Commercial in confidence

Ocean Power Innovation Network value chain study: Summary report

A report for Scottish Enterprise

November 2019

Document history

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Contents

1. Introduction

Marine renewable energies started emerging a few decades ago, in times of oil crises, but lost momentum afterwards. In more recent years, as energy demand and climate change concerns have been growing, an increase in renewable energy, notably from offshore renewables, is required. Whilst offshore wind energy is experiencing a sustained growth not only in Europe but also in Asia and in the US, wave, tidal and floating wind energy are slowly but steadily finding their place in the energy mix and in the value chain.

Europe has important marine renewable resources, and these are for the most part unused. It has been estimated that 100GW of wave and tidal energy capacity could be deployed in Europe by 2050[1] and up to 300GW worldwide[2].

OPIN

The Ocean Power Innovation Network (OPIN) is a 3-year initiative, running from 2019 to 2021, with a total project budget of €2.6 million. Of this, €1.5 million is provided by the Interreg North West Europe Programme from the European Research and Development Fund (ERDF).

OPIN aims to encourage both cross-sectoral and cross-regional collaboration for SMEs working in offshore renewable energy. It has three key objectives:

- To stimulate cross-sector innovation between SMEs
- To provide in-depth support to the development of new products and processes in the OE sector, and
- To build a transnational network of SMEs in the ocean energy sector.

It is crucial that OPIN has deep understanding of the value chain and the processes and organisations that will contribute to the success of tidal, wave and floating wind as mainstream energy generation. OPIN has been set up in recognition that there are gaps and disparities both across and within partner countries. A full understanding of these gaps and disparities and the measures needed to fill them is clearly a high priority.

There are several challenges that are common to all three technologies, notably around cabling, mooring systems, manufacturing and installation logistics, and operational strategies. A role for OPIN can be to ensure that this cross-dissemination is maximised.

The report

This project, undertaken by BVGA for Scottish Enterprise and the other OPIN partner organisations, was focussed on quantifying the value chain for three marine energy technologies:

- Tidal stream energy
- Wave energy, and
- Floating wind energy.

This involved a thorough, desk-based, research task and literature review, with the main aim of identifying the main SMEs and other organisations in the value chain. The result was a large report (hereby referred to as the “main report”), *Ocean Power Innovation Network value chain study*. Organisations were categorised according to value chain area to inform the OPIN partners on suitable SMEs, technologies and thematic areas to engage with.

This summary report is a shortened version of the main report, presenting the key information and findings.

2. Methodology

2.1. Value chain

We used a robust taxonomy to define the value chain. For components and services across the value chain, we defined a series of ‘elements’ covering the phases of a project’s life:

- Development and project management
- Turbine (generating device) supply
- Balance of plant (including transmission) supply
- Installation and commissioning
- Operations, maintenance and service (OMS), and
- Decommissioning.

We further divided the above elements into a number of sub-elements, depending on the technology, allowing a suitable level of granularity for this project.

Within the body of the main report, we provided the following for each value chain sub-element:

- Costs
- Synergies with other sectors
- Maturity of technology
- Maturity of supply chain
- Capability in each partner country, and

[1] SI Ocean (2014), Wave and tidal energy market deployment strategy for Europe.

[2] OES (2017), An international vision for ocean energy

- Companies and organisations for engagement. Contact details were provided in a supporting Excel document.

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2.2. Costs

The representative costs provided in this document have been sourced using our internal models and database. All three technologies consider a project commissioned in 2020. The numbers, in particular the sub-element costs, are indicative and rounded, and are purely to give an appreciation of where the most significant project costs might be expected for a Northern European project. In reality these will vary greatly depending on the technology and suppliers used, local site conditions and jurisdiction (among other aspects).

For all technologies, decommissioning costs were estimated as being about 65% of total installation costs and contingency and insurance represents 10% of capital expenditure (CAPEX), these values rounded in the tables.

All costs are given in €/MW, except for OMS costs which are given in €/MW/year

3. Tidal energy

3.1. Technology summary

Electricity generated by tidal energy has been growing steadily in Europe in the last decade, sharply increasing from 2015, with the UK and France leading activity. In 2018, 3.7MW of tidal stream energy was deployed in European waters.[3] Since 2010, about 12MW of projects have been installed and are still operating. France, Ireland, the Netherlands and the UK have existing test sites. However, large-scale projects are being built and developed only in the UK at the moment.

The first 6MW-phase of the world's first large-scale tidal stream project (up to 398MW when fully deployed and operational, by 2022), MeyGen, was inaugurated in September 2016.

Significant cost reductions can be expected in the near future and these may come from improved power harnessing and design of the tidal generating device, improved mooring systems and other innovations (see below). Furthermore, an important learning rate is expected as projects will go full-scale.

Research and development efforts are taking place and SMEs are receiving funding for their projects. For example, the Scottish Government have made £10m available through the Saltire Tidal Energy Challenge Fund, of which £3.4m was awarded to Orbital Marine Power in August 2019.

Whilst prices are dropping, making this technology more viable, it is still crucial for policymakers and governments to provide support for tidal energy, in order to allow the development of large-scale projects. Funding is of utmost important for tidal energy because part of the current projects do not produce any return on investment so often need a financing of up to 100%.

Innovations

- Some innovations involving contra-rotating turbines (e.g. Nautricity), wet-gap turbines (e.g. ORPC) and turbines with variable pitch and flapping blades (e.g. CarBine) have emerged and could lead to significant increase in production, notably reducing losses in the energy conversion. Moreover, innovations involving direct-drive power take-off systems are being tested and developed in the context of projects (TAOIDE, TiPA (Nova Innovation)).

- For the balance of plant there have been advancements in the field of floating tidal devices (e.g. Orbital Marine Power, Sustainable Marine Energy) and sea bed connection systems (e.g. Sustainable Marine Energy's RAPTOR anchor, which is capable of enduring higher loads or Vryhof's anchor bag). In addition, different companies and projects have been developing dynamic power cables, which allow a higher bending capacity (e.g. NSW, HDPC4FMEC (MaRINET2)) which is critical for floating tidal projects.

- Regarding installation, different new installation concepts (e.g. towing of floating structures, new anchoring and mooring solutions) have emerged in offshore and floating wind, and tidal technology could draw from this.

- Finally, when it comes to OMS, there have been some design innovations as well (e.g. floating structures/platforms, direct drive power take-off systems, new mooring and anti-corrosion solutions).

[3] Ocean Energy Europe (2019), Ocean Energy: Key trends and statistics

3.2. Typical costs

Table 1 shows typical costs for a tidal project commissioned in 2020. The top level elements were estimated from internal and confidential data sources, which cannot be shared. The sub-elements were adapted from cost trends seen in offshore wind. The values reflect a small scale (<10MW) farm of horizontal axis turbines, mounted to the seabed using gravity base foundations.

Table 1 Typical cost breakdown for a small-scale (<10MW) tidal stream project commissioned in 2020 with an expected lifetime of 25 years. Values have been rounded. Note that operation, maintenance and service costs are in units of €/MW/year.

Element	Cost (€/MW)	Contribution to level above	Sub-element	Rounded cost (€/MW)	Contribution to level above
Development and project management	250,000	5.7%	Development and consenting services and expenditure incurred by lost projects	220,000	**88%**
			Professional and enabling services	30,000	**12%**
Generating device supply	2,000,000	45.5%	Rotor	500,000	25%
			Nacelle	1,250,000	63%
			Tower	250,000	12%
Balance of plant supply	1,250,000	28.4%	Support structure	450,000	36%
			Sea bed connection	500,000	40%
			Subsea cables	200,000	16%
			Onshore electrical	100,000	8%
Installation	500,000	11.4%	Turbine installation	200,000	40%
			Support structure installation	175,000	35%
			Cable installation	100,000	20%
			Professional and enabling services	25,000	5%
Contingency	400,000	9.1%	Contingency	400,000	100%
Operations, maintenance and service	150,000 €/MW/year	100%	Maintenance and service	85,000 €/MWh/year	57%
			Operations	45,000 €/MWh/year	30%
			Professional and enabling services	20,000 €/MWh/year	13%

Element	Cost (€/MW)	Contribution to level above	Sub-element	Rounded cost (€/MW)	Contribution to level above
Decommissioning	300,000	100%	Decommissioning	300,000	100%

3.3. Conclusions and recommendations

The main report presented high level recommendations on both a country and technology level. These are also included here. They were formulated using both our expertise and the understanding and learning gained on the project.

National recommendations

Table 2 Prioritised recommendations per country for tidal energy.

Country	Recommendations
BE	Belgian companies are virtually absent from the tidal energy supply chain. There are however governmental institutes and enabling bodies involved in tidal energy and this could enable the creation and insertion of Belgian companies in this technology, preferably in other countries where the tidal resources are more important. In addition, Belgian companies could benefit from the experience acquired in the development of offshore wind projects.
FR	Given the good tidal resources in France as well as the numerous companies involved in tidal energy, France should take the opportunity of becoming a big player not only in French but also other European projects. It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. In addition, the gap in supply chain for support structures for tidal energy could be closed by French companies. Furthermore, since offshore and floating wind are also about to take off, the local tidal supply chain could benefit from this.
DE	German companies should focus on developing and being involved in projects outside of Germany (with a focus on generating device supply), where the tidal resources are more important, as is already the case for some companies. In addition, the gap in the dynamic cable supply chain could be closed by German companies. Furthermore, German companies could benefit from the experience acquired in the development of offshore wind projects.
IR	As Irish companies (especially SMEs) are involved in projects outside of Ireland, these should seize the opportunity of developing projects in Ireland. There is a recognised challenge in the fact that consenting regime is not sufficient to support this development, However, some focus should be afforded by government where tidal resources are important – so that the country can become one of the leaders in tidal energy in Europe. It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. In addition, the gap in the supply chain for project development and generating device supply for tidal projects could be closed by Irish companies.
NL	Dutch companies, helped by governmental organisations and institutions, should focus on developing and being involved in projects outside of the Netherlands, where the tidal resources are more important, as is already the case for a number of companies. In addition, the gap in the supply chain for project development for tidal projects could be closed by Dutch companies. Furthermore, Dutch companies could benefit from the experience acquired in the development of offshore wind projects.

Country	Recommendations
UK	Given the important tidal resources in the UK, the numerous companies involved in tidal energy as well as a mature offshore wind supply chain, the UK should take the opportunity of becoming a leader not only locally but also in European projects. It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. In addition to this, there is a gap in the supply chain of dynamic subsea cables which could be closed by British companies. Moreover, British tidal developers could benefit from the experience acquired in the development of offshore wind projects.

Technology recommendations

Technology challenges

- Tidal energy is technologically proven, with devices in the water generating electricity. Learning from many industries has contributed to this progress. A notable example is offshore wind, which explains much of the industry convergence to a horizontal axis device type.
- While there are two competing schools of thought, floating vs bottom-fixed devices, they capture different parts of the water column and so might be able to co-exist at some locations.
- The main challenge for tidal stream now is now cost reduction and getting wider market acceptance. The industry needs to bring costs down to align with other renewables. There is learning to be had by getting devices into the water, but this can be costly for SMEs. The vessels required will depend on the technology, for example bottom-fixed projects might require more costly jack-up vessels (as was the case for the Meygen Project Phase 1A) which will drive up cost.
- There is also a challenge on the policy side. At its current level of maturity, tidal will not be able to compete with offshore wind in technology neutral auctions. This was apparent in 2017, where Simec Atlantis were unable to secure a CfD for Phase 1C of the Meygen Project. Creating a tidal energy lobby from the main developers and stakeholders could be a way to push for more supportive government policy. Examples could include technology neutral auctions or feed in tariffs. A recent high feed in tariff, secured outside of Europe, was obtained by Halagonia Tidal Energy, a subsidiary of DP Energy, for a 9MW project deployed at the FORCE test facility in Canada.
- Floating tidal devices share challenges with floating offshore wind, including dynamic cables, mooring system design and installation, device connection and operation and maintenance. See the floating offshore wind section for more detail.
- Tidal devices are needed which can exploit the energy in slower tidal flows than the earlier generation devices. High velocity tidal flows only occur in a few locations, whereas lower velocity flows are much more widespread. Developing cost efficient devices for these lower flows will unlock much more global potential. Such devices are likely to be smaller and lighter, except for the rotors, which will need to cover more area. This could be achieved in part by larger diameter rotors and in part by multi-rotor-generator systems.
- While tidal stream is highly predictable, the resource might not always coincide with demand (and higher electricity price) and so energy storage is an interesting prospect. UK based company Nova Innovation are trialling a Tesla battery with their small scale tidal technology, and such projects could gain increasing interest as tidal and energy storage costs both fall. This could be an interesting area for OPIN to examine: bringing together tidal SMEs and battery suppliers/energy storage experts.

Countries of interest

- At the present time the UK and France are of increasing interest for tidal projects and research activity.
- There is also high interest in tidal outside of Europe, for example Canada and Japan. For the former, the FORCE test facility is a hotbed of activity and had seen European companies successfully export their skills across the Atlantic (for example UK based SME Sustainable Marine Energy recently merged with Schottel's tidal division and have deployed their platform at FORCE).

4. Wave energy

4.1. Technology summary

Within Europe there has been sustained interest in wave energy over the last decade, with companies from the UK, Denmark, Italy and France making notable recent contributions. Since 2010 about 11MW of projects have been installed, with about 3MW in 2018.[4] The majority of these have been at open water test sites, for example in France, Ireland, the Netherlands and most notably the UK (at the European Marine Energy Centre, or EMEC). The UK is a key market of interest, due to a strong wave resource and the large number of companies working in the sector to date. It should be noted that wave energy is in a pre-commercial, R&D stage: no supplier has been able to sell wave energy devices in any kind of volume, or demonstrate a device that can operate at a cost-competitive rate

Recent developments include:

- Laminaria, a Belgian company, have developed a 200kW prototype that will be tested at EMEC.
- Irish company Ocean Energy built a 500kW device that will be tested in Hawaii.
- In 2018, Australian company Bombora Wavepower secured a £10.3m European Regional Development Fund grant to test its 1.5MW prototype in Welsh waters.
- GEPS Techno, a French company, deployed their WAVEGEM device at SEM-REV test site for an 18 month testing programme.

Cost reductions can be expected in the future and will come from improved power harnessing and design of the wave energy converter, as well as more general innovations. Learning-based reduction is also expected over the next decade: as more devices are deployed in the water and as projects go full-scale.

Research and development efforts are being made and SMEs are receiving funding for their projects (for example a £13 million grant was awarded from the European Union for Marine Power Systems). Whilst prices appear to be decreasing, making wave energy more viable, it is crucial for policymakers and governments to provide support for this technology to allow the development of large-scale projects. Funding is of utmost important for wave energy because most of the current projects do not produce any return on investment, so often need a financing of up to 100%.

One of the challenges for the wave energy industry is the convergence towards a smaller number of technology concepts. Currently there are a huge variety of device types, all with their own unique technological challenges, which makes it difficult to provide funding and support at a sector-wide level.

Innovations

- Some interesting device concepts include modular multi-point absorbers (e.g. Albatern), novel structural membranes and polymers (e.g. AWS Ocean Energy, SBM Offshore, the PolyWEC project) and oscillating surge devices (e.g. AW-Energy and CCell Renewables).
- Balance of plant is an active area of research, for example concerning pin pile technology (Sustainable Marine Energy) and elastomeric moorings (University of Exeter). Mooring systems are of critical importance in wave energy to keep devices on station, and can also be an active part of the power producing mechanism. In addition, R&D for dynamic cable is ongoing for the tidal and floating wind sectors and could be of great benefit to the wave energy industry.
- Finally, some design innovations (e.g. floating platforms, new mooring and anti-corrosion solutions) might induce reduced facilitated maintenance and service.

[4] Ocean energy – key trends and statistics 2018

4.2. Typical costs

The top level cost elements were obtained from our models and supporting literature, with supporting definitions provided in the Appendix. The detailed sub-elements were generally adapted from trends seen in offshore wind, for example using The Crown Estate *Updated guide to an offshore wind farm*. For wave energy, we modelled a small-scale (<5MW) project of 1MW point absorbers with an expected lifetime of 20 years.

Table 3 Typical cost breakdown for a small-scale (<5MW) wave energy project (point absorber type) commissioned in 2020 with an expected lifetime of 20 years.

Element	Cost (€/MW)	Contribution to level above	Sub-element	Cost (€/MW)	Contribution to level above
Development and project management	300,000	3%	Development and consenting services and expenditure incurred by lost projects	250,000	83%
			Professional and enabling services	50,000	17%
Main structure	5,000,000	58%	Generating device	5,000,000	100%
Balance of plant supply	1,500,000	17%	Support structure and mooring system	1,150,000	76%
			Subsea cables	250,000	17%
			Onshore electrical	100,000	7%
Installation	1,000,000	12%	Main structure installation	450,000	45%
			Support structure and mooring system installation	400,000	40%
			Cable installation	100,000	10%
			Professional and enabling services	50,000	5%
Contingency	850,000	10%	Contingency	850,000	100%
Operations, maintenance and service (OMS)	400,000 €/MW/year	100%	Maintenance and service	225,000 €/MW/year	56%
			Operations	125,000 €/MW/year	31%
			Professional and enabling services	50,000 €/MW/year	13%
Decommissioning	650,000	100%	Decommissioning	650,000	100%

4.3. Conclusions and recommendations

As for tidal, high level recommendations are provided on both a country and technology level. These were formulated using both our expertise and the understanding and learning gained on the project.

National recommendations

Table 4 Prioritised recommendations per country for wave energy.

Country	Recommendations
BE	Belgian companies are virtually absent from the wave energy supply chain. There are however governmental institutes and enabling bodies involved in wave energy and this could enable the creation and insertion of Belgian companies in this technology, preferably in other countries where the wave resources are more important. In addition, Belgian companies could benefit from the experience acquired in the development of offshore wind projects.
FR	Given the country's good wave resource levels as well as the presence of some companies in this technology, France should take the opportunity of getting involved in local and European projects. It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. In addition, the gap in the wave energy OMS supply chain could be closed by French companies. Furthermore, since offshore and floating wind are also about to take off, the local wave supply chain could benefit from this.
DE	German companies should focus on developing and being involved in projects outside of Germany (with a focus on generating device supply), where the wave resources are more important, as is already the case for some companies. In addition, the gap in the dynamic cable supply chain could be closed by German companies. Moreover, German companies could benefit from the experience acquired in the development of offshore wind projects.
IR	Given the good resource levels as well as the presence of Irish companies in wave energy projects (locally as well as outside of Ireland), Ireland should seize the opportunity of developing more local projects so as to become a big player in wave energy in Europe. It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. Furthermore, the gap in the generating device supply chain could be closed by Irish companies.
NL	Dutch companies helped by governmental organisations and institutions, should focus on developing and being involved in projects outside of the Netherlands, where the wave resources are more important, as is already the case for a number of companies. In addition, the gap in the supply chain for project development for tidal projects could be closed by Dutch companies. Furthermore, Dutch companies could benefit from the experience acquired in the development of offshore wind projects.
UK	Given the important wave resources in the UK, the numerous companies involved in wave energy as well as a mature offshore wind supply chain, the UK should take the opportunity of becoming a leader not only locally but also in European projects. It is therefore also important that R&D and funding efforts from governmental organisations and institutions continue. The gap all along the wave energy supply chain could be closed by the numerous British companies involved in this technology (and other marine renewables). In addition, British wave developers could benefit from the experience acquired in the development of offshore wind projects.

Technology recommendations

Technology challenges

- For wave energy the biggest challenge is technical. Proof of concept is critical, getting to a device that can produce electricity consistently which is a more desirable prospect to early investors. These early designs then need to be optimised with cost reduction in mind, without impacting the performance and structural integrity of the device.

- There are lots of SMEs who are developing wave devices. These are at various stages of maturity, and each have their own unique set of strengths and challenges, making it difficult to “pick a winner”. These devices all tend to look and operate very differently, with few common components between them, which makes cross collaboration a challenge.
- One class of wave device with more inherent commonality is the point absorber. These are generally fixed to the seabed like fixed offshore wind, using piles or gravity anchors, and so could utilise knowledge from early offshore wind projects. The operating principle of these devices is also similar, although the control systems can differ and this is where some companies see their main USP (for example CorPower Ocean and their “WaveSpring” technology). We think that point absorber devices could be a good place for OPIN to focus attention, for example by bringing together different developers in an attempt to share knowledge and pave out a viable market.
- Critical to any device is the power take-off (PTO) system. While these can also differ considerably, as for the devices, there are two main types: hydraulic systems and linear generators. While developers will have the best knowledge of their proposed systems, there is room for more collaboration in this area. Wave Energy Scotland could be a good partner to bring into any discussions, as they have allocated funding to organisations through the PTO development programme. £7.5m was awarded to three projects in 2017, involving 15 organisations in total, and represents the third stage of a stage gated competitive process to target grant money. Large organisations have been involved in this kind of work before, for example Bosch Rexroth on the WavePOD project, and could open the door to new approaches and ways of thinking.
- Mooring systems is another area of commonality, where cross collaboration could be beneficial. The University of Exeter could be a useful organisation to approach, as they operate testing facilities like DMaC and FaBTest and are regarded as a research leader in this area.
- Finally, one area that wave energy would really benefit from is focus on standardised techno-economic modelling tools. Most developers will have their own models or tools, which are very sensitive to the input assumptions (for example the learning rate assumed). Some of the claims that come out of this modelling, regarding LCOE potential, can be dubious, and there is a historic problem in the industry of “over promising and under delivering”. There are several companies and organisations who have created tools for the industry: including Exceedence, Wave Venture, and the DTOcean project. The latter was a collaborative project, made up of partners from research institutions across Europe, and is currently in a second phase: DTOcean+.
- Having standard tools to allow third party validation of the claims being made by developers would help the industry to be taken more seriously by investors, and would be useful for policymakers and funding bodies to focus attention on the most promising technologies.
- There is a debate in the industry on whether devices should go big (MW) or small scale (tens to hundreds of kW). Both have advantages and disadvantages. Small scale devices would be very well suited for niche markets and off-grid industries: for example, aquaculture, island communities, oil and gas platforms and scientific monitoring. Companies with experience in these industries could be very valuable sources of knowledge, for example Mowi (formerly Marine Harvest) who have been working with wave energy developer Albatern to supply power to their fish farms. If PPAs could be arranged for these kind of projects then it would encourage investment in wave energy and demonstrate that there is a viable route to market. OPIN could make a valuable contribution to initiating these kind of discussions, by bringing developers and electricity users together.

Countries of interest

- The UK and Ireland both have a good combination of resource potential, history in the sector and active research institutions, so we would recommend that these are a good starting places for OPIN to focus on.
- There are many locations suitable for wave energy globally, where SMEs could export their skills, although no commercial market has emerged so opportunities are limited.
- Wave energy could also be beneficial for countries with larger offshore wind presence. There is an argument that wave devices could benefit offshore wind farms by shielding them from extreme waves, making them easier to access and reducing the loading on the structures. This is likely to be of increasing benefit as wind farms move further offshore. There have been research projects in this area, however OPIN could facilitate discussions between wave developers, wind farm operators and research institutions to quantify this benefit for a more detailed case study.
- As previously noted, wave energy has not reached market maturity, with very few devices installed in the water and no commercial projects. For this reason, we think that there is currently limited opportunity for SMEs outside the sector or countries of interest to invest or export their skills. Markets to watch include the USA, Australia, Chile, China and Japan, which balance good resources and governments that have assisted the sector in various ways.

5. Floating wind

5.1. Technology summary

Floating wind is a fascinating prospect. The technology will open up brand new markets to offshore wind, where the water is currently too deep for established foundation options (mainly monopiles and jackets). Globally around 40 designs of floating foundation technology have been proposed and are at various stages of commercial readiness. European countries are at the forefront of innovation; notable examples including Norway, France and the UK. Recent developments include:

- The world's first commercial floating wind farm, Hywind, was commissioned in 2017 in Scotland. This project was developed by Equinor and is a 30MW farm made up of five 6MW turbines.
- Equinor also recently made a final investment decision on the Hywind Tampen project (October 2019). This project will see 11 floating turbines (88MW) deployed in the North Sea to power oil and gas platforms, with roughly half the investment coming from the Norwegian government.
- The Kincardine project saw a 2MW turbine installed 15km off the Scottish coast, using Principle Power's WindFloat semi-submersible technology. The full project will see a further 48MW installed by 2020.
- In 2018 two demonstration projects, consisting of single grid connected turbines, were installed in France. The Floatgen project involved installing a 2MW turbine on Ideol's Damping Pool foundation, at the SEM-REV test site. The second project saw EOLINK installed a 1/10 scale prototype off the coast of Brittany.

As of 2018, 46MW had been installed worldwide, consisting of the Hywind project and a number of smaller demonstrators (with 9MW in Asia). Market projections predict that 6-12GW of floating wind will be installed globally by 2030. It is unlikely that any single floating foundation design concept will achieve market dominance. Instead a range of technology solutions will be deployed according to different site conditions, also influenced by local infrastructure and supply chain capabilities.

Compared with tidal and wave energy, the floating wind industry is developing at a faster rate and significant cost reductions can be expected in the near future. This is mainly due to the similarities with fixed offshore wind and offshore floating structures from the oil and gas industry, which has reduced the technological barrier to market entry. Because offshore wind is a proven commercial product, it is a far less risky prospect for investors and hence is not plagued by the funding problems which wave and tidal have historically seen.

Research and development efforts are being made and SMEs are receiving funding for their projects; for example the EU awarded a €31m grant for the EMEC and SEAI led AFLOWT project. Whilst prices are dropping, making this technology more viable, it is still crucial for policymakers and governments to provide support for floating wind energy, in order to allow the development of large-scale projects.

Innovations

- GE has received funding to develop its 12MW floating wind turbine which could be used in French projects.
- There are several competing foundation concepts that can be broadly categorised into four types: spar buoys, semi subs, barges and tension leg platforms (TLPs). The associated design choices, for example materials that are used (for example steel or reinforced concrete), and supply chain are where key innovations are expected.
- Research and development in the field of dynamic cables for floating wind projects is ongoing. As there is movement in the floating platforms, cables are subject to higher mechanical stresses which increases the chance of failures. Dynamic designs using more suitable materials will reduce O&M cost and improve the reliability of the electrical system. It is expected that cables with the desired mechanical strength will be produced in the next decade.
- As well as floating turbines, floating offshore substations are also being developed for projects located far from shore and in deep waters (e.g. Ideol/Chantiers de l'Atlantique).
- Finally, some design innovations related to new mooring systems and anti-corrosion solutions might lead to reduced maintenance and service.

5.2. Typical project costs

As for wave energy, the top level cost elements were obtained from our models and are defined in Table 8 within the Appendix. More detailed sub divisions of these costs, where stated, were generally adapted from trends seen in offshore wind, for example using The Crown Estate *Updated guide to an offshore wind farm*. For floating offshore wind, we considered a small-scale (<40MW) project with an expected lifetime of 20 years and 8MW turbines.

Table 5 Typical cost breakdown for a small-scale (<40MW, 8MW turbine rating) floating offshore wind project commissioned in 2020 with an expected lifetime of 20 years. Note that there is no offshore substation, due to the size of the project, and operation, maintenance and service costs are in units of €/MW/year.

Element	Cost (€/MW)	Contribution to level above	Sub-element	Cost (€/MW)	Contribution to level above
Development and project management	200,000	4.8%	Development and consenting services and expenditure incurred by lost projects	175,000	88%
			Professional and enabling services	25,000	12%
Turbine supply	1,500,000	35.9%	Rotor	375,000	25%
			Nacelle	875,000	58%
			Tower	250,000	17%
Balance of plant supply	1,750,000	41.9%	Foundation	1,400,000	80%
			Array cable	100,000	6%
			Export cable	200,000	11%
			Offshore substation	0	0%
			Onshore substation	50,000	3%
Installation	350,000	8.4%	Foundation and turbine installation	140,000	40%
			Array cable installation	50,000	14%
			Export cable installation	125,000	36%
			Offshore substation installation	0	0%
			Onshore substation construction	20,000	6%
			Professional and enabling services	15,000	4%
Contingency	380,000	9.1%	Contingency	380,000	100%
Operations, maintenance and service	125,000 €/MW/year	100%	Maintenance and service	75,000 €/MW/year	60%

Element	Cost (€/MW)	Contribution to level above	Sub-element	Cost (€/MW)	Contribution to level above
			Operations	35,000 €/MW/year	28%
			Professional and enabling services	15,000 €/MW/year	12%
Decommissioning	225,000	100%	Decommissioning	225,000	100%

5.3. Technology recommendations

As for the other two technologies, the main report provided high level recommendations on both a country and technology level, which are also included here. These were formulated using our internal knowledge, as well as understanding and learning gained on the project.

National recommendations

Table 6 Prioritised recommendations per country for floating wind energy.

Country	Recommendations
BE	There will be limited opportunities for floating wind projects in Belgium due to shallow waters. However, Belgian companies (e.g. providers of offshore contracting and services) should seek opportunities in projects in France and in the UK for example. In addition, Belgian companies could strongly benefit from the experience acquired in the development of offshore wind projects.
FR	There are a number of floating wind projects under development in France, especially in Mediterranean waters. This is the opportunity for French suppliers to become involved. The expertise acquired by these suppliers could then be exported to other countries such as the UK or Japan. In addition, the gap in the floating foundation supply chain could be closed by French companies.
DE	There will be limited opportunities for floating wind projects in Germany due to shallow waters. However, German companies (e.g. wind turbine suppliers) should seek opportunities in projects in France and in the UK for example. In addition, the gap in the dynamic cable supply chain could be closed by German companies.
IR	While resource and offshore conditions (i.e. water depths) in Ireland are very suitable for deploying FOW technologies, there are still many areas where fixed bottom wind could be deployed which makes immediate market entry for floating wind a more difficult prospect. As there are limited players in the industry, currently focussed on markets like the UK and France, Ireland might struggle to compete although have made notable steps recently (for example a €31m project was announced in 2019, funded by Interreg, and in 2017 a lease was granted to test floating wind turbines at the Galway Bay test site). The limited experience and relatively small number of companies involved in offshore wind means that there is not much expertise to export to other countries where floating wind projects are being developed. However, the SMEs involved in development and project management as well as marine contractors could seek opportunities in the UK or France.
NL	There will be limited opportunities for floating wind projects in the Netherlands due to shallow waters. However, Dutch companies (e.g. providers of offshore contracting and services) could seek opportunities in projects in France and in the UK for example.
UK	It is likely that some floating wind projects will be developed and built in the northern parts of the UK. British companies have extensive experience in offshore wind and should benefit from the growth of floating wind and find a place in its supply chain. There is a gap in the supply chain of dynamic subsea cables which could be closed by British companies.

Technology recommendations

Technology challenges

- Floating wind has the advantage over wave and tidal technology in that the generating device is mature technology and the risk profile of floating wind farms can be more easily be accommodated.
- Dynamic power cables either: need to be made at lower cost, to enable the whole cable (on the seabed and hanging from the device) to be the same, and be installed from a continuous drum; or smart ways need to be found to join and install cables that have one or two dynamic ends with a non-dynamic centre portion.
- Mooring systems are needed that retain the best features of current low-cost marine moorings, but that are adapted to the needs of floating offshore wind and tidal projects. This includes post-installation testing and adjusting to length and 'storage' until needed by the floating device. Design features are needed to enable simpler, safe and robust device connection to both the moorings and to the dynamic power cable (and disconnection if required by the operation and maintenance strategy).
- Operation and maintenance systems that reduce the need for personnel to travel offshore and transfer to a floating device are needed. This means more and better remote monitoring systems that better analyse the current health of all key systems and can better predict future maintenance requirements. For times when human intervention is necessary, better systems to safely transfer personnel between two floating 'vessels' are needed. The remote monitoring systems need to extend to the status of the floating hull and the mooring system and dynamic cable. These systems also need to cover biofouling as well as structural condition and operational loads.
- Floating foundations themselves are not yet optimised. While some designs need large scale fabrication facilities, others can use smaller-scale suppliers delivering raw materials or modular sub-components. Development of design concepts that enable cost reductions in large scale manufacturing and allow high degrees of localisation is a key goal.
- The key challenge is technology convergence and optimisation of the floating foundation. Interventions that can accelerate that process will have a major impact on the growth of the industry. A problem is that concept developers have invested in considerable IP. These companies are also developing early stage projects and demonstrators, using their own technology with bespoke manufacturing processes, which means that the technology will not necessarily be the lowest cost solution for any specific project. In contrast, in fixed offshore wind, there is very little IP the substructure and project design is driven by cost, by developers or EPCI contractors. Attempts at introducing novel foundation concepts for fixed offshore wind have largely failed.
- Many of the technology challenges needing to be addressed in floating wind will be defined by project developers and EPCI contractors wishing to optimise costs. Joint industry projects that involve these companies, with key suppliers, are likely to be the most effective means of tackling major industry challenges. The Carbon Trust Offshore Wind Accelerator has been highly effective in this respect and there is real value in OPIN using existing initiatives such as this rather than creating new structures.

Countries of interest

- The key markets in the next decade are those where the opportunity for fixed offshore wind is limited. In major markets such as Denmark, Germany, Netherlands and the UK can meet 2030 targets comfortably with fixed projects. Even in submarkets such as Scotland, where there is significant political appetite, floating projects have to compete with fixed projects across the UK.
- France can be a key market because it has less available shallow water. France was the only country in Europe to include a figure for floating wind in their draft National Energy Plan for 2030. France is planning floating auction rounds and the competitive nature of these can be crucial in optimising designs. This means that there is promising room for industry to get involved across all areas of value chain, but this will be harder for organisations without a presence in France.
- Even important markets such as France may not be big enough to secure the investment needed for sustained cost reduction. Companies that wish to succeed in the floating wind market will need to develop a business in other key markets. This is especially challenging for SMEs, and OPIN can usefully help companies operate outside their home markets.

6. Cross-sectoral collaboration opportunities

All three technologies require high level political support, to create a market that will drive the investment needed to bring costs down to levels competitive with other renewable energy technologies. Examples of the processes involved include marine spatial planning, allocation of lease areas (including demonstration sites) and, crucially, differential price support mechanisms. Other sectors have had to go on similar journeys, to gain funding and get buy-in from policymakers, and so there is key political and technical knowledge that can be passed on to the marine renewable industry.

Table 7 summarises learning that could be gained from other sectors and highlights some notable instances where this has already occurred. Offshore wind is not considered as this was the main sector of comparison throughout the main report.

Table 7 Key sectors that the three marine technologies could learn more from through cross-collaboration.

Sector	Themes	Most relevant technology	Comments
Aerospace	• Modelling techniques (e.g. CFD) • System design (e.g. rotors) • Industry partnerships	• Tidal • Floating	The aerospace industry has benefitted from increased collaboration, for example schemes like the Aerospace Growth Partnership. There are several synergies, especially with tidal stream and floating, for example the modelling techniques that are employed. Computational Fluid Dynamics (CFD) is a notable case. One example of a company which started out as a spin-off from an aerospace company is tidal developer Minesto, founded in 2007 from Saab. This shows that aerospace expertise is directly applicable to the tidal sector. A challenge is that aerospace, as an industry, is more geared towards performance optimisation, and companies generally have a lot of money to fund research on topics like advanced control systems and materials. This is a different stage to the technologies examined in this report, which are mainly focussed on cost reduction, and so many of the technological developments from the aerospace industry will be too expensive for the renewable energy industries to adopt. Attempts to explore synergies with wind concerning composites have foundered for similar reasons. In aerospace, weight is the major consideration because of the impact on fuel usage. In wind, capital cost is the main driver.

Sector	Themes	Most relevant technology	Comments
Automotive	• PTO systems • Methodology (e.g. reliability and processes) • Manufacturing techniques • Industry partnerships	All three (notably wave)	There have been cross-collaborations before. One example, Phase 1 of the RiaSoR reliability project, examined establishing guidelines for assessing reliability of wave energy devices by using procedures from the automotive industry. Another area of synergy is in the wave energy PTO system. The NEAPED project, with funding from Wave Energy Scotland, examined the feasibility of using high reliability electric vehicle motor/generators for wave devices. All three technologies could learn from manufacturing processes, for example the way that the automotive industry has standardised components and processes to drive down costs together (for example building different cars on the same base models). In general, volumes are significantly higher in automotive than ocean energy but there are certain lean manufacturing applications from low-volume automotive.
Aquaculture	• Mooring systems • Vessels • EIA/consenting • Collaborations on projects	• Wave • Tidal	There are multiple opportunities for learning, including on mooring system design for floating bodies and development processes. There could also be learning on biofouling, as there are various solutions being examined in the aquaculture sector (for example net cleaning robots are provided by companies like MPI (NO) and Yanmar Marine (NL)) Aquaculture is a growing industry. More exposed locations are of increasing focus, as they have better water circulation and many sheltered sites have already been developed. These higher energy sites could also be advantageous for wave energy systems, which could protect floating fish farm cages by taking energy out of the waves. Fish farms also tend to be off-grid, so there is room for collaboration to investigate hybrid energy solutions. Previous collaborations have included Albatern and Mowi (previously Marine Harvest), and Wave Dragon and Seaweed Energy Solutions. This kind of collaboration could also encourage cost-saving initiatives, for example wave developers using aquaculture vessels or mooring system suppliers. Belgium could be a market of interest as, due to the small size of EEZ, the government are keen to examine multi-sea use solutions. The country was one of the first to implement a multi-use marine planning system.

Sector	Themes	Most relevant technology	Comments
Energy storage and off-grid project developers	• Collaborations on projects	• Wave • Tidal	Energy storage is important for smaller scale devices in off-grid applications, and within other devices to smooth output power. Some companies have investigated combining their systems with battery storage. In the UK, Nova Innovation, integrated a Tesla battery within their Shetland Tidal Array. Another example is French SME Sabella, who installed an onshore battery system at their Ushant Island site to improve grid stability. There are also companies developing off-grid energy systems, for applications like island communities and niche applications. Examples include MAN Energy Solutions (DE) and Energy Solutions (UK). These companies typically develop solar and onshore wind systems, but much of the knowledge (for example system control) would also be relevant for marine energy projects.
Oil and gas	• Development • Floating platform design • Array cabling • Foundation supply • Installation • Maintenance and inspection • Collaborations on projects	All three (notably floating)	Learning from oil and gas (O&G) has been utilised in conventional offshore wind, and has seen a number of oil and gas companies enter the market (for example Equinor (NO) and Wood (UK)). This has been driven by recent low oil prices, which have seen companies attempting to diversify. Some of these companies have made acquisitions in the examined technologies, for example Shell signed an agreement to purchase floating wind developer EOLFI in October 2019. The oil and gas sector has most effectively diversified in the area of subsea engineering and surveying where the technologies employed are similar. The major oil and gas marine contractors and fabricators have in general been less successful. All three of the technologies examined in this study could learn from the O&G sector, and indeed already have been (for example floating wind foundations are largely based on proven O&G designs). Other areas of learning are in project development, maintenance and inspection (for example condition monitoring) and cabling. Marine energy could also learn from O&G installation processes. As for aerospace, there is a lot of money in the industry and so not all technological solutions will be applicable for the fledgling marine renewable industry. There might be scope to collaborate on projects in the O&G industry, to provide power for ancillary systems. Examples include the Hywind Tampen project (see Section 5.1 for a description of this) and US wave developer OPT, who signed an agreement for a demonstration project with Eni (IT) in 2018.

Sector	Themes	Most relevant technology	Comments
Shipbuilding/naval architecture	• Hull design • Mooring systems	• Floating • Wave • Tidal (floating)	This expertise could help to optimise floating device concepts, for example improving hull shape to increase energy yield (in the case of wave energy) or to reduce loading on the structure. There have been some recent collaborations. For example, in October 2019 four Italian companies announced a partnership to create a wave energy project development business. One of the parties, Fincantieri, is the largest shipbuilding company in Europe. Another recent example is Chantiers de l'Atlantique's partnership with Ideol, aimed at designing a floating substation based on Ideol's floating foundation concept. In fixed offshore wind, offshore substation fabrication has typically been undertaken at shipyards and this is likely to be the case for larger floating projects once they reach a size when a substation is needed.
Space	• Satellite data	All three	Satellite data collected by agencies like the European Space Agency (ESA) could help renewable energy developers improve their models and identify suitable project locations. ESA note business applications and software on their website, including software to identify remote villages for micro-grids (Village Data Analytics) and eOdyn, which provides meteorological data for O&G operations.[5] The ISSWIND programme examined ways that the space sector could help support the wind industry, and from it a hindcasting and forecasting service was set up to provide data.

[5] https://business.esa.int/projects/theme/energy (accessed 05/11/19)

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Appendix A: Element definitions

Table 8 Element definitions for cost breakdown of wave and floating wind energy.

Element	Definition
Development and project management	Development, consenting and project management work paid for by the developer up to work completion date (WCD). Includes: • Internal and external activities such as environmental and wildlife surveys, met mast (including installation) and engineering (pre-front-end engineering design (FEED)) and planning studies. • Further site investigations and surveys after FID • Engineering (FEED) studies • Environmental monitoring during construction • Project management (work undertaken or contracted by the developer up to WCD) • Other administrative and professional services such as accountancy and legal advice • Any reservation payments to suppliers Excludes: • Development costs of transmission system • Construction phase insurance • Suppliers own project management
Generating device	Includes: • Tower (floating wind) or device body (wave) • Payment to turbine or generating system manufacturer for the supply of all the elements of generating systems (such as tower, nacelle and its sub-systems, the blades and hub for floating wind, device structure and prime mover for wave, and the electrical systems to the point of connection to the array cables) • Delivery to nearest port to supplier • Warranty • Commissioning costs Excludes: • Operational expenditure (OPEX) • RD&D costs • Insurance and contingency
Balance of plant	Includes: • Payment to suppliers for the supply of any support structure comprising the foundation/support structure and mooring system (including any secondary steel work such as J-tubes and personnel access ladders and platforms) • Delivery of support structure and array electrical to nearest port to supplier • Support structure and array electrical warranty • Development of transmission system • Payment to manufacturer for the supply of onshore and offshore export cables and substations • Installation of onshore and offshore substations and export cables Excludes: • Tower for floating wind • Support structure OPEX • Array electrical OPEX • RD&D costs
Installation and commissioning	Includes: • Transportation of all from each supplier's nearest port • Pre-assembly work completed at a construction port before the components are taken offshore • All installation work for support structures, mooring systems, array cables and devices • Commissioning work for all but device (including snagging post WCD) • Scour protection (for support structure and cable array) • Subsea cable protection mats etc., as required Excludes: • Installation of offshore substation / transmission assets (except for floating wind costs where this is included) • Device commissioning

Contingency	• Construction phase insurance cover, from start of construction until operation start, including all construction risks & third party • Construction phase contingency
Operations, maintenance and service (OMS)	Includes operation and planned (routine) maintenance, unplanned service (in response to faults; may be either proactive or reactive), operations phase insurance, other OPEX and transmission OPEX. Starts once first turbine/generator is commissioned. Operation and planned maintenance includes: • Operational costs relating to day-to-day control and condition monitoring • Planned preventative maintenance, health and safety inspections Unplanned service includes: • Reactive service in response to unplanned systems failure in the device or balance of plant. Operations phase insurance: • Takes the form of a new operational “all risks” policy and issues such as substation outages, design faults and collision risk become more significant as damages could result in farm outage. Insurance during operation is typically renegotiated on an annual basis. Other OPEX covers fixed cost elements that are unaffected by technology innovations, including: • Site rent • Contributions to community funds • Monitoring of the local environmental impact Transmission OMS, using the timing and other definitions above, includes: • Planned maintenance and unplanned service of transmission assets • Generation transmission use of system (G-TNUoS) charges.
Decommissioning	• Planning work and design of any additional equipment required • Removal of the turbine and support structure to meet legal obligations and further environmental work and monitoring