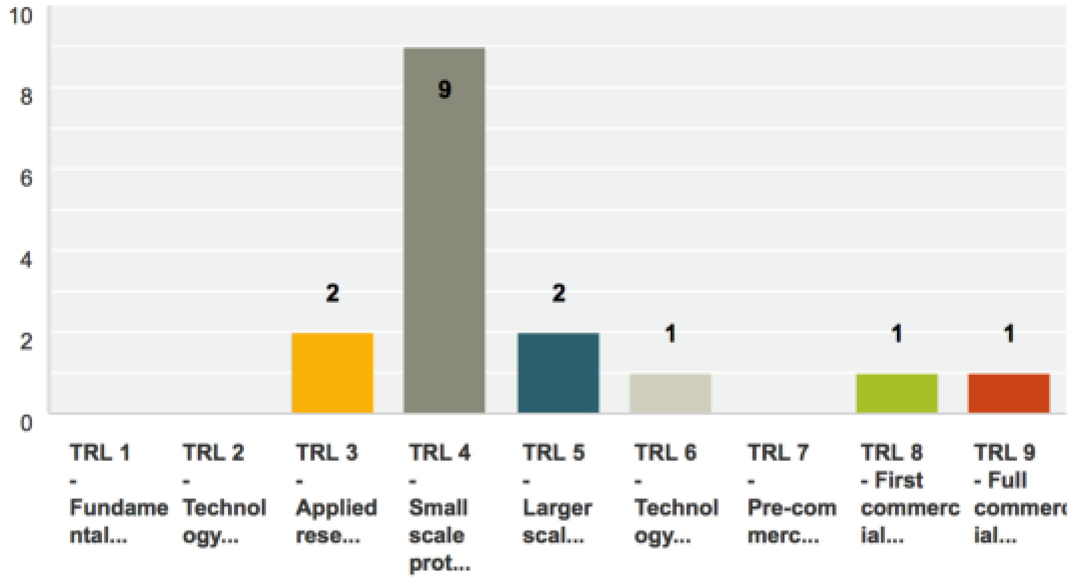


Figure 29 Technology Readiness Levels of the respondents; most are at TRL 4 (Small scale prototype).

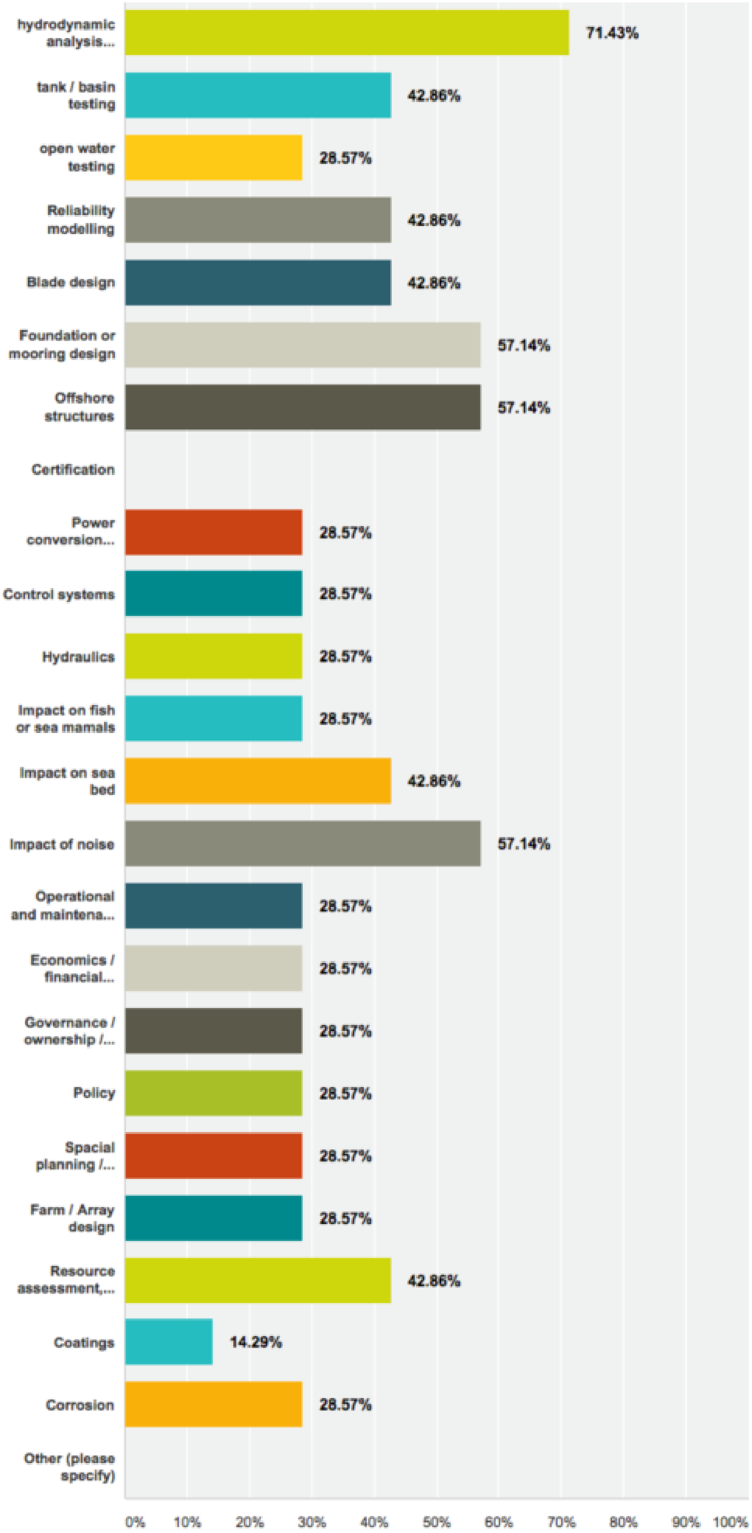


Figure 30 Expertise at research facilities: high number offer hydrodynamic analysis, resource assessment, noise impact and offshore know-how. Few offer expertise on testing, power electronics, coatings. None on certification.

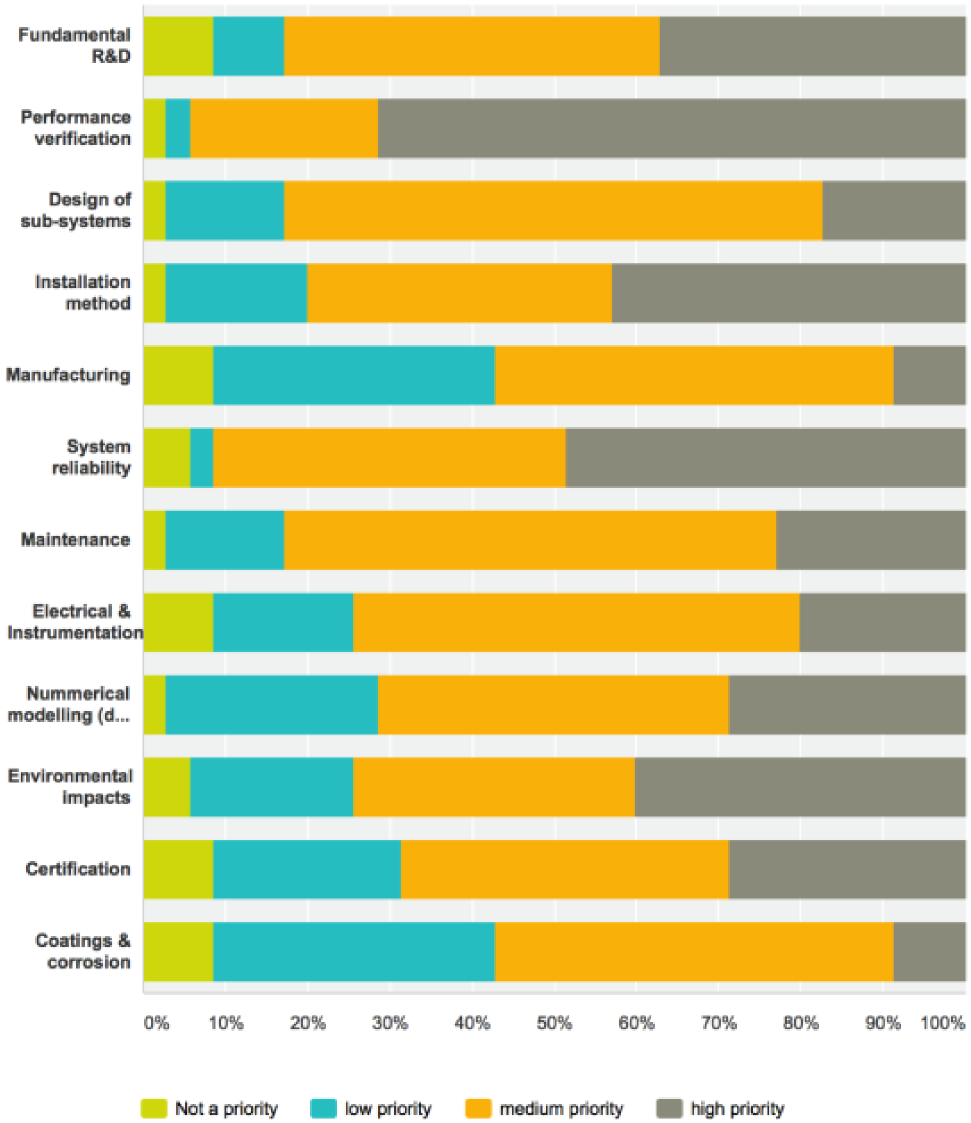


Figure 31 Priority of technical challenges according to the respondents. Highest priority is: performance verification, system reliability, environmental impacts and installation methods. Low priority items are: manufacturing, coatings and certification.

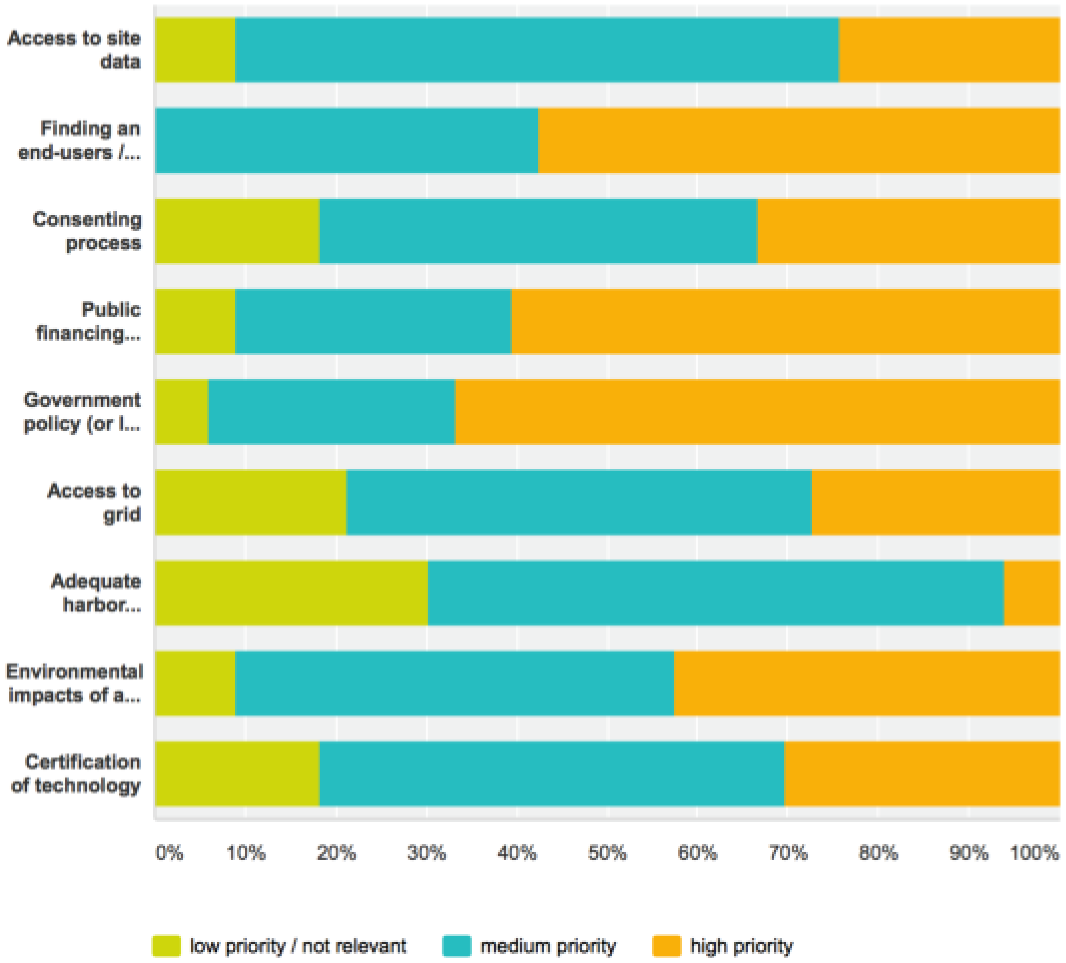


Figure 32 Priority of market challenges according to respondents. High priority are; end-users, setting national policies and public funding

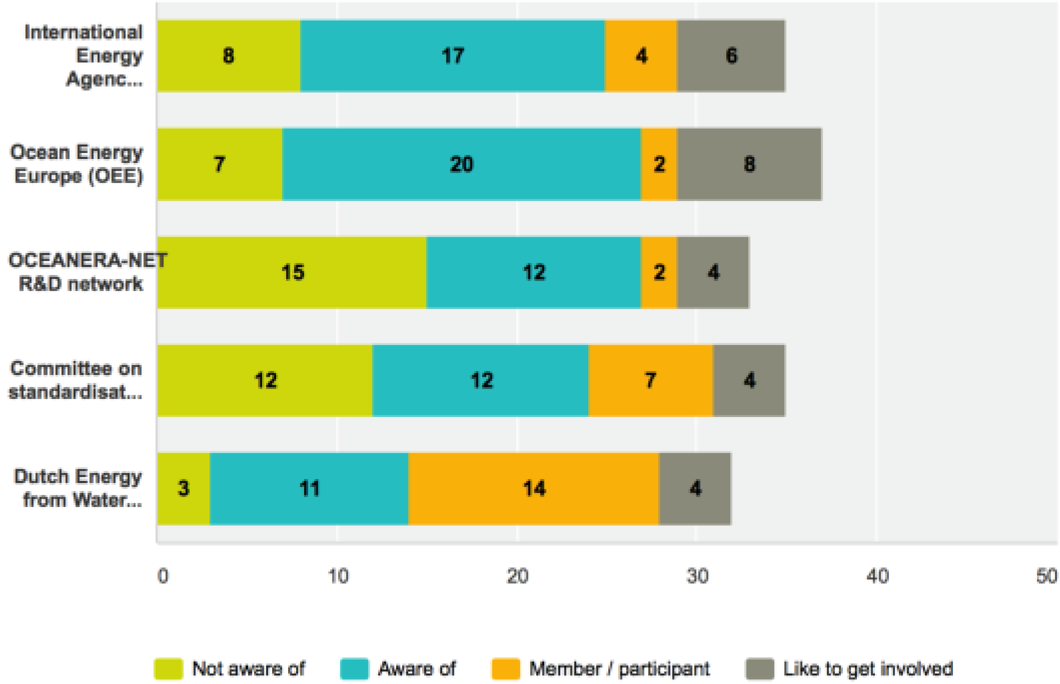


Figure 33 Awareness of international networks. High awareness or membership for Ocean Energy Europe, IEA-OES and the Dutch Energy from Water Association EWA. Low awareness of OCEANERANET and the IEC TC 114 committee on standardisation for marine energy convertors.

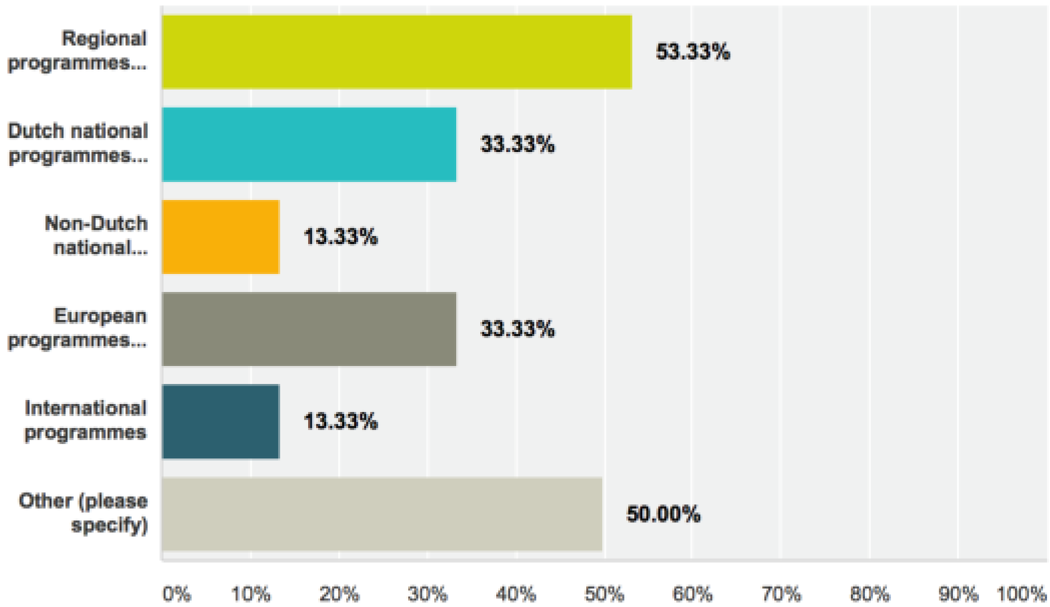


Figure 34 Main sources of funding applied for: predominantly regional programmes (like EFRO), followed by EU programs and Dutch programmes. Few applied for non-Dutch national funding.

6 Roadmap

The barriers and opportunities for the ocean energy sector can be divided in technical and non-technical. The following section summarizes the findings from the responses of the Dutch sector as well as areas identified in relevant international reports for the sector.

Findings from relevant international studies have been included in this roadmap and adapted for the Dutch sector (SI Ocean Project 2014; SI Ocean 2014; Low Carbon Innovation Coordination Group 2012; Carbon Trust 2011; KIC InnoEnergy 2014; JRC 2015; ETI 2015a). The full references are included in the section 8 and some of the results are included in the Annexes.

This chapter concludes with a Roadmap, proposing a number of actions to overcome the barriers and enable the development of the sector, maximizing the value to the Dutch economy.

6.1 Technology development needs

The wave and tidal sector is still at an early stage, with a large number of technical challenges that need to be overcome. This section describes a list of technical needs aggregated in 7 main areas, six of them related to the typical breakdown of ocean energy technologies and a first one focused on resource and performance assessment.

Resource and Performance modelling, measurement and assessment	
R&D Area Needs	**Dutch Expertise ***
• Improved resource assessment: models, methods, measurement systems, understanding of details, adequate forecasting. • Better understanding of extreme conditions (for design, maintenance, control and operation, installation) • Improved and validated models for performance assessment (single device & array hydrodynamics, techno-economic analysis) • Adequate infrastructure and standard methods for independent performance assessment.	**Institutes**: NIOZ, Deltares, ECN, NEN/IEC standards, TU Delft **Consultants/suppliers**: Aquavision, Nortek, Fugro
Structure & prime mover	
R&D Area Needs	**Dutch Expertise ***
• Design optimisation and especially reduction in mass of main structures, based on experimental and modelling results. • Fundamental R&D: New and better design concepts and structural configurations (especially for wave). • Improvement at subsystems/components level: Evolution of component level capabilities (e.g. high integrity tidal turbine blades). • Improved reliability and lifetime at component level. Fatigue analysis of systems and sub-systems.	**Institutes**: TU Delft , TTC NL, TNO, MARIN, Deltares, ECN **Consultants**: Teamwork Technology, MET-support, Entry Technology, Royal

• Use of alterative materials: such as GRP (glass-reinforced plastics), rubbers and concrete. Integration of innovative materials on moving parts and structure. Effects of ageing, fouling and corrosion. • Innovations in manufacturing processes: such as "batch production" of multiple units likely to reduce manufacturing costs and improve design through learning. • Robustness of devices: design for extreme conditions, robustness and efficiency • Field testing of prototypes and demonstration units (TRL based)	Haskoning DHV, DNV GL **Supply Chain**: SKF, Kyoga Bearings, Trelleborg, Airborne.
Power take off	
R&D Area Needs	**Dutch Expertise**
• Performance verification at subsystem/component level • Improved reliability and lifetime at subsystem/component level. Fatigue analysis and system redundancy. • Improved yield: through control systems. Improvements in control systems/software will help drive yield improvements in marine applications • Develop disruptive subsystems and components: to advance approaches to drivetrain and power take-off systems. Innovation expected in second generation power take-off technologies	**Institutes**: TU Delft (linear Power Take Off), TUE. **Consultants**: Teamwork Technology, PIAK, **Supply Chain**: Bosch-Rexroth, INNAS, Emerson, Siemens, SEV, Schottel
Moorings & Foundations	
R&D Area Needs	**Dutch Expertise**
• Moorings & seabed structures require design optimisation to improve durability & robustness and reduce costs • Improved station-keeping technologies. Floating wave devices use conventional mooring systems with arguably little direct cost reduction potential. However, savings are nevertheless expected to stem from improved deployability • Improved materials and manufacturing leading to cost reduction. • Environmental impact assessment • Use of common structures and sharing of system (e.g. anchor points) to reduce costs at array level.	**Institutes:** TU Delft **Supply Chain:** Bluewater Energy Services, Vryhof Anchors, Tecnip, DSM (Dyneema), ActaMarine, Van Oord
Electrical Connection	
R&D Area Needs	**Dutch Expertise**
• Development of next generation cables, connectors and transformers, including using higher voltage HVAC or HVDC and developing wet mate connectors (connectors that allow connections and installation in wet conditions) for marine applications, leading to cost reduction • Fatigue dynamics of systems and sub-systems (e.g. umbilical and power connectors) • Grid and cabling integration. Collaboration with wind. • Array cabling positioning and cable protection	**Institutes**: TU Delft. **Supply chain**: Twentsche Tabel Fabrikant, Nexans, Prysmian, ABB,

Installation and logistics	
R&D Area Needs	**Dutch Expertise**
• Installation techniques including vessels that are suited for deeper water, large scale installations, larger weather windows and at lower costs • Wave: alternative intervention solutions which allow faster deployment using lighter weight (cheaper) vessels. • Tidal: effective drilling techniques that are less prone to the fundamental challenges of operating in the tidal current. • Health and Safety requirements • Optimization of installation with common structures and sharing of systems (e.g. anchor points), shared vessel mobilization, etc.	**Supply Chain**: Van Oord, ActaMarine, Mammoet, Heerema, Boskalis, BAM, Strukton
Operation & Maintenance	
R&D Area Needs	**Dutch Expertise**
• Improved reliability: in design expected to reduce costs significantly • Maintenance Methods: Access technologies for O&M, retrieval rather than on-site intervention and remote condition monitoring. Development of new intervention techniques, with retrieval rather than on site-intervention. • Better provision of ports and infrastructure: lead to lower servicing and transport costs (in the UK, not in the Netherlands) • Development of knowledge on component failures (e.g. data gathering from existing projects and other sectors as wind).	**Institutes**: ECN, TU Delft **Supply Chain**: Van Oord

The following table summarizes the R&D priorities for the Dutch ocean energy sector, based on the identified needs, the market size and potential cost reduction taking into account the Dutch sector as well as findings from reference studies.

R&D need:	Market Share Based on Project Cost	Impact on LCoE reduction	Dutch Advantage	R&D Priority
Resource & performance assessment	-	-	HIGH	MEDIUM
Structure & prime mover	15-30%	8-24%*	MED / HIGH	MED / HIGH
Power take off	10-25%	5-20%*	MEDIUM	MEDIUM
Moorings & Foundations	5-15%	2-13%	HIGH	MED / HIGH
Electrical Connection	5-10%	1-3%	MEDIUM	LOW / MED

Installation & logistics	10-35%	5-28%	HIGH	HIGH
O&M	15-30%	12-26%	HIGH	HIGH

Table 4 R&D priorities and their share on impact on cost reduction compared to the Dutch advantage

A large share of the value of marine energy projects is related to offshore operations and components, where the Dutch industry has a leading position worldwide. Installation and O&M represents typically around 30-65% of the Project Cost along the project lifetime, depending on the type of device. These are also the areas where more cost reduction is expected (with the structural costs) and thus are identified as a top priority for the Dutch sector. Although moorings and foundations represent a lower share of the costs, due to the close link to the previous two areas and the strength of the Dutch industry, it may be considered as a top priority.

Device costs, i.e. structural components and PTO, also represent a large share of the Project Costs (25-55% depending on type of device). The Dutch, do not have such a leading position globally, although there are a large number of Dutch companies developing wave and tidal energy concepts, which deserve a medium to high priority level (not so much PTO components).

Although resource and performance assessment is not directly associated to hard components and thus not included in the Project Cost, these areas represent the basis of design for the rest of components and marine operations. Also the Dutch account for world-class knowledge in resource assessment and know-how of performance assessment in related sectors as offshore wind. Thus, this area is considered to be a medium to high priority.

Finally, the electrical connection components represent a relevant share of the project costs (5-10%), but it is a more mature technology with significant competition in other mature sectors as offshore wind and limited cost reduction potential. However, there are some “niche” areas such as the development of umbilical cables and subsea connectors / substations for deep sites that require innovative solutions. It is important that these components can also be employed in areas as floating offshore wind and O&G that have a large market potential.

Assuming a domestic market potential of 20 to 130MW, around 130 and 830 million € could be spent until 2050. By then the market would be stabilized with around 6 to 40 million Euros spent per year in O&M and replacement of units.

Market potential	2050 Capacity	Cumulative Market[2]	Annual Market[3]
Domestic	20 – 130 MW	100 – 620 m€	6 – 40 m€/yr
Export	60 – 300 GW	290 – 1.440 bn€[4]	30 – 140 bn€/yr

However, the greatest opportunity remains for the global export potential, especially in the case of wave energy. Until 2050, 400 to 1900 billion Euros could be spent in investment and O&M of ocean energy projects, with a stable expenditures of between 30 to 140 b€ per year in 2050.

6.2 Market development needs

This report is mainly focused on characterizing the technical needs but still it includes a list of important aspects that should be taken into account for enabling the market development.

The non-technical barriers and constraints are typically aggregated in the following aspects and briefly described in the following sections:

- Consenting and Planning
- Grid
- Finance

The following table describes the needs to enable market development at European level (export and competing markets), as well as in the Dutch context:

Consenting and Planning	
European context	**Dutch Context**
• Allow for integration of wave and tidal energy into long-term planning and with existing users • Streamline and accelerate the consenting processes by removing excessive administrative and cost burdens	• Dutch consenting is fragmented (many different actors), there is a lack of know-how with the authorities on marine energy issues, there many on-going changes in consenting laws, there is a lot of duplication in information requests from various authorities. • Setting a national plan with **strategic targets** in terms of installed capacity or energy production from ocean energy

2 Cumulative expenditures until 2050 assuming an avg. CAPEX of 3M€/MW and OPEX as 3% of CAPEX for 20 years (note that first projects will have higher costs while in long term lower than average values).

3 The annual expenditures by 2050 will be on O&M and replacement of the old equipment. The annual expenses have been calculated assuming a future LCOE of 100€/MWh for ocean energy and an average capacity factor 35%.

4 Billion Euros as 10^9 Euros.

<table>
<tr><td></td><td>gives confidence for the private sector to invest.</td></tr>
<tr><td colspan="2">Grid</td></tr>
<tr><td>European context</td><td>Dutch Context</td></tr>
<tr><td>Explore innovative ways to reduce prohibitive costs and delays for connecting early stage projects (especially in UK).
Extend the grid to reach the wave and tidal energy resource rather than constraining ocean projects to grid-connected areas
Allow for integration of wave and tidal energy into long-term planning and with existing ocean users
Streamline and accelerate the consenting processes by removing excessive administrative and cost burdens</td><td>The Dutch grid is operated by TENNET and generally accepted as high quality, well maintained and widely spread across the country (competitive advantage)
High cost for grid extension for planned tidal plant in Brouwersdam maybe a bottleneck for an attractive business case.</td></tr>
<tr><td colspan="2">Finance</td></tr>
<tr><td>European context</td><td>Dutch Context</td></tr>
<tr><td>Introduce market push and pull support to ensure that up to ten pilot arrays – of three devices or more – can reach financial close by 2020 across Europe
Develop clear and flexible European Commission State Aid checks for financing up to ten pilot arrays in Europe by 2020
Continue to push game-changers, challengers and frontrunners up the Technology Readiness Levels (TRL1–8)
Encourage early investment in innovation for materials, supply chain components and services, enabling innovation, standardisation and cost reduction along the supply chain.</td><td>Considerable capital support schemes exist with the new DEI-regeling, the Hernieuwbare Energie Regeling, EFRO funds and Horizons 2020. However the level of funding per project may not be adequate for large projects.
Lack of private investments especially from utilities, lack of incentives to invest in the Netherlands.
SDE+ scheme is attractive for mature and competitive technologies. It is not ideally suited for implementing innovative projects for wave and tidal.
Supply chain are starting to invest through active participation and risk taking in demonstration projects</td></tr>
</table>

6.3 Recommendations

This section proposes a list of actions that have been identified by the Dutch sector as well as wider European initiatives to accelerate the development of the ocean energy sector. It provides a list of actions with a brief description, which is summarized in the Roadmap. These actions represent a combination of technology push and market pull mechanisms, which depend on the level of maturity of the technologies and may vary from technology to technology.

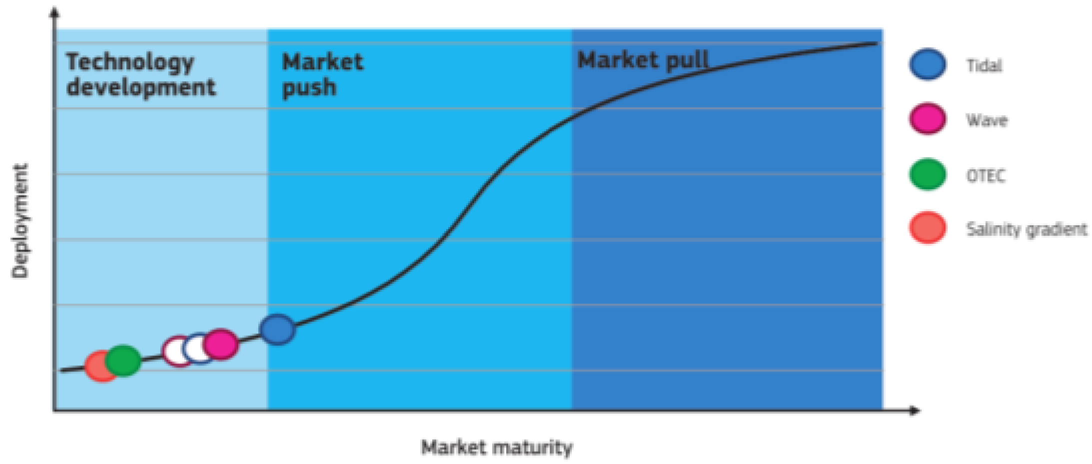


Figure 35. Support mechanisms according to market maturity (JRC 2015)

- **R&D Programs:** described in the previous section, there are R&D needs to further develop marine energy technologies and enabling components and services. A specific R&D call for Ocean Energy, perhaps under MIT or OCEANERA-NET focused on critical and strategic topics would be an enabler. It should be open not only for SMEs but also large companies, such offshore industries.

- **Call for demonstration projects:** for those technologies at higher TRLs, the final step is to demonstrate its performance in controlled and or exposed conditions. The Netherlands has ideal conditions for part-scale testing (both wave and tidal) of single or multiple devices, and the opportunity to capture critical know-how and help develop the sector cost-effectively. Considering the strong export potential, there is a need for a programme for Dutch companies to demonstrate their technology at full-scale sites *outside* the Netherlands. Existing demonstration grant schemes, such DEI, should consider increasing the level of funding per project to match the needs of larger projects like Brouwersdam.

- **Testing infrastructure:** There is a need for testing infrastructure at different TRL levels. Although the Netherlands accounts for good infrastructure, there is limited use of it. Facilitating access to the facilities would help progress as well as capture practical experience. The various test sites of the Tidal Testing Centre need further support to build required infrastructure. Also the Netherlands does not account for full-scale, exposed open water test sites (no appropriate conditions), and access to other test sites in EU should be stimulated. This can be done for example by active and financial participation in the OCEANERA-NET project.

- **Develop Standards and certification:** standards and certification play a key role in consolidating knowledge and experience, and bringing confidence for investors, financers, legislators and other stakeholders. The continued involvement of Dutch stakeholders, led by NEN should be promoted and supported.

- **Involve supply chain:** bringing the experience of the supply chain into wave and tidal is a great opportunity for the marine energy sector and the Dutch offshore and maritime industry in particular. Actions to attract its interest can have a great impact on the sector. This can be achieved through supporting network activities, such as conferences and dissemination of information via existing coordinated actions such as NEN, NWP, FME, the Dutch Energy from Water Association and the EIP Action Group on Energy from Water Works.

- **Simplify consenting process:** Currently there is no streamlined consenting process in the Netherlands. Also there is a lack of know-how on marine energy at government levels. Up to seven public authorities are typically involved in applying for all permits required. A single point of contact, who has background knowledge on marine energy technology, would be helpful for developers and could streamline the application process.

- **Market support:** Policy and targets: marine technology development requires significant investment (both public and private) to reach TRL9. Financial incentives will play a critical role in attracting private investment and sharing risks. Concretely:
    - Capital grants: for R&D and demonstration projects, with decreasing share of public funding with increase in TRL.
    - FITs: feed-in tariff to provide revenue type incentive for first pre-commercial and commercial projects.
    - National targets: setting national targets for marine energy is also a good indicator for the private sector to invest.

- **International cooperation:** To achieve cost-effectively all the previous points, ensuring that the Netherlands does not replicate work done in other EU countries and focuses on its competitive advantages, it is critical to cooperate closely with other leading countries and participate in international networks such as the the EC Ocean Energy Forum, IEA-OES, European Ocean Energy Association and OCEANERA-NET. These activities should not be undertaken only at government level, but should include active participation of industry**.**

- **Export support:** a number of companies is on the brink of commercialising their technologies. Their chances of success can be increase with coordinated support for export activities, eg through embassies and international networks such as IRO, NWP, FME, Dutch Maritime Cluster etc.

The figure on the following page is a synthesis of the needs and actions.

Needs	Proposed Actions	Specific Objectives	Specific Targets	5 year Investment (public&private)
Technology Needs	**R&D Program calls**	Advance TRL levels and optimize design.	5 products by 2020 (TRL9)	10-20mEUR[5]
	Develop Standards & certification	Technology convergence and reduce risks.	5-10 products certified.	150kEUR/year
	Involve supply chain	Bring knowhow from mature sectors (e.g. offshore sector for installation & O&M)	30-50 companies involved in R&D projects	Fiscal incentives
	Testing infrastructure	Validation, convergence and risk reduction.	2 new test infrastructures (GTTC, OFFGRID)	5-15mEUR[6]
	Call for demonstration projects	Demonstrate high TRL and cost/risk reduction.	5 products by 2020 (TRL9)	50 - 150mEUR[7]
Market Needs	**International cooperation**	Share experience / maximize international support	1000 Dutch persons in intentional networks	30kE/yr for fees
	Simplify consenting	Accelerate the deployment of first projects.	10-30 MW installed by 2020	n.a.
	Policy & targets	Provide confidence to attract private investment with national vision.	10-30 MW installed by 2020	n.a. (internal vision paper)
	Feed-in tariff	Attract private investment with adequate market support mechanisms.	10-30 MW installed by 2020	FIT > 150 EUR/MWh

2015 2016 2017 2018 2019 2020

[5] Based on 10 to 20 R&D projects of 1-2M€ budget.

[6] Estimate cost for infrastructure investments at TTC Den Oever and Grevelingen, including a off-grid test facility

[7] Based on 10 to 30MW installed by 2020, with an average CAPEX of 5M€/MW (O&M costs not included, but assumed to be covered by FIT support).

7 Key sources and references:

1. RenewableUK – Channeling the Energy, October 2010. (www.renewable-uk.com)
2. Renewable UK – State of the Industry Report, March 2011. (www.renewable-uk.com)
3. IEA – Implementing Agreement on Ocean Energy Systems, Annual Report 2010 (www.iea-oceans.org)
4. PMSS, renews, Marine Special Report 2011 (www.pmss.co.uk)
5. WWF - The Energy Report – 100% Renewble Energy by 2050. WWF, Ecofys, OMA.
6. World Economic Forum – Scaling Up renewables – April 2011
7. Douglas-Westwood – the world Wave and Tidal Market Report 2011-2015.
8. ReCharge newspaper – Tuesday May 3, 2011 (www.rechargenews.com)
9. Alstom, 2014. Tidal Power Solutions,
10. Black & Veatch & Carbon Trust, 2005. TIDAL STREAM ENERGY RESOURCE AND TECHNOLOGY SUMMARY REPORT,
11. Carbon Trust, 2011. Accelerating marine energy. , (July).
12. ETI, 2015a. Insights into Tidal Stream energy.
13. ETI, 2015b. Wave Energy. Insights from the Energy Technologies Institute.
14. IEA, 2009. World Energy Outlook 2009,
15. IEA-OES, 2011. An International Vision for Ocean Energy.
16. IPCC, 2011. Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change,
17. JRC, 2015. 2014 JRC Ocean Energy Status Report
18. KIC InnoEnergy, 2014. Ocean Energy - Strategy and Roadmap,
19. Low Carbon Innovation Coordination Group, 2012. Technology Innovation Needs Assessment (TINA). Marine Energy Summary Report.
20. Revision, 2012. The Future Potential of Wave Power in the United States,
21. SI Ocean, 2014. Wave and Tidal Energy Market Deployment Strategy for Europe,
22. SI Ocean Project, 2014. Wave and Tidal Energy Strategic Technology Agenda

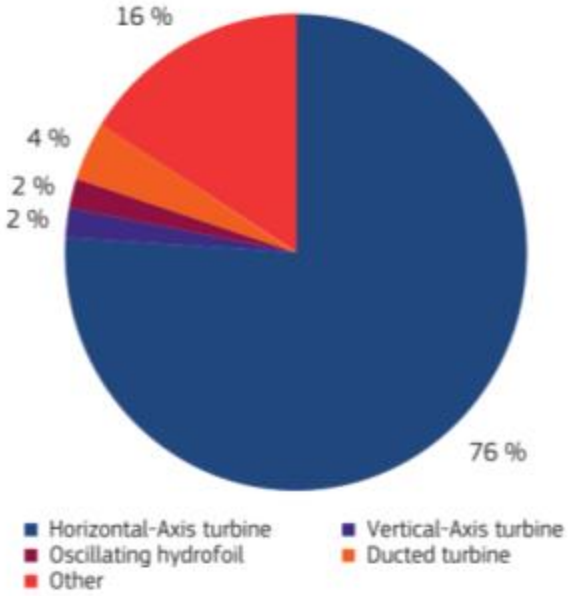
Appendices

A. Wave and tidal device classifications
B. TRL levels
C. List of companies
D. Planned Projects
E. Economics
F. Relevant Roadmaps
G. Support mechanisms in other countries

A. Wave and tidal device classifications

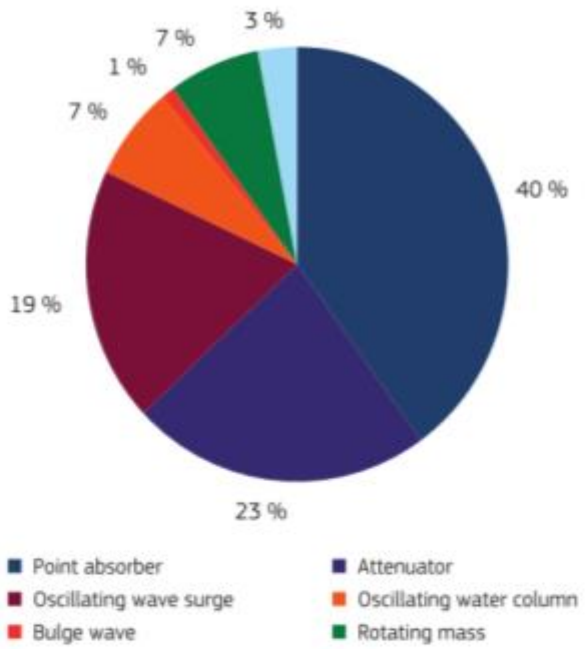
Tidal Energy device classification

Device type	Class	Description
Horizontal-Axis Turbine	A	Similarly to wind energy converters, this technology exploits the lift from the tidal flow to force the rotation of the turbine mounted on a horizontal axis. This operates a rotor, converting mechanical energy to electrical energy through use of a generator.
Vertical-Axis Turbine	B	The principle of operation of vertical axis turbines is similar to the horizontal devices, except the turbines are mounted on a vertical axis.
Oscillating Hydrofoil (Reciprocating Device)	C	Oscillating hydrofoils comprise a hydrofoil located at the end of a swing arm, which is allowed to oscillate in pitching mode by a control system. The motion is then used to pump hydraulic fluid through a motor. The rotational motion that results can be converted to electricity through a generator.
Ducted Turbine or Enclosed Tips	D	Enclosed tips (ducted) turbines are essentially horizontal-axis turbines contained within a Venturi duct. This is designed to accelerate and concentrate the fluid flow. Ducted structures could also reduce turbulence around the turbines and facilitate the alignment of water flow towards the turbines.
Archimedes' Screw	E	These devices are a variation of the on vertical-axis turbines, drawing power from the tidal stream as the water flows up through the helix.
Tidal Kite	F	Tidal kite devices comprise a tethered kite with a small turbine. The kite effectively flies through the flow, increasing the relative flow velocity entering the turbine.
Other	G	Novel tidal concepts currently under development that do not fit any of the above categories.



Wave Energy device classification

Device Type	Class	Description
Attenuator	A	Attenuators exploit the incoming wave power to generate an oscillatory motion between adjacent structural components. The resulting motion activates the power take-off (PTO), either by pumping high-pressure fluids through a hydraulic motor or by operating a direct-drive generator. Attenuators are designed to operate offshore, and are commonly surface floating, although fully submerged devices have been proposed.
Point Absorber	B	Point absorbers are normally heaving/pitching devices that exploit the relative motion between an oscillating body and a fixed structure or component, which can be either moored to the seabed or installed on the seabed through a large foundation mass. Point absorbers are normally smaller in dimension compared to other WECs. They are non-directional devices, as their performances are not affected by wave directionality.
Oscillating Wave Surge Converter (OWSC)	C	Oscillating wave surge converters exploit the surging motion of near-shore waves to induce the oscillatory motion of a flap in a horizontal direction. OWSCs are bottom-mounted devices, although prototypes of floating OWSC are already under development.
Oscillating Water Column (OWC)	D	Oscillating water columns (OWC) use the oscillatory motion of a mass of water induced by a wave in a chamber to compress air to drive an air turbine. The water column thus acts as a piston on the air volume, pushing it through the turbine as the waves increase the water level in the chamber, and drawing it as the water level decreases. OWCs are one of the first types of wave energy converters developed, and different operational ones are installed onshore in self-contained structures. Floating OWCs have been tested and are currently under development for offshore deployment.
Overtopping	E	Overtopping devices or terminator WECs convert wave energy into potential energy. This is stored in a reservoir and used to drive low-head turbines. The design of overtopping devices facilitates waves breaking on a ramp to be collected in a reservoir above the free water surface. Water contained in the reservoir can produce energy by flowing through a low-head hydraulic turbine. Overtopping devices have been proposed to be built for integration in breakwaters, for self-contained onshore operation and for offshore installation.
Submerged Pressure Differential	F	Submerged Pressure Differential devices are fully submerged devices, exploiting the hydro-dynamic pressure induced by waves to force an upward motion of the device, which then returns to its starting position once the pressure differential is reduced.
Bulge Wave	G	Bulge wave devices use wave-induced pressure to generate a bulge wave within a flexible tube. As the bulge wave travels within the device it increases in size and speed. The kinetic energy of the bulge is used to drive a turbine at the end of the tube.
Rotating Mass	H	Rotating mass converters exploit the relative motion of waves to induce pitching and rolling in a floating body, thus forcing the rotation of an eccentric mass contained within the device. As the mass rotates it drives an electrical generator.
Other	I	Novel wave energy devices currently under development that do not fit any of the above categories.



Source: (JRC 2015)

B. TRL levels

As shown in the following figure, leading tidal energy developers are said to be around TRL 6/7, with the first arrays in development, which would increase to TRL8. In the case of wave energy, there are a number of prototypes at TRL 5/6 and perhaps one at TRL7, corresponding to the OWC technology onshore (but with low commercial outlook given the low resource available). However, as previously mentioned a number of the leading wave technologies have not succeed, and a new generation of innovative technologies are being design and tested in laboratories (TRL 2-4).

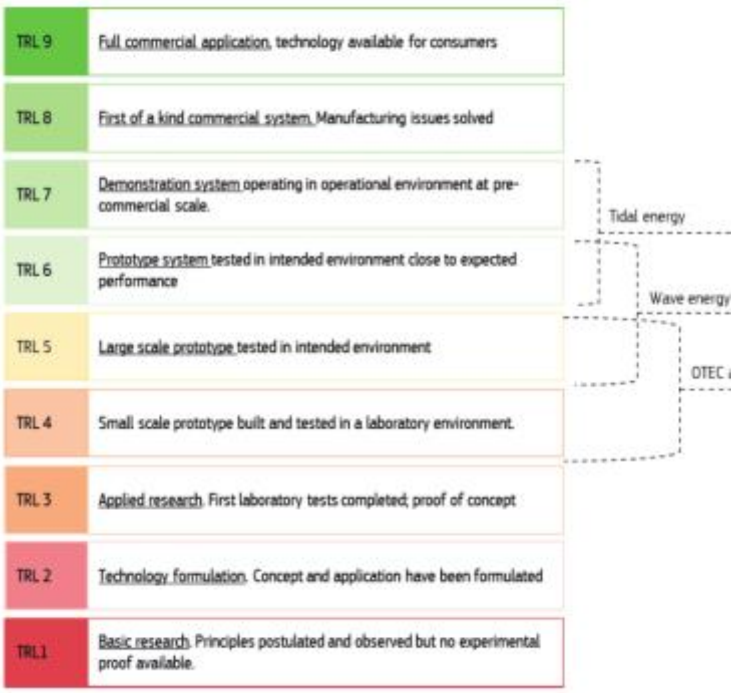


Figure 36 TRL levels in Marine Sector(JRC 2015)

C. List of companies

Both in Tidal and Wave there have been a number of pioneering players who have built up a prominent position over the last 10-15 years. Examples of such companies which have large devices operating offshore are Marine Current Turbines (tidal, UK), Hammerfest Strom (tidal, Norway) and Pelamis Wave Power (wave, UK).

These companies where shortly thereafter followed by a group of technology developers who have received specific attention, support and/or funding from the key industry players in the (hydro) power generation market (such as Alstom Power, Siemens, ABB, Andritz Hydro, Voith Hydro, Bosch Rexroth and Rolls Royce).

The following pages include a list of the key players in the sector:

Tidal Energy Conversion – key players

Company Name	Model	Operational Testing	Country	Website
Alstom Hydro/Tidal Generation Limited	TGL series	Full-scale	France/UK	www.alstom.com/power/renewables/ocean-energy/tidal-energy
Andritz Hydro Hammerfest	HS series	Full-scale	Norway/Austria	www.hammerfeststrom.com
Aqua Energy Solutions	AES tidal devices	Part-scale	Norway	www.aquaenergy.no
Atlantis Resources Corporation	AN series, AR series, AS series	Full-scale	Singapore/UK	www.atlantisresourcesltd.com
BioPower System Pty Ltd	bioStream	Full-scale	Australia	www.biopowersystems.com
Bluewater	BlueTEC	Part-scale	Netherlands	www.bluewater.com/new-energy/tidal-energy/
Clean Current Power Systems	Clean Current Turbine	Full-scale	Canada	www.cleancurrent.com
Deepwater Energy BV	Oryon Watermill	Part-scale	Netherlands	www.deepwater-energy.com
EEL Energy	EEL Tidal Energy Converter	Small-scale	France	www.eel-energy.fr/en
Elemental Energy Technologies	SeaUrchin	Small-scale	Australia	www.eetmarine.com
Flumill	Flumill	Part-scale	Norway	www.flumill.com
Hydra Tidal Straum AS	Hydra tidal	Part-scale	Norway	www.hydratidal.info
Hyundai Heavy Industries		Part-scale	South Korea	www.hyundaiheavy.com/news/view?idx=332
IHC Tidal Energy/ Tocardo[a]	OceanMill	Part-scale	Netherlands	www.ihctidalenergy.com
Kawasaki Heavy Industries Ltd		Full-scale	South Korea	www.khi.co.jp/english/news/detail/20111019_1
Marine Current Turbines	SeaFlow, SeaGen	Full-scale	UK/Germany	www.marineturbines.com
Magallanes Renovables	Atir	Part-scale	Spain	www.magallanesrenovables.com
Minesto	Deep Green	Part-scale	Sweden	www.minesto.com
Nautricity	CoRMaT	Full-scale	UK	www.nautricity.com
New Energy Corporation	EnCurrent Turbine		Canada	www.newenergycorp.ca
Nova Innovation	Nova-I	Part-scale	UK	www.novainnovation.co.uk
Ocean Flow Energy	Evopod	Small-scale	UK	www.oceanflowenergy.com
Ocean Renewable Power Company	TidGen	Small-scale	USA	www.orpc.co
Oceana Energy Company	Oceana	Small-scale	USA	www.oceanaenergy.com
OpenHydro (DCNS)	Open Centre Turbine	Full-scale	Ireland/France	www.openhydro.com
Sabella SAS	Sabella D03	Part-scale	France	www.sabella.fr
Schottel Group	STG series	Full-scale	Germany	www.schottel.de
Scotrenewables	SR series	Part-scale	UK	www.scotrenewables.com
Tidal Energy Ltd	DeltaStream	Part-scale	UK	www.tidalenergyltd.com
TidalStream Limited	Plat-O	Part-scale	UK	www.tidalstream.co.uk
Tidalys	Electrimar1800, 4200	Part-scale	France	www.tidalys.com
Tocardo Tidal Turbines	T series	Full-scale	Netherlands	www.tocardo.com
Uppsala University: The Ångström Laboratory		Small-scale	Sweden	
Verdant Power	Free Flow System	Full-scale	USA	www.verdantpower.com
Voith Hydro	HyTide	Full-scale	Germany	www.voith.com/en/products-services/hydro-power-377.html
Vortex Hydro Energy	VIVACE	Small-scale	USA	www.vortexhydroenergy.com

Figure 37 Leading tidal energy developers

Tidal Developer	Blade Manufacturer	Website
Marine Current Turbines/Siemens	AEL	www.aviationenterprises.co.uk
Alstom/TGL	AEL	www.aviationenterprises.co.uk
Tocardo	Airborne Marine	airborne-marine.com/
Andritz Hydro/Hammerfest	Gurit	www.gurit.com/
Atlantis	Norco Ltd	www.norco.co.uk
OpenHydro/DCNS	Norco Ltd	www.norco.co.uk
Schottel	Avantgarde Technologie	www.avantgardetechnologie.de/
Pulse Tidal	Designcraft	www.designcraft.co.uk/
Tidal Energy Ltd	Designcraft	www.designcraft.co.uk/
Ocean Flow	Designcraft	www.designcraft.co.uk/
Scotrenewables	Designcraft	www.designcraft.co.uk/
TidalStream	Designcraft	www.designcraft.co.uk/

Developer	Bearings	Brakes	Shaft	Gearbox	Control	Generator	Electrical
Alstom/TGL			Invo-tech	Orbital2 Wikov		In-house	
Andritz Hydro/ Hammerfest			Schottel			In-house	Converteam
Atlantis R.C.		Altra Industrial Motions	Schottel	David Brown	Schottel	ATB Morley	ABB
Nova Innovation				Siemens		Siemens	
Ocean Flow		James Fisher Defence	James Fisher Defence	James Fisher Defence			
OpenHydro						In-house	
Pulse Tidal		Bosch Rexroth	Bosch Rexroth	Bosch Rexroth	Fraunhofer IWES	In-house	Senergy Econnect
Schottel	Wolfgang Preinfalk					In-house	
Scotrenewables					MacArtney	In-house	ABB
MCT/Siemens	NKE		Invo-tech	Orbital2 Wikov		In-house	
Tidal Energy Limited				Siemens		In-house	General Electrics

Figure 38 Tidal energy component suppliers

Wave Energy Conversion – Key players

Company Name	Model	Operational Testing	Country	Website
40South Energy	R115, Y series, D series	Full-scale	Italy/UK	www.40southenergy.com
Albatern	SQUID	Part-scale	UK	http://albatern.co.uk/
AquaGen Technologies	SurgeDrive	Small-scale	Australia	www.aquagen.com.au
Aquamarine Power	Oyster	Full-scale	UK	www.aquamarinepower.com
Atargis Energy		Small-scale	USA	www.atargis.com
AW Energy	WaveRoller	Full-scale	Finland	www.aw-energy.com
AWS Ocean Energy	AWS-III, Archimedes Wave Swing	Full-scale	UK	www.awsocean.com
BioPower Systems Pty Ltd	bioWave	Small-scale	Australia	www.biopowersystems.com
Bombora WavePower	Bombora WEC	Small-scale	Australia	http://www.bomborawavepower.com.au/
Carnegie Wave Energy Ltd	CETO	Full-scale	Australia	www.carnegiewave.com
Columbia Power Technologies	Manta, SeaRay	Part-scale	USA	www.columbiapwr.com
COPPE Subsea Technology Laboratory		Part-scale	Brazil	www.coppenario20.coppe.ufrj.br/?p=805
DexaWave A/S	DexaWave	Small-scale	Denmark	www.dexawave.com
Eco Wave Power	Wave Clapper, Power Wing	Part-scale	Israel	www.ecowavepower.com
Floating Power Plant AS		Part-scale	Denmark	www.floatingpowerplant.com
Fred Olsen Ltd	FO3, Bolt, Bolt 2 Lifesaver	Full-scale	Norway	www.fredolsen-renewables.com
Intentium AS	ISWEC, IOWEC	Full-scale	Norway	http://www.intentium.com/
Kymaner	Kymanos	Part-scale	Portugal	http://www.kymaner.com/
Langlee Wave Power	Rubusto	Full-scale	Norway	www.langlee.no
LEANCON Wave Energy	MAWEC	Small-scale	Denmark	http://www.leancon.com/
Neptune Wave Power	Neptune WECD	Part-scale	USA	http://www.neptunewavepower.com/
Ocean Energy Ltd	OEBuoy	Part-scale	Ireland	www.oceanenergy.ie
Ocean Harvesting Technologies		Full-scale	Sweden	http://www.oceanharvesting.com/
Ocean Power Technologies	PowerBuoy	Full-scale	USA	www.oceanpowertechnologies.com
Oceantec	Oceantec WEC	Small-scale	Spain	www.oceantecenergy.com
Offshore Wave Energy Ltd (OWEL)	OWEL WEC	Small-scale	UK	www.owel.co.uk
Oscilla Power	Wave Energy Harvester	Small-scale	USA	www.oscillapower.com
Pelamis Wave Power [a]	Pelamis	Full-scale	UK	www.pelamiswave.com
Perpetuwave	Wave Harvester	Part-scale	Australia	http://www.perpetuwavepower.com/
Pico Plant EU Consortium	Pico Plant OWC	Full-scale		
RESEN Waves	LOPF Buoy	Small-scale	Denmark	http://www.resen.dk/resen_standard.asp?pageid=120
Resolute Marine Energy Inc.	SurgeWEC	Full-scale	USA	www.resolute-marine-energy.com
SDE Energy	Sea Wave Power Plants	Full-scale	Israel	http://www.sdeglobal.com/
Seabased AB	Seabased	Full-scale	Sweden	www.seabased.com
Seatricity	Oceanus	Full-scale	UK	www.seatricity.net
Spindrift Energy	Spindrift	Small-scale	USA	http://www.spindriftenergy.com/
Trident Energy Ltd	PowerPod	Full-scale	UK	www.tridentenergy.co.uk
Voith Hydro Wavegen	Limpet OWC, Mutriku OWC	Full-scale		
Wave Dragon	Wave Dragon	Part-scale	Denmark	http://www.wavedragon.net/
Wave Energy Technology New Zealand (WET-NZ) [b]	WET-NZ	Part-scale	New Zealand	www.waveenergy.co.nz
WaveRider Energy	WaveRider Platform	Part-scale	Australia	www.waveriderenergy.com.au
WaveStar Energy	WaveStar	Part-scale	Denmark	www.wavestarenergy.com
Wedge Global		Part-scale	Spain	www.wedgeglobal.com
Wello OY	Penguin	Full-scale	Finland	www.wello.fi
WePTO	WePTO WEC	Part-scale	Denmark	www.weptos.com

[a] Pelamis filed for administration in November 2014 [b] WET-NZ sold its technology to a US-based company in 2014

Companies shortlisted by IRENA

Figure 39 List of leading wave energy developers

Company	Fabrication	PTO & Generator	Electrical & Automation	Bearings	Marine Operations	Hydraulic Components	Certification	Coating	Diagnostic
40South Energy			ABB						
Albatern	Zeus Engineering, Purepipe	Bosch Rexroth			Mallaig Marine	Mallaig Marine			
Aquamarine Power	Burntisland Fabrications	Bosch Rexroth	ABB	Hutchinson	Fugro Seacore	Hunger Hydraulics	DNV GL		BAE Systems
AW Energy			Metso				DNV GL, Lloyds Register	Hempel	
Carnegie		Bosch Rexroth		Hutchinson					
Fred Olsen Ltd	A&P Falmouth, Supacat	Siemens			SeaRoc		DNV GL		
Langlee Wave Power	Repnaval						DNV GL		
Pelamis Wave Power	Barnshaws		KTR Couplings	Schaeffler					
Seatricity	A&P Falmouth								
Wave Star Energy									
Wello OY	Riga Shipyard	The Switch	Veo	Schaeffler		Hydac, Seaproof Systems			

Figure 40 Wave energy component supplier

D. Planned Projects

Tidal Energy Projects

Name	Capacity (MW)	Status	Project Developer
Bluemull Sound	0.5	In planning	Nova Innovation Ltd
Brough Ness	100	In planning	Sea Generation (Brough Ness) Ltd
Cantick Head	200	In planning	Cantick Head Tidal Development Ltd
Esk Estuary	0.6	In planning	GlaxoSmithKline Montrose plc
Inner Sound (MeyGen)	392	In planning	MeyGen Ltd
Isle of Islay	30	In planning	DP Marine Energy Ltd
Kyle Rhea	8	In planning	Sea Generation (Kyle Rhea) Limited
Mull of Kintyre	3	In planning	Argyll Tidal Ltd
Ness of Duncansby	100	In planning	ScottishPower Renewables UK Ltd
Sanda Sound	0.035	In planning	Oceanflow Development Ltd
Sound of Islay	10	In planning	ScottishPower Renewables UK Ltd
St David's Head	10	In planning	Tidal Energy Developments South Ltd
Westray South	200	In planning	Westray South Tidal Development Ltd
Afsluitdijk	3	In development	Tocardo, Tidal Test Centre
Fair Head	100	In development	DP Marine Energy & DEME Blue Energy
Lashy Sound	30	In development	Scotrenewables Tidal Power
Nepthyd	5.6	In development	Alstom/GDF Suez
Normandie Hydro	14	In development	OpenHydro/DCNS/EDF/ADEME
Perpetuus Tidal Energy Centre	20	In development	Isle of Wight Council
Ramsey Sound	1.2	In development	Tidal Energy Limited
Fromveur	1	In development	Sabella/IFREMER/Veolia Environnement/Bureau Véritas
Norway	2	In development	Flumill
Raz Blanchard	12	In development	GDF Suez/Voith Hydro/CMN/Cofely Endel/ACE
Inner Sound (Meygen)	6	In construction	MeyGen Ltd
Strangford Lough (Minesto 2)	0.003	In construction	Minesto AB
EMEC Shapinsay Sound	n.a.	Nursery facilities	European Marine Energy Centre Ltd
Lynmouth	1.6	Interrupted	Pulse Tidal Ltd
Skerries, Anglesey	10	Interrupted	Sea Generation Ltd
EMEC Fall of Warness	10	Operational	European Marine Energy Centre Ltd
Ness of Cullivoe	0.03	Operational	Nova Innovation Ltd
Strangford Lough (Minesto 1)	0.003	Operational	Minesto AB
Strangford Lough (SeaGen)	1.2	Operational	Sea Generation Ltd

Sources: The Crown Estate 2014; France Energies Marines 2014

Projects expected to become operational by the end of 2016 (green) | Projects of uncertain status (orange) | Interrupted projects (red)

Figure 41 Planned tidal projects

Project Name	Location	Capacity	Funding Awarded	Funding Body	Expected Operation Date	Status and Updates
Sound of Islay	Islay, Scotland, UK	10 MW	20.65 m EUR	NER 300/EU	31/10/2016	Project put forward by ScottishPower Renewables and to employ Andritz Hydro and Alstom turbines.
Kyle Rhea	Isle of Skye, Scotland, UK	8 MW	16.77 m EUR	NER 300/EU	31/12/2016	The EU has approved up-front funding for this project of 10 m EUR.
MeyGen	Pentland Firth Inner Sound, Scotland	6 MW	10 m GBP	MEAD/UK	Jan–Jun 2016	The project has reached financial close for the development of phase 1A (6 of 86MW). Construction was expected to begin in the fourth quarter of 2014. DECC and The Crown Estate are among the financing sources.
Skerries Array	Anglesey, Wales, UK	10 MW	10 m GBP	MEAD/UK	Jan–Jun 2016	Project halted following delays to expected operation date.
Nepthyd	France	5.6 MW	Undisclosed	ALSTOM / GDF SUEZ / ADEME	31/12/2017	ADEME has awarded Alstom/GDF Suez and OpenHydro/DCNS/EDF funds for the creation of pilot tidal projects in France. The total sum provided by ADEME is 103 m EUR, and the total costs over 20 years are expected to be 210 m EUR.
Normandie Hydro	France	14 MW	Undisclosed	OpenHydro / DCNS/ EDF/ ADEME	31/12/2018	ADEME has awarded Alstom/GDF Suez and OpenHydro/DCNS/EDF funds for the creation of pilot tidal projects in France. The total sum provided by ADEME is 103 m EUR, and the total costs over 20 years are expected to be 210 m EUR.

Figure 42 Funding for the expected tidal projects

Wave Energy Projects

Table 16: Upcoming wave energy demonstration projects

Project Name	Device	Capacity	Type	Expected Completion Date	Updates
Western Australia	Carnegie CETO5	0.72 MW	Demo array	2014	The project is currently under construction, with the first device having started operations (ReNews 2014b).
EMEC – Oyster	Oyster 801	0.8 MW (up to 1.6 MW)	Single device/ Demo array	2015	Oyster 801 represents an improvement on the existing Oyster 800, deployed currently at EMEC. The two devices will be installed closely and connected to the same power station. Oyster 802 will be also installed, with the total array capacity expected to be 2.4 MW once completed. Oyster 800 underwent significant upgrades in summer 2014.
Sotenas	Seabased	10 MW	Array	2016	The construction of the array is currently underway with the first 10 devices out of a total of 340 already installed.
Wave Hub	Seatricity Oceanus	10 MW	Demo array	2016	The first Oceanus device was installed at Wave Hub in June 2014. Electricity generation will begin in 2015. Seatricity aims to deploy 60 devices at Wave Hub to a total of 10 MW. Oceanus devices are being fabricated in Falmouth.
Garden Island	Carnegie CETO6	3 MW	Demo array	2016	Carnegie is currently upgrading its CETO5 technology from 204kW to 1MW, and is expected to install in Garden Island in 2016.
Swell	Wave Roller	5.6 MW	Demo array	01/01/2018	16 Wave Roller devices should be installed off the coast of Peniche. The project has received NER 300 funds.
Wave Hub	Carnegie CETO6	3 MW	Demo array	N/A	Carnegie was awarded a berth at Wave Hub in June 2014. They plan a 3 MW installation of its CETO6 devices, with an option to expand up to 10 MW. The development of the project is to be carried out in parallel with the Garden Island 3MW demo array.
Wave Hub	Wello Oy Penguin	5 MW	Single device	N/A	In February 2014 Fortum signed a lease with Wave Hub for a berth. It later announced that it would be used for testing the upscaled version of the Penguin device, developed by Wello.
West Wave	Wave Roller Pelamis Oyster	5MW	Demo array	30/06/2018	In September 2014 it was announced that Wave Roller and Pelamis were shortlisted as the wave energy technologies to be deployed at the site.
Canary Islands	Langlee Robusto	0.5 MW	Demo array	N/A	Langlee has announced plans for the construction of devices in the Canary Islands and is also pushing forward testing and potential development in the Canary Islands, including a 500kW array.

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Figure 43 Planned wave projects

Project Name	Location	Capacity	Funding Awarded	Funding Body	Expected Operation Date	Status and Updates
Development projects						
Pelamis & Aquamarine Power	Scotland	N/A	13 m GBP	MCRF Wave First Array Support Programme	N/A	Support for Device Development and Proving and Site Development Fast Track, aimed at accelerating the development and proving of the core device technology alongside the site development work necessary to progress towards first wave demonstration arrays in Scottish waters.
EMEC, Green Theme, Tension Technology International	Scotland	N/A	4.8 m GBP	MRCF	N/A	EMEC to implement a seabed monitoring pod. Green Theme to develop a cable-mounted device, aiding cable installation in fast flowing conditions. Tension Technology International to design a novel mooring system.
MHK System Performance Advancement	USA (Federal)	N/A	13 m USD	US DOE	In progress	Advanced R&D fund for PTO and structure optimisation and advanced WEC control
Deployment projects						
West Wave	Co. Clare, Ireland	5 MW	23.3 m EUR	NER 300/EU	30/06/2018	West Wave shortlisted Pelamis Wave Power and AW-Energy as potential technologies for installation.
Swell	Peniche, Portugal	5.6 MW	9.1 m EUR	NER 300/EU	01/01/2018	The project will receive upfront funding of 5.5m EUR on 01/01/2016.
Perth Wave Energy Project (Carnegie)	Perth, Australia	1 MW (up to 2 MW)	22.4 m AUD	ARENA, Western Australia Government	Construction completed	The Perth wave energy project may become the first wave energy array to become commercial, comprising four CETO5 devices and expected by the end of 2014. Offshore construction is completed and device assembly has begun.
Carnegie CETO6	Garden Island, Australia	3 MW	13 m AUD	ARENA	Announced	Arena awarded funds to Carnegie in June 2014. The total project value is of 46 m AUD.
BioPower Wave	Port Fairy, Australia	0.25 MW	5.6 m AUD	ARENA	Under development	Demonstration funds aim at installation of the pilot bioWave in 2015.
Oceanlinx	Victoria, Australia	1 MW	3.9 m AUD	ARENA	Closed 20/06/2014	Structural failures to the Ocealinx device whilst it was towed to location.
Victorian Wave Power Station	Ocean Power Technologies (OPT)	19 MW	66.5 m AUD	ARENA	Closed 08/08/2014	OPT closed the project announcing that it was economically unviable.
Test Centres						
Atlantic Marine Energy Test Site (AMETS)	Belmullet, Ireland	20 MW	24 m EUR	Sustainable Energy Authority of Ireland (SEAI)	T.B.A.	A decision for foreshore lease application submitted in December 2011 was expected during early 2014.
Biscay Marine Energy Platform (BIMEP)	Armintza, Spain	20MW	20 m EUR (infrastructure)	Ente Vasco de la Energía (EVE), Spanish Energy Agency	Operational	The site was grid connected in 2014, and is currently operational.
EMEC	Orkney, UK	Six grid-connected berths	36 m GBP	Scottish Government, Highlands and Islands Enterprise, The Carbon Trust, UK Government, Scottish Enterprise, Orkney Islands Council.	Operational	Aquamarine Power, Pelamis, Wello and Seatricity are among the wave energy developers that have tested at EMEC.
Ocean Plug	Leira, Portugal	80 MW (up to 250 MW)	N/A	Redes Energéticas Nacionais (REN)	In progress	Development of the Pilot Zone to receive, in pre-commercial and proof of concept stages, generators of electricity (based on wave energy devices).
Oceanic Platform of the Canary Islands (PLOCAN)	Canary Islands, Spain	10 MW (up to 100 MW)	N/A	Spanish Government, Regional Government of the Canary Islands.	Operational	
Site d'Expérimentation en Mer pour la Récupération de l'Energie des Vagues (SEM-REV)	Le Croisic, France	8 MW	13.26 m EUR	Ecole Centrale de Nante, Pays de la Loire, Loire-Atlantique	Operational	
Wave Hub	Hayle, UK	20MW	42 m GBP	DECC, Southwest Regional Development Agency	Operational	Seatricity installed the first two Oceanus2 devices in summer 2014.

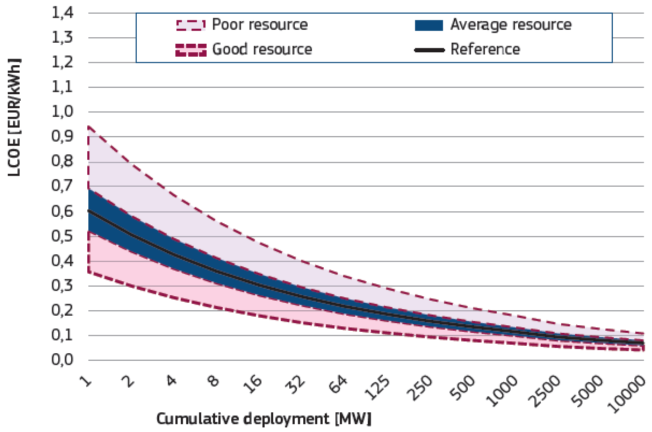
Figure 44 Funding for the first wave projects and test sites

E. Economics

Tidal Energy Economics

	Unit	2010	2020	2030	2040	2050
Technical						
Net electrical power [a]	MWe	10	10–20	20–30	30–40	50–400
Max. capacity factor	%	36	45	47	47	50
Avg. capacity factor	%	34	37	40	42	45
Technical lifetime	Years	20	20	20	20	20
Costs						
CAPEX ref.	EUR_{2013}/kWe	10700	4400	3400	2100	1900
CAPEX low	EUR_{2013}/kWe	9300	3600	3000	1800	1700
CAPEX high	EUR_{2013}/kWe	12300	5500	3100	2800	2500
Quality of CAPEX estimate				Low		
CAPEX learning rate	%	12	12	12	12	12
FOM	% of CAPEX ref.	3.4	3.6	3.8	4.3	4.9
Evolution						
Max. potential	GWe	0.04	0.4	2.9	3.1	10

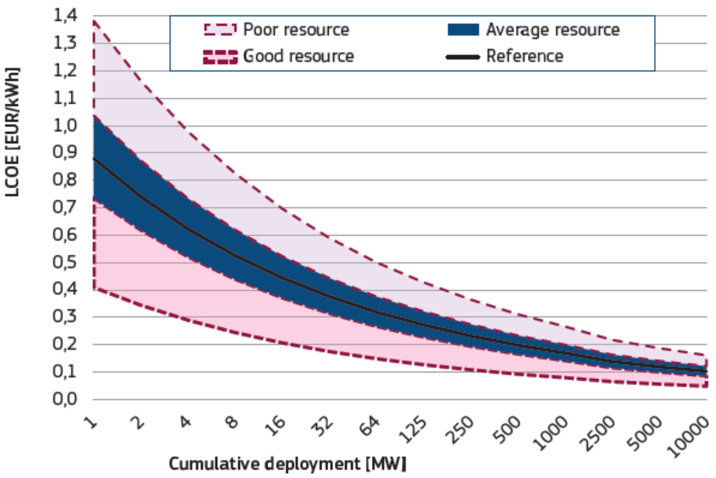
[a] Current estimates for tidal energy plants focus on the development of 10 MW arrays; however, projects of up to 400MW have been announced, but no clear timescale is currently available. Source: ETRI 2014



Wave Energy Economics

	Unit	2010	2020	2030	2040	2050
Technical						
Net electrical power [a]	MWe	1–5	5–20	30–40	40–50	50–400
Max. capacity factor	%	36	45	47	47	50
Avg. capacity factor	%	20	23	28	32	36
Technical lifetime	Years	20	20	20	20	20
Costs						
CAPEX ref.	EUR_{2013}/kWe	9080	5790	4480	2700	2300
CAPEX low	EUR_{2013}/kWe	7590	5060	3890	2560	2050
CAPEX high	EUR_{2013}/kWe	10700	6390	5490	2650	2560
Quality of CAPEX estimate				Low		
CAPEX learning rate	%	12	12	12	12	12
FOM	% of CAPEX ref.	3.6	4.1	4.7	5.8	5.8
Evolution						
Max. potential	GWe	0.03	0.19	1.9	2.0	3.2

[a] Current estimates for wave energy plants focus on the development of 10 MW arrays; projects for up to 140 MW have been announced but no clear timescale is currently available. Source: ETRI 2014



F. Relevant Roadmaps

ETI – Wave and Tidal Energy Insights (2015)

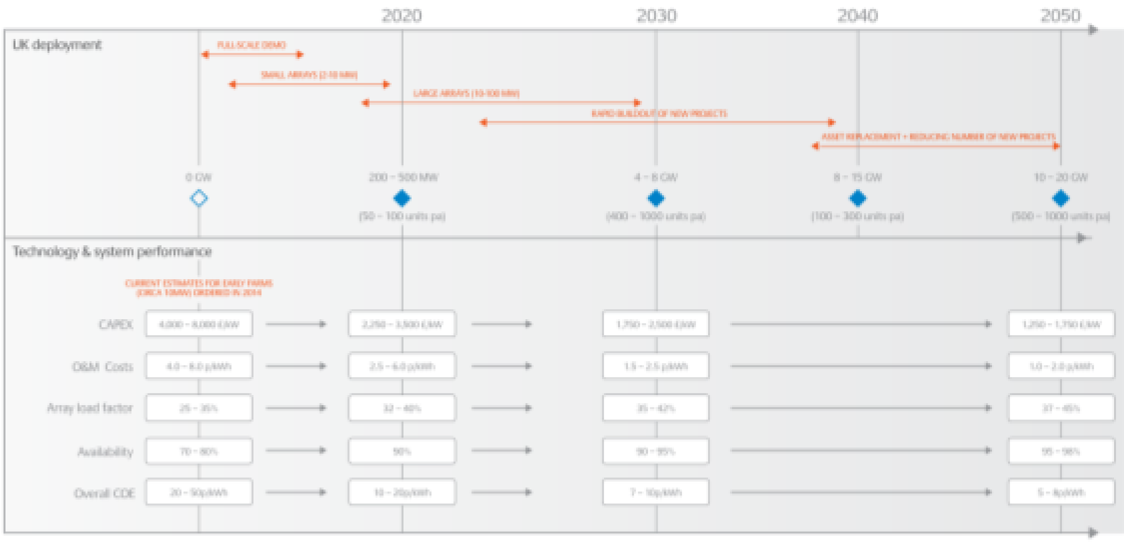


Figure 45 Table of UK deployment of marine energy and technology & system performance (ETI 2015b)

	Priority topics	Recommended mechanisms
Technology development	• Technology advancement • Reliability demonstration • Performance data collection • Design for maintenance • Sub-system development and optimisation • Array design & modelling tools • Novel system concepts • Knowledge transfer & dissemination	• Establishment and reinforcement of RDI&D programmes for development of novel technology and towards TRL progression, with strong emphasis on sub-systems • Validation of performances and reliability of WECs and TECs reaching capacity factors of >25% and an availability >75% • Standards and guidelines for evaluation and testing of devices • Co-operation at European scale for addressing overarching issues
Deployment and risk reduction	• Pre-commercial array sea trial and demonstration • Predictive Maintenance Systems • Resource analysis tools • Offshore grid design & optimisation: – Array electrical system – Sub-sea electrical system – Array interaction analysis – Offshore umbilical / wet mate MV connectors • Techno-economic tools	• Demonstrating WECs and TECs through facilitated access to test and demo facilities in Europe • Standardised procedures for installation, maintenance and retrieval of devices • Co-operation with supply chain for standardised manufacturing • Collaboration with other energy sectors for grid integration and connection issues

Area	Topics
Resource measurement and assessment	- Resource assessment methodologies, measurement systems, understanding of details, adequate forecasting - Design for extreme conditions (including maintenance, control and operation, installation) - Resource quantification and characterisation for long-term climate impact - Forecasting of incoming wave power
Technology design, performance and integrity	- Reliability and performances of devices for 20-year lifetime expectancy (devices and subcomponents) - Robustness of devices: design for extreme conditions, robustness and efficiency - Field testing of prototypes and demonstration units (TRL based) - Reduction of O&M costs - Modelling of devices and arrays - Materials: effects of ageing, fouling and corrosion, and development of novel materials
Components and sub-components for balance of plant and system	- Grid and cabling integration - Array cabling positioning and cable protection - Collaboration with wind on grid issues - Fatigue dynamics of systems and sub-systems (e.g. umbilical and power connectors) - Moorings and foundations: common structures, designs and survivability - PTO optimisation
Logistics, installation and operations	- Operations and maintenance: best procedures, installation methods, maintenance access and scheduling, and vessles - Atomisation of inspection techniques - Monitoring health of assets - Health and Safety requirements - Vessels and offshore supply chain - Optimisation of operation, weather windows and capacity factors

Figure 46 Recommendations from SI Ocean Strategic Technology Agenda

G. Support mechanisms in other countries

Country	Type	Description
United Kingdom	Pull	Renewable Obligation (RO) Scheme. Renewable Obligation Certificates (ROCs) buyout price set to 30 GBP in 2002/3 rising to 43 GBP in 2014/15. RO scheme will be replaced by a Contract for Difference (CfD) scheme in 2017.
	Push	Renewable Energy Investment Fund (REIF) Scotland, 103 m GBP.
		Marine Energy Array Demonstrator (MEAD), 20 m GBP. MEAD aimed at supporting two pre-commercial projects to demonstrate the operation of wave and/or tidal devices in array formation for an extended period of time, MeyGen project (Table 8).
		Energy Technologies Institute (ETI), about 12 m GBP for wave and tidal projects.
		The Crown Estate, 3 m GBP spent for enabling activities in the area of project development processes, committed to invest and manage an additional 5.7 m GBP in enabling actions for Pentland and Orkneys. Plans to invest up to 20 m GBP in first array projects.
		Marine Renewables Commercialisation Fund (MRCF) Scotland, 18 m GBP. Aquamarine Power and Pelamis Wave Power have been awarded 13 m GBP. 5 m GBP for enabling technologies.
		Marine Renewables Proving Fund (MRPF), 22.5 m GBP. Managed by Carbon Trust. Funds awarded to six projects.
		Saltire Prize, Scotland, 10 m GBP. For first device delivering > 100 GWh for two years.
France	Pull	Feed-in Tariff for renewable electricity. Currently 15 c EUR/kWh for ocean energy.
	Push	ADEME, 1125 m EUR (renewable energy and green chemistry). Specific call for ocean energy funds projects with 4–6 machines at min. generation of 2500 MWh per machine for 2 years. Eight projects have submitted proposals, selection finalised by end of 2014. Each project might receive 30 m EUR and benefits from a Feed-in Tariff of 17.3 c EUR/kWh.
Ireland	Pull	Feed-in Tariff for ocean energy of 0.26 c EUR/kWh (up to 30 MW) from 2016.
	Push	SEAI Prototype Development Fund, 26 m EUR.
		Ocean Energy Development Budget will be increased by 16.8 m EUR to 26.3 m EUR by 2016, mainly for test centres.
		SEAI Sustainable RD&D programme, 3.5 m EUR.
Portugal	Push	Fundo de Apoio à Inovação (FAI) for renewable energies, 76 m EUR total.
Spain	Pull	Feed-in Tariff suspended for all renewables, replaced in 2014 by a scheme of a fixed annual investment bonus for existing installations.
	Push	EVE, 3 m EUR scientific programme for ocean energy demonstration.
Denmark	Pull	Maximum tariff of 8 c EUR/kWh (sum of market price and bonus) for ocean energy.
	Push	Energinet.dk, 2.4 m EUR for minor renewable energy technologies (e.g. PV, wave, biogasification) by ForskVE. In 2015 round, the programme for development and demonstration projects will provide about 13.4 m EUR of funds.
Germany	Pull	Feed-in Tariff, 3.5–12.5 c EUR/kWh for ocean energy, depending on installed capacity.

Figure 47 Market pull and push from member states.

Fund	Type	Description
NER 300	Push	Demonstration programme for renewable energy and CCS projects, 2.1 bn EUR. Funds five ocean energy projects (two wave, two tidal, one OTEC) in the EU (about 140 m EUR).
H 2020	Push	EU Research and Innovation programme, 80 bn EUR from 2014 to 2020. Ocean energy is one of the priorities of the programme. Until now, four calls in the area of low-carbon energy (approx. 85–110 m EUR each) have been launched, funding the development of innovative designs and components, and research to ensure efficiency and long-term reliability, but also the demonstration of advanced full-scale devices in real-world conditions. About 200 m EUR have been earmarked for marine research and innovation in 2014 and 2015.
Structural and cohesion funds	Push	The two structural funds, the European Regional Development Fund (ERDF) and the European Social Fund (ESF), provide support for the creation of infrastructure and productive job-creating investment, and for the integration into working life of the unemployed and disadvantaged sections of the population. The cohesion funds (total 63.4 bn EUR) also support projects related to the use of renewable energy.
Sources: Commission Decision C(2012) 9432 2012; Commission Decision C(2014) 4493 2014; Commission Decision C(2014) 383 2014; Marine Institute 2014; EC 2014c; EC 2014d; EC 2014e		

Figure 48 Market pull and push from EU

Country	Type	Description
China	Push	Special funding programme for MRE (SFPMRE) of about 40 m USD. Twelve R&D and demonstration projects (wave and tidal) are being funded.
	Pull	Renewable energy electricity price tariff (about 1.5 c EUR/kWh).
US	Push	Water Power Program (WPP) of Department of Energy (DOE) focussing on wave energy mainly. Portfolio in 2013: 87 projects, 33.8 m USD
		Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) program of DEO, awards up to 150 k USD per company working on technology development.
Korea	Pull	Renewable Portfolio Standard (RPS) requires utility companies to supply a certain amount of electricity produced by renewable energy.
	Push	Ministry of Oceans and Fisheries (MOF) and Ministry of Trade, Industry and Energy (MOTIE) operate RD&D programmes for ocean energy (fundamental R&D and demonstration projects).
Norway	Pull	Feed-in Tariff of about 7–8 c EUR/kWh (total compensation).
	Push	Norwegian Energy Agency (Enova), Innovation Norway, Research Council of Norway, total funds approximately 110 m EUR.
Canada	Pull	Feed-in Tariff for tidal energy for projects at development or testing stage, initial tariff of 37.5 c USD/kWh to 57.5 c USD/kWh declines with increasing output.
		Feed-in Tariff in Nova Scotia for small-scale in-stream devices from local communities (COMFIT), 65.2 c USD/kWh.
	Push	Clean Energy Fund (CEF), Program for Energy Research and Development (PERD), ecoENERGY Innovation Initiative (ecoEII), total funds of 37 m USD since 2010.
		Sustainable Development Technology Canada (SDTC), 13 m USD for development and demonstration of ocean energy technologies.
Australia	Push	Australian Renewable Energy Agency (ARENA) with funds of about 2.5 bn AUD until 2022, also responsible for ocean energy where capacity building, knowledge generation and pilot-scale projects will be funded.

Figure 49 Current market pull and push from non-EU states