Ocean Energy Technology: Gaps and Barriers

SI OCEAN

strategic initiative for ocean energy

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Glossary

DP	Dynamic Positioning
GWh	Gigawatt Hour
KPI	Key Performance Indicator
kWh	Kilowatt Hour
LCOE	Levelised Cost of Energy
MEAD	Marine Energy Array Demonstrator (capital grant funding scheme)
MWh	Megawatt Hour
O&G	Oil and Gas
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
PV	Solar Photovoltaic
RD&D	Research, Development and Demonstration
SEII	Strategic European Industrial Initiative
SRA	Strategic Research Agenda

Executive Summary

SI Ocean is an Intelligent Energy Europe project that was conceived to strengthen Europe's ocean energy networks, enhance collaboration on research and development and overcome technology, policy and market barriers to build a Pan-European ocean energy sector. SI Ocean is focused on identifying a realistic trajectory for the commercialisation of wave and tidal stream energy across Europe, and establishing routes to increase supply chain confidence in the emerging ocean energy sector.

This Gaps and Barriers report is the third Deliverable from the Technology Assessment work package within the SI Ocean project. Significant engagement with industry, in both stakeholder interviews and a supply chain focussed workshop, has allowed for a diverse range of inputs into what is a challenging and demanding topic within the ocean energy sector: Identifying the gaps in knowledge and the barriers that are inhibiting development and deployment of nascent ocean energy technology.

Technology gaps can be considered as areas in which new enabling technologies or innovation is required in order to make technical progress in the ocean energy sector. Barriers to deployment are challenges that inhibit the deployment of ocean energy technology, making it difficult for the sector to achieve its targets and goals.

This document presents technology gaps and barriers in developing the ocean energy sector – the solutions to which could represent a key opportunity to reinforce Europe's leadership in RD&D as the ocean energy sector progresses from concept to commercialisation.

1. The major challenges and obstacles facing the sector have been outlined and discussed. These include:
    - Enabling Technology;
    - Risk Management;
    - Commonality and Design Consensus;
    - Grid Access;
    - Economic Perspective; and
    - Establishing Equitable Environmental Mitigation Measures.

Through discussion with ocean energy industry representatives within the stakeholder engagement process, a list of innovation activities were created, identifying the technology needs of the ocean energy sector. While all topics are important, some are more urgent than others. This report has identified the list of activities, and carried out prioritisation work that identifies the most urgent needs of the sector, and which actors should take responsibility for the delivery of these activities.

2. A prioritised list of activities has been developed, identifying the most urgent action areas to be considered by government, industry, and the research sector. The opportunities for intervention by each actor are summarised in metrics below, with specific activities and priorities detailed in Section 4:
    - **Government**: The development activities which are perceived to require government funding in order to proceed. Government (at a European, Member State, and regional level) must identify suitable mechanisms to support the development of these activities in order to allow timely resolution; otherwise the challenges may remain in place for a significant time. Examples of activities that

require government funding support include device and sub-component level reliability demonstration (technology push); array level reliability demonstration (technology push & market pull); and knowledge transfer & dissemination.

- **Industry**: The development activities that require industry and supply chain leadership to develop solutions. While it is acknowledged that funding may be a requirement, the activity requires industry or supply chain leadership in order to outline potential solutions. Examples of activities that require industry leadership include design for maintenance; performance data collection; foundations & moorings; and offshore grid design & optimisation.
- **Research**: The activities that require fundamental underpinning research in order to develop state of the art knowledge. The skills, facilities, and capabilities of research institutes will benefit these activities greatly. Examples of activities that would benefit from fundamental research include novel system concepts; device and sub-component level reliability demonstration; reliability tools; resource analysis tools; techno-economic analysis tools; knowledge transfer & dissemination, and array interaction analysis.

The barriers and challenges facing the sector will require significant cross-industry effort, with responsibility and risk needing to be shared by all stakeholders. The high level goals for the sector are clear, but the challenges must be overcome:

- Address technology fragmentation to increase supply chain appetite for investment;
- Address lack of cooperation and collaboration by identification of collaboration opportunities;
- Identify the best strategies that will allow safe and efficient deployment of arrays.

By working together, the industry can overcome these challenges and demonstrate that the sector is capable of large-scale technology production, addressing the three-fold challenge of energy security, CO_2 emission reduction, and inward investment within the EU. It is only through achievement of these challenges that the sector can gain traction and accelerate towards 2030 and 2050 ocean energy deployment targets.

1. Introduction

1.1. SI Ocean

SI Ocean is an Intelligent Energy Europe project being led by a consortium of partners, including the European Ocean Energy Association, and the European Commission's Joint Research Centre (EU); the University of Edinburgh, Carbon Trust, and RenewableUK (UK); WavEC (Portugal); and DHI (Denmark).

The SI Ocean project was conceived to strengthen Europe's ocean energy networks, enhance collaboration on research and development and overcome technology, policy and market barriers to build a Pan-European ocean energy sector. SI Ocean is focused on identifying a realistic trajectory for the commercialisation of wave and tidal stream energy across Europe, and establishing routes to increase supply chain confidence in the emerging ocean energy sector.

The University of Edinburgh, Carbon Trust, WavEC, and the Joint Research Centre of the European Union have prepared this report to highlight the gaps and barriers that exist within current technology development and planned project deployment in the emerging ocean energy sector. Identification of these gaps and barriers will facilitate opportunities to allow combined effort for addressing these challenges, demonstrating a cohesive ocean energy sector that is capable of building a new industry, helping to meet carbon emission reduction targets and providing a source of sustainable energy, enhancing energy security and building a skilled workforce across several EU Member States.

In addition, this document will underpin a Strategic Technology Agenda that will outline the obstacles facing the sector and the opportunities that exist in order to overcome these challenges, providing clarity on the route to a more integrated ocean energy industry.

1.2. Progress to Date

The Gaps and Barriers report follows the release of two earlier documents within the SI Ocean Technology Assessment work stream: a Technology Status Report [1] (released in December 2012), and a Cost of Energy Report [2] (released in May 2013). The earlier deliverables within the SI Ocean project have provided a high-level overview of the wave and tidal sector, including technology types and information on the modes of operation; the Cost of Energy report has summarised the plausible current, and projected future, cost of ocean energy scenarios, based on current best practice. These documents will be complemented by the addition of the Gaps and Barriers Report, which will identify the key challenges facing the ocean energy sector, outlining areas where there are opportunities for knowledge transfer from other more mature renewable energy sectors, and highlight areas that will require detailed investigation in order to minimize potential obstacles and bottlenecks in full scale market development.

The Strategic Technology Agendas for more mature renewable energy technologies will be compared and contrasted with the information collected within the SI Ocean consultation process to help identify the gaps and barriers to the commercial development of wave and tidal technologies.

All documents within the SI Ocean project are available to download from the SI Ocean project website, www.si-ocean.eu.

1.3. Document Outline

Section 1 provides an introduction to the SI Ocean project, explaining the project deliverables that have been released to date, and detailing the requirement for the Gaps and Barriers Report, which is a linking step between the initial project deliverables and the forthcoming Strategic Technology Agenda.

Section 2 examines the stakeholder engagement process that underpinned the work of the SI Ocean project, describing the mechanisms through which the responses of the sector were sought, and how this data was used in the subsequent analysis.

Section 3 expresses the findings of the stakeholder engagement process, looking separately at the interview process and the stakeholder engagement workshop. Identification of gaps and barriers within the wave and tidal sector will begin to emerge from the discussion in this section, although will be discussed more thoroughly in sections that follow.

Section 4 looks at the innovation needs for the ocean energy sector, and carries out a prioritisation of the identified technology opportunities. This section will also highlight the key actors that are needed in order to allow the development of each activity to progress, and the opportunities for intervention that exist for each actor. This prioritisation work has been carried out in order to aid the decision making process for funding bodies, highlighting the urgent needs of the sector and allowing adequate allocation of funding. This allows the different stakeholders to focus on the technology areas that are most appropriate for their remit.

Section 5 forms the main identification of gaps for commercial development in the current technology focus for wave and tidal technologies, summarising the discussion from within previous chapters and outlining the key action areas that must be addressed for commercialisation of the ocean energy sector. The chapter will not present solutions to these challenges, but outline the needs of the wave and tidal energy sector. The opportunities that exist for removal of the identified barriers will come from industry collaboration; specific targeted support from the relevant stakeholders will be an essential ingredient to overcoming the challenges, as discussed in Section.

Section 6 summarises and concludes, paving the way for the remaining SI Ocean technology assessment work, which will culminate in a Strategic Technology Agenda (STA). This STA document will identify the means by which the key gaps and barriers can be addressed, facilitating cross-transfer of information between technology and policy needs, ensuring that appropriate policy mechanisms can be recommended for implementation to support the development needs of the ocean energy sector.

An appendix, contained at the foot of this document, considers other, more mature, renewable energy technologies such as wind and solar photovoltaic (PV); by engaging with the Strategic Research Agendas of existing technologies, suitable lessons can be learned for wave and tidal, feeding into research needs appropriate for the emerging ocean energy sector.

There are opportunities for the sector to learn and evolve, and this report will identify the challenges to be overcome, paving the way for a Strategic Technology Agenda that will outline the routes to overcoming the barriers currently in place.

2. Stakeholder Engagement Process

The SI Ocean project has incorporated significant stakeholder engagement within the data collection and analysis process. In order to bring together key players within the ocean energy sector, and to present a common voice from the industry, the SI Ocean stakeholder engagement consisted of three mechanisms, as identified in Figure 1 below.

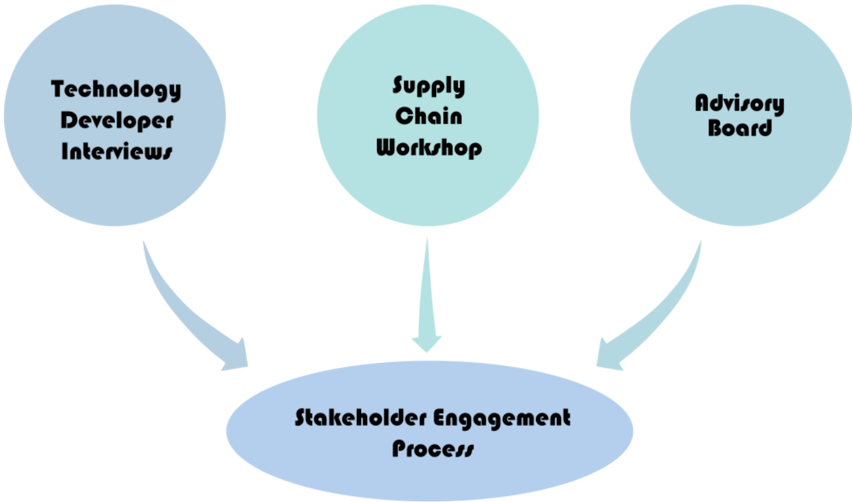

Figure 1: the Stakeholder Engagement Process

Technology and Project Developer Interviews: the initial means of engagement was achieved through interview with technology developers, supply chain companies and utilities. The interview process allowed for direct interaction with technology developers across a wide range of technology types (including both wave and tidal energy), representing a broad range of countries and Technology Readiness Levels (TRLs). This approach also allowed consideration of the differing needs of technology and project developers, and the role of the supply chain within the development process. By including developers at both early and mature stages of development, the barriers facing the sector as a whole could be more accurately defined. A written record of each interview transcript was generated for subsequent analysis.

Supply chain and stakeholder engagement workshop: A workshop was held to inform stakeholders of the results of the interview process, and to give an opportunity for discussion on a range of issues. It also allowed validation of the interview analysis to take place. The workshop included an increased number of stakeholders, beyond those who participated in the interview process, ensuring that there was a continuation of the broad industry representation. Furthermore, there were several additional topics that received significant levels of interaction between those present, identifying several barriers that require urgent attention in order to allow accelerated development of the sector.

The Advisory Board for the SI Ocean project were kept appraised of the engagement process, and were given opportunities to provide recommendations for maximising benefit from the stakeholder engagement. Members of the advisory board were also approached as part of the interview process, ensuring that solid and robust information was collected, and providing value to the project.

2.1.Process and Methodology

2.1.1. Interviews

The interview process involved meeting with 16 wave and tidal energy technology developers, using discussions with key technical and managerial staff to collect information on a number of topics including technology development, installation, maintenance and reliability, supply chain, and economic, regulative and legislative barriers. For this purpose, a standard interview questionnaire was established to collect common information from a number of developers, and assess where challenges lay that strongly affected a large number of developers. Discussion with each interview candidate lasted between 1 and 2 hours.

It was recognised that technology developers, project developers (utilities), and the supply chain have differing priorities, and so in order to generate a holistic overview of the sector, companies from each of the three groups were approached.

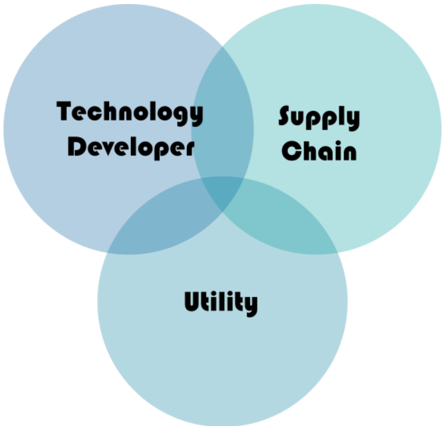

Figure 2: Three Key Stakeholder Types Considered in Interview

There was significant diversity in the range of inputs, as both early and more mature stage developers were approached for interview purposes. The technology developers represented a number of EU countries, and were spread across a range of Technology Readiness Levels. This allowed for a breadth of responses, addressing barriers at all stages of technology development. It is important to consider that there will always be a need for research and innovation, even when mature technology options exist. As a result, it was important to consider both technologies at an earlier stage of research and innovation, and those at a mature stage of full-scale deployment.

Throughout the consultation process, 16 interviews were carried out with wave and tidal technology developers, supply chain companies, and utilities. Interview transcripts were recorded, and the references to individual developers were removed in order to maintain anonymity.

An inductive coding technique was used to extract quantitative information from a qualitative set of interview transcripts, highlighting priority areas that resulted from the discussions. The results of the analysis will be presented in Section 3.

2.1.2. Workshop

The workshop attracted over 60 attendees, including presentations from industry representatives. There was a significant supply chain focus in order to engage and encourage device developers, project developers, and supply chain companies to approach barriers with a common purpose, and to facilitate discussion of the needs and priorities of each stakeholder type.

The discussions held during the workshop identified several areas where lack of consensus between different stakeholders provided complexity; a level of tangible frustration at the urgent need to address these barriers was present. Several topics emerged as focus areas during the discussion, and this has been documented within Section 3.2.

The technology findings from the stakeholder engagement process will be discussed in the following section of this report.

3. Technology Findings

The stakeholder engagement process ensured that the voice of the industry was the focus of the analysis throughout the SI Ocean project. While there was a broad and diverse range of technologies under consideration, there were several common findings, regardless of technology type and Technology Readiness Level. This section presents the findings from sector engagement, both from the interview process and from the workshop, and represents the current challenges and barriers facing the wave and tidal sector across Europe.

A number of dominant themes present themselves within the data collected, and these themes will be discussed herein. While the dominant themes from the interviews represent individual viewpoints from the technical engineering and/or executive managers within stakeholder organisations, the workshop key themes arose from discussion between delegates, and included multiple approaches to the dominant themes. However, in short timescales, it is very difficult to achieve clear consensus, and the topics presented within this section reveal where there is need to build upon current best knowledge in order to overcome the gaps and barriers.

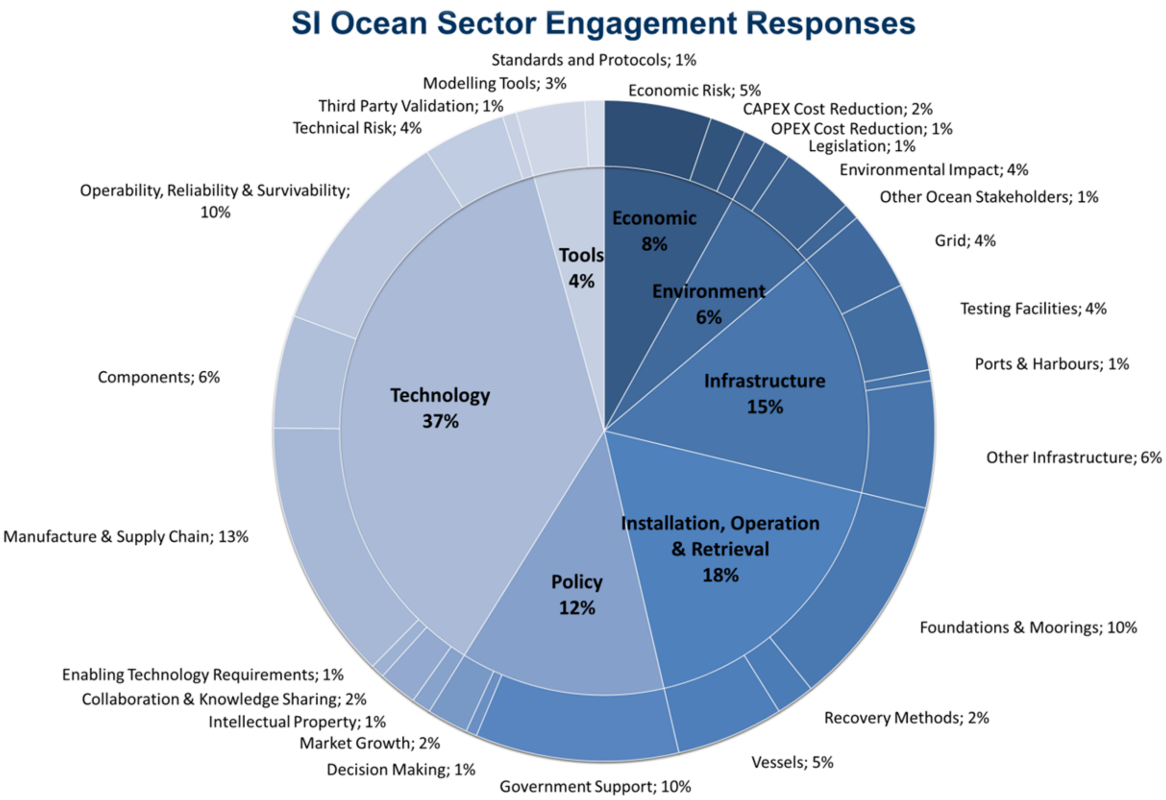

Figure 3: Key Topics from Stakeholder Interviews

Engagement with the wider ocean energy sector has revealed the challenging conditions that technology developers and project developers are operating within. For those developing the technology solutions, there is significant pressure for fast deployment in short timescales, both at an economic and a political level. Financial pressures exist through the requirement to provide returns for investors. Political pressures arise from competition with other renewable energy sectors that may offer a more competitive and attractive cost for policymakers. Optimistic deployment forecasts, which have pushed the sector to achieve large scale deployments in the short-term, are possibly misaligned with the type, and level, of funding available to the ocean energy sector. Many of the sub-themes within this section reflect this conflict.

3.1. Interviews

Each interview transcript was analysed, and broken into specific segments of information known as excerpts. An excerpt may be a single comment made during the interview process, or a short paragraph covering a particular topic. The analysis process applies a theme to each of the excerpts, based on the dominant topics being discussed within the excerpt. The analysis of the interview transcripts generated 7 main themes and 26 sub-themes, as indicated in Figure 3, which shows a breakdown of all the excerpts, expressing the percentage of excerpts associated with each theme and sub-theme as a proportion of the total number of excerpts.

The main themes **(bold)** and associated sub-themes *(italic)* were as follows:

- **Technology;** *Intellectual Property; Collaboration & Knowledge Sharing; Enabling Technology Requirements; Manufacture & Supply Chain; Components; Operability, Reliability & Survivability; Technical Risk; and Third Party Validation*
- **Installation, Operation & Retrieval;** *Foundations & Moorings; Recovery Methods; Vessels*
- **Infrastructure;** *Grid; Testing Facilities; Ports & Harbours; Other Infrastructure*
- **Policy;** *Government Support; Decision Making; Market Growth*
- **Economic;** *Economic Risk; CAPEX Cost Reduction; OPEX Cost Reduction*
- **Environment;** *Legislation; Environmental Impact; Other Ocean Stakeholders*
- **Tools;** *Modelling Tools; Standards & Protocols*

Within each theme, there were several quotes from the interview candidates that demonstrate clear consensus on the barriers and challenges. Each theme will be analysed in succession, and relevant findings within each section discussed in more detail.

3.1.1. Technology

The technology theme represented the largest portion of the interview responses, and as a result, there are more sub-themes relating to this topic than for others. While there is a diverse range of sub-themes, each of these has significant implications on the technological development of the ocean energy sector.

The dominant sub-theme within the technology theme was ‘manufacture & supply chain’. It was clear that, while several concepts exist within different technology types, device developers are keen to reach a base product that can be suitable for use across many sites, taking advantage of existing supply chain companies from sectors such as wind energy.

> *“It is important to stabilise the design [as a] standard design envelope which will be the basis for several arrays.”*

Several developers also discussed their use of off-the-shelf components, recognising that there is not a desire to use bespoke components within the devices, or lead development on new conceptual sub-components, instead utilising proven technology from other sectors that have been marinised for the off-shore environment. This was evident in the responses of several of the wave and tidal device developers.

> *"The only novel part of the turbine is the blades. All other components are off the shelf, marinised components. It is evolution rather than revolution."*

> *"We design to use components already available within the wind industry, where a supply chain already exists. Hydraulic, electrical, and control systems make use of standard industry components."*

Design consensus came up as a sub-theme in many of the discussions, and there is recognition that there is an opportunity for commonality in components. There was, however, a lack of agreement on how this could be achieved in practice. While most agreed that design consensus within certain systems or sub-systems could benefit the sector, there is also caution, due to the desire to avoid getting locked into a non-optimal technology. There were interesting perspectives from project developers, alluding to the need for compromises to be made:

> *"Compromises on design and/or cost may have to be made when achieving commonality in design for a particular component such as foundations, or nacelle quick connection. A step change in thought is required to achieve this aim, as well as buy in from multiple device developers"*

Evidence of commonality between different technologies is still absent in wave energy devices, although some component convergence is being seen within tidal energy devices. Without any significant level of collaboration, the notion of commonality reflects developers' desires to make ready their own product for mass manufacture, rather than to try and reach greater levels of design consensus amongst the sector.

A limiting factor within the Technology theme was the Operability, Reliability & Survivability of devices and sub components. With few devices having achieved extensive levels of operational hours, there is much still to be learned within this area. Developers recognise this shortfall, and the need for demonstration of reliability.

> *"The industry needs to get around the current maintenance intervals – a lot of innovation is required in this area."*

After at sea testing, there have been some experiences that can be taken forward into future deployments as lessons learned. It is important that the sector does indeed make proper use of these learning by doing effects, and ensure that setbacks are not repeated.

> *"Many components, including control and instrumentation cable connectors, hydraulic hoses, non-return valves and accumulators have performed much less reliably than expected."*

> *"Electrical equipment is a source of a high percentage, circa. 75%, of failures and maintenance needs."*

While certain developers suggested sources of risk in reliability, there was also concern that specific location of a device may warrant extra consideration in aspects such as overall downtime and loss of electrical production due to difficult access and a hostile deployment location.

> *"Downtime waiting for device accessibility will be a big issue in [ocean energy] devices."*

In addition, there was recognition that other sectors, such as offshore wind, have had larger than anticipated maintenance requirements. Despite the intervention requirements to maintain any device failures, it has been noted that the majority of failures are caused by small components.

> *"80% of offshore wind maintenance can be traced to single components that weigh less than 25kg [i.e. a one man job to replace]. Our design target is to make component access easy and convenient at low cost."*

Certain developers expressed their recognition that failures could be expected within the sector, and some had the opinion that significant learning can be gained from understanding how and why failures occur.

> *"Every good product is born out of lessons learned."*

It must be noted that there is a real urgency to advance the rate of deployment in order to unlock some of the real cost saving benefits, such as economies of scale. However, as warned by one developer, the economies of scale work equally as well for losses as they do for profits. There is a difficult balancing mechanism between device cost and the level of deployment that can be achieved in short timescales.

While the need to use technologies that have demonstrated reliable operation exists, certain developers did express concern at the lack of engagement with new supply chain companies – citing lack of interest and high price requests from the supply chain. In addition, some of the technologies that exist within the O&G marketplace are over-engineered for the purposes of the wave and tidal energy market.

> *"Oil and gas pricing [and quality standards] are too high for ocean energy. For example the ocean energy sector doesn't need wet-mate connectors [suitable for deployment in depths] to 3000m."*

In order to improve the technology supply chain for ocean energy, lessons learned from existing wind energy supply chain need to be taken in to account, but it must be remembered there are significant differences between the wind energy resource and device operating regime, and the ocean energy resource and device operating regime of wave and tidal energy converters.

While there is much offshore knowledge and expertise from the oil and gas sector, there is a distinct gap between the price that the O&G sector is willing to pay, and the price that offshore renewables are capable of paying. To remedy this requires a step-change in thinking, in order to generate cost effective solutions for an ocean energy supply chain then high value bespoke equipment cannot be commonplace.

The progression from single pre-commercial device deployment to the installation of array projects represents a significant milestone in the development of the ocean energy sector. With this transition comes a big step in risk – in the present deployment focus, technology that is yet largely unproven (with respect to long term reliable operation) will require investment in the order of tens of millions of Euro in order to deploy at the array scale. Significant discussion has taken place surrounding the need for someone to take on the risk in order for development to progress. Given the magnitude of 'utility scale' demonstration projects, risks may be too big for one company to bear. Technology developers are unable, at present, to offer production guarantees, and project developers need some baseline guarantee to help with the investment case and the decision on which technology to deploy at a given site, as is conventional practice within the wind energy sector.

There was strong recognition of the need for deployment of MW scale devices, to initiate the market for ocean energy technologies, and, perhaps more crucially, to enable the sector to meet the deployment targets that have been set. However, there was also a strong surge of technology development within the small-scale and community-scale projects, which have the ability to test technology at a lower overall cost and risk.

One pathway to minimise risk is to prove reliable performance that can allow performance guarantees and confidence in reliable technology operation. With utility scale projects, long term operation and demonstration is a costly endeavour. Without guarantee of return on investment, there may be limited investment appetite to maintain significant levels of funding at a large scale. This requires time for achieving the required operational data, and may also reduce the pace of ocean energy deployment.

By placing a greater emphasis on the generation of kWh, performance metrics can be used to determine the development status of a given device and improve the visibility of devices or technologies that are performing well. The focus needs to be on demonstration of sustained levels of reliable grid-connected power generation, which will increase confidence in the technology, and allow technology developers the possibility of providing project developers with performance guarantees.

An alternative development pathway is to manage risk by starting with small technology and up-scaling the technology in tandem with increasing confidence in the ability of the technology to perform. By deploying at a smaller scale, a larger number of iterations will be possible for a lower overall cost than deploying technology at a large scale. A gradual evolution allows phased steps of risk. There needs to be support mechanisms set in place that will assist and enable the development of arrays of small scale technologies in the same way that funding is made available for large multi-MW arrays; this pathway could result in a reduction in the overall level of risk.

> *"The reasoning behind starting small is risk management. Managing the engineering and financial risk associated with a small scale project is easier than attempting to manage the risk at a large scale"*

> *"Prove technology first then innovate. It is very difficult to innovate at large scale as there are considerably greater costs. Devices should follow a gradual evolution approach"*

A number of emerging technology developers are focussing on small scale devices to reduce the risk associated with initial deployment. Figure 4 outlines some of the different geometries under development, highlighting that the diverse range of pre-commercial device deployments that are taking place. Increase in scale brings increased risk in all aspects of project development, from finance through to installation and deployment, yet large scale technologies have been the focus of investment in the sector to date.

A twin-track technology development strategy is necessary, however, in order to generate a market pipeline: Large-scale devices will ensure that EU deployment capacity targets are met, and credibility of the sector is raised – potentially securing a future market for ocean energy; small-scale technologies will allow a more rapid build out and proving of early arrays, complementing the overall sector learning-by-doing. There are also sites across the EU, and globally, that will be suitable for smaller scale technology, where existing large-scale technology would not be viable. A balanced pipeline will include both large scale and small scale devices, covering a range of technology scales indicated below.

In order of rotor size:

[1] Schottel STG50; rotor diameter = 4.0m

[2] Nova Innovation NOVA-I; rotor diameter = 4.5m

[3] Tocardo T200; rotor diameter = 7.3m

[4] Andritz Hydro Hammerfest HS1000; rotor diameter = 21m

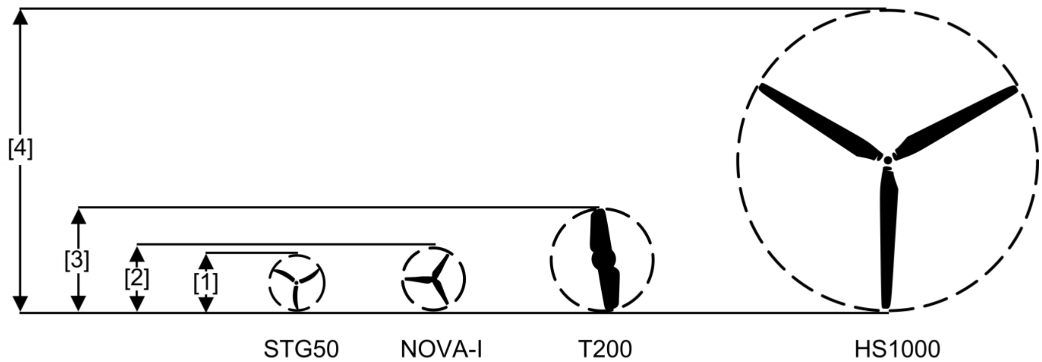

Figure 4: Tidal Turbine Rotor Diameter Variations

Developers of small scale technologies, such as Schottel (50kW), Nova Innovation (30kW; with 100kW turbine under development), and Tocardo (100kW; 200kW; with 500kW turbine under development) are following a distinctly different approach to the conventional pre-commercial demonstration that has taken place to date at European test centres, choosing instead to mitigate and manage risk through phased deployments of smaller scale technologies. The innovation and development of optimised technology can be carried out at a lower overall cost in this approach.

It should be noted that some of the developers of the smaller scale turbines have confirmed orders, or have already delivered commercial products to date, and so are making rapid progress in establishing a competitive position in the market. By starting with a small-scale platform, future devices can be increased in scale at an incremental rate, following a gradual development process, more akin to that seen by the wind energy sector.

While smaller scale technology is able to offer lower risk and lower cost capital investment, the market has to date focussed predominantly on the Megawatt scale devices, creating an uneven playing field in the sector. By re-evaluating the risk, it must be ensured that an open and fair market exists for all device developers; that the term “full-scale” is no longer used purely to refer to MW class machines; and that array funding and market pull mechanisms are appropriately targeted towards the relevant multiple *device* projects instead of solely seeking multiple *MW* array projects - the goal and target should be that of economically efficient deployment trajectories regardless of technology scale.

3.1.2. Installation, Operation & Retrieval

Despite forming a part of the demonstration of the core technology, there was significant focus on the installation, deployment and retrieval of devices. This merited a unique sub theme within the analysis. It was widely recognised amongst the vast majority of candidates interviewed that the installation practices carried out to date are significant cost-drivers. It should be noted that this is a particularly important issue for tidal energy technologies, the majority of which are situated on the sea bed tens of metres below the surface.

> *"Installation aspects of the supply chain are a current challenge. Overly large costs exist for installation relative to other aspects of project development and deployment. Installation is a cost driver. There is a lack of installation experience across the entire sector – even offshore drilling companies have little experience in strong tidal flows."*

> *"The high cost of installation of tidal devices on the sea bed could cause a cost bottleneck, and limit the opportunities for cost reduction."*

One developer stated that there were similarities between the foundation installation procedure for their device and others within the sector, pointing towards a possible opportunity for more commonality in the tidal energy sector and potential future convergence on optimal techniques.

> *"A variety of piling techniques can be used, but we think that the industry will probably converge on the best."*

For convergence to occur, a greater level of knowledge sharing on best practice, and of performance of individual foundation types used to date, will be required.

Vessels represent a significant challenge within the installation, deployment & retrieval theme, and some insight was shared on vessel costs and suitability, revealing that what was initially thought to be a better solution ended up less promising than initially hoped for.

> *"Moored barges are cost efficient, but not very flexible; DP [Dynamic Positioning] vessels are very expensive and not as flexible as expected."*

> *"Cost of large vessels is dominated by O&G spot market prices; Renewables cannot compete."*

While in most cases for tidal energy, devices have required the use of heavy lift vessels from the offshore O&G sector, wave energy deployments have utilised smaller jack up barges and anchor handling tugs – which offer a lower cost than the heavy lift vessels used elsewhere.

> *"There is also significant opportunity for cost reduction within installation optimisation – procedures that allow installation in hours, not days, saving on vessel costs. Another key area*

for cost reduction would be O&M, but this has not yet had the opportunity to be demonstrated and developed. [It is] An area for future work, once operational experience becomes available."

There are some tidal developers, and members of the supply chain, that are designing and deploying devices or platforms that float on the surface of the water. While being more exposed to any wave action that occurs at the surface of the ocean, the floating devices offer reduced installation costs, and ease of retrieval for maintenance. There may be a requirement for sheltered sites for the use of these foundation solutions, where the site is sheltered from the worst storm waves.

3.1.3. Infrastructure

The UK currently leads the way with regards to test centre infrastructure and opportunities for device deployment, but feedback from this section revealed some insight into the needs of technology developers at all stages of product development, and not just those currently at the forefront of deployment activity. This infrastructure section considers not only test facilities, but also port and harbour facilities, and grid connection opportunities.

A significant amount of device deployment is currently taking place in the UK, and some of the challenges highlighted may focus on the UK market. However, where specific challenges refer to the UK, other countries across the EU can heed the warning or take advice from the situation in the UK to enable efficient deployment in other Member States.

In order to provide context for some of the issues that arose, it is prudent to consider the national grid infrastructure within the UK. As the country with the most significant deployment levels at present, the UK infrastructure is having an impact on project development for the majority of the technology developers interviewed. The situation in the UK reveals that the grid infrastructure focusses on centralised power generation close to the major population centres, with distribution of electricity from the centralised locations out to the load demand. In the more rural areas, there is very weak grid infrastructure, due to the historical requirement of taking relatively small amounts of electricity to the homes and properties at the fringes of the network.

Renewable energy resources, in particular the ocean energy resource, are generally located at the fringes of the UK grid network; the north coast of Scotland, the English Channel, and the west coast of the UK and Ireland contain the strongest resource – this creates the need for distributed generation and power transmission/distribution from the remote sites into the centralised population centres. This reversal of the traditional electricity grid network set-up is causing complex challenges, as there is a need to replace existing transmission assets with power lines capable of exporting large amounts of renewable energy from the remote source back to the population and load centres.

Furthermore, the cost burden of connecting to the grid falls upon the project developer (or indeed a technology developer, in the case that they also have to develop their own projects to secure a suitable deployment site for their technology) – a cost burden that not all existing project developers can afford. It may be noted that in countries such as Portugal and Spain, the grid connection cost for power generation projects has traditionally fallen upon consumers, even in the construction of conventional power plants.

Across the remainder of the EU, there may be differing situations, such as the proximity of strong grid infrastructure to the location of ocean energy resource. There may also be examples of deployment locations across the EU where grid connection costs are shared between consumers rather than placed on the technology and project developers. In these instances, the countries involved can learn from the first-mover experience of the UK and benefit from the experience that will be gained through the first array deployments, and the solutions employed by technology and project developers in order to overcome the hurdles.

The stand out barrier in the infrastructure category for device developers was grid connection. This is seen as a significant hurdle, and a delay to project development. All existing consented projects are being challenged by these issues, and there were some big concerns over the ability to resolve grid issues within the near term.

> *"Grid access is the most significant constraint. All existing projects of a commercial nature have grid access and/or grid connection issues. This is creating a significant barrier to deployment."*

The issues surrounding grid connection also have significant impact on other elements, such as access to project financing. In some cases, the delay to grid connection puts projects that are currently under development out of reach of the confirmed support of existing mechanisms, leading to significant uncertainties in ensuring the 'bankability' of a project.

> *"There is a significant technical challenge associated with the delays to grid connection dates. Several sites have had grid connection put back to 2018 – delaying projects and project development work."*

> *"In the north of Scotland [where there is a substantial tidal and wave resource] there is a significant lack of grid capacity, and limited grid connectivity options. Until grid reinforcement [which will appear from around 2017 onwards] becomes a reality, it will be a struggle to accelerate deployment. The necessary infrastructure needs to be put in place in order to allow this acceleration to happen."*

As well as providing temporal delays, there was also concern of the lack of clarity in the UK grid application and charging process. High upfront costs, large lead times and uncertainties were all mentioned as problematic for the sector. All ocean energy projects require access to the grid in order to distribute the energy generated to the locations in which the energy is consumed, but there is a significant bias against projects connecting to the grid off the mainland. Despite a significant level of resource existing in remote locations within the Scottish islands, there is a large financial penalty for any project that connects to the grid outside of the UK mainland.

> *"Grid connection is a large part of project cost, and carries with it a long lead time and therefore a great uncertainty. It is expensive to apply for grid connection, and is not a transparent process at present."*

"Grid connection charges are a substantial burden to renewable energy operators that are not on the [UK] mainland. Connecting to the grid in Orkney results in network charges that are seven times greater than those of the MeyGen project [where grid connection is to the UK mainland]."

In addition to the grid reinforcement requirements, there were other infrastructure topics that presented themselves within the interview process. Another developer implied that it would be advantageous if a test centre could lease a tidal site with intermediate flow properties, filling the gap between the extremely energetic tidal test centres and the "benign" nursery sites currently available:

"There would be significant value in adding in test facilities at an intermediate flow regime to allow full scale device testing in a less risky environment."

The development of new intermediate test facilities for tidal energy within the EU would open up opportunities for further deployment: a site offering test conditions appropriate for developers who wish to test in an energetic environment, but at a reduced risk to the highly energetic Pentland Firth, would benefit the sector. With existing full-scale test facilities fully occupied, expansion or development of new sites will benefit greater technology development, and provide a stepping stone between existing nursery and full-scale test sites. There is a recognised need for improved access to grid connected test facilities, perhaps indicating that an appropriately sited "Tide Hub"[1], where shared offshore infrastructure for the demonstration and proving of tidal energy converters would be utilised by the sector if the infrastructure existed.

It should be noted that the Perpetuus Tidal Energy Centre, located off the coast of the Isle of Wight in the UK, is under development to help meet this demand – with a 20MW test facility due to be completed by 2016.

There was recognition of the value added in enhancement to existing ports and harbours when they are close to the location of device deployment. There has been significant use of the improved Hatston pier facility at Kirkwall on the Mainland of Orkney, and developers recognise the need for improved facilities at other locations close to particular deployment sites.

"Improved port facilities in the vicinity to deployment sites, in addition to manufacturing facilities and component lay down areas are seen as a vital part of facilitating growth."

There were comments praising the ability to carry out shore-based drivetrain and blade testing at regional testing facilities. However, it was felt that certification from testing could be advantageous: If test centres were to offer a stamp of approval for satisfactory completion of testing, then this could provide a benchmark for testing that all developers would meet.

[1] This is being compared to the Wave Hub test site in the UK, where a fully grid connected sub-sea hub is located in an area suitable for deployment of a multiple device array.

"It would be nice if they [test centres] offered a certification – a stamp of approval of the robustness of devices under testing. A standardisation of the testing and certification procedures could be of benefit to device developers, so that there can be even comparison."

3.1.4. Policy

Policy mechanisms for supporting the growth of the ocean energy sector are the mainstay of another work-stream within the SI Ocean project, and so will not be discussed in great detail within this report. However, it is recognised that policy support mechanisms can help 'make or break' the ocean energy sector and some discussion here will provide a direct link with upcoming work in the SI Ocean project. Inevitably, although the interviews focussed on technology, the effects of policy on technology development were frequently mentioned.

The development of ocean energy, to date, has focused on areas where attractive market mechanisms exist. In order for ocean energy to become a truly European development, then there needs to be appropriate support mechanisms in place across all the Member States with suitable ocean energy resource, to stimulate development.

"Progress is needed in countries without specific feed in tariff rates. Although Europe is making progress, clear mechanisms are needed to create and sustain the suitability for large scale deployment."

Despite the relatively advanced stage of the identification of suitable sites for wave and tidal deployment in UK waters, several developers were concerned at the cost of leases and permits due to the scale of the current leasing zones. The scale of the existing leasing rounds has been too large and too costly for many developers, preventing all but those with utility partners and strong OEM backing to progress with project development in tandem with technology development. Within the offshore wind sector, Round 1 leasing zones were intended for demonstration farms, Round 2 leasing zones were intended for moving into commercial arrays, while Round 3 represented fully commercial large array projects in challenging locations such as deeper water further from shore. This stepped approach needs to be followed within the wave and tidal sector deployment across Europe.

There is evidence to support additional leasing rounds, or permits, for smaller sites, where there is feasibility of smaller project developers or technologies being able to afford the costs, or where small multi MW arrays in the region of 5-10MW can allow staged development of several megawatt scale technologies in a particular region. It may indeed facilitate a greater likelihood of project development within a realistic timescale. It is perceived by many that there is a mismatch between the scale of leasing rounds and the current capability of the ocean energy sector, and it is imperative that viable areas of seabed can be attained by developers at a scale that is suitable for a realistic deployment trajectory.

"There are two main blockers [to ocean energy] deployment: The first is the release of viable seabed. The second is investment."

The leasing of large sites in the order of one hundred megawatts creates a large investment risk for project developers. While technology developers may be able to benefit from economies of scale in engineering production, the financing of a project of such magnitude will acquire significantly more debt than more modest sites of tens of megawatts. In addition, there may be an increase in the length of time taken for a larger project to reach profitability, given the capital intensive investment nature of ocean renewable energy projects, making investment decisions very difficult for project developers.

Several interviewees deploying technologies in the UK identified a lack of clarity around the application process for leasing areas of seabed, with many developers feeling that the process was too long and complicated, and lacked guidance. At an EU level, clarity needs to be provided on the application process for seabed leasing, streamlining the means by which application must be made.

> *"The application process is lengthy and complex, not ideally suited to facilitate ease of deployment."*

However, while most of the current deployment has been focussed around the UK, certain technologies being deployed elsewhere in the EU noted a relatively straightforward application process for permits and sea-bed leases, particularly when a short term application was made in the region of 5 years.

> *"Applying for the permits and licences was straightforward. The license is valid for 5 years, for demonstration and prototyping. The conditions of the license mean that we cannot leave anything on the seabed once the project is complete."*

This duration is appropriate for demonstration and prototyping, and facilitated a much smoother application process than permits for longer durations. It is notably more difficult to obtain permits for longer term deployment, however, there was no consistency in the level of effort required to obtain permits across the EU.

Some companies are questioning whether enough is being done to quantify the resource characteristics in leased sites within an appropriate timescale. There are sites that have been leased in the UK where very little work has taken place to understand the resource, and project developers may be sitting on sites without making progress in the necessary site resource characterisation work. There are developers within the industry that do not have access to sites for characterisation, who would like to see more progress at an accelerated pace from those who have acquired a lease.

> *"Governments should consider implementing a timescale or deadline for completion of defining the resource at a site, or the site should be forfeited to someone that will do the resource characterisation work more promptly."*

Technology developers did note a mismatch of funding – the level of funding made available to the ocean energy sector does not meet the level of expectation placed on the sector in terms of deployment capacity and performance. Policies in place across a number of Member States suggest high ocean renewable energy deployment targets, but there is not allocation of suitable levels of funding support mechanisms to allow initial deployments to take place.

It was the viewpoint of some that a bias towards large scale technologies had overlooked smaller players in the industry.

> *"If you don't have a 3MW array in the pipeline then there is no point in applying for funding, as you won't receive it. There should be consideration for developers of small scale technology that may also have array projects in the pipeline, as there is currently not a route to securing similar funding support as for the larger scale projects. It is an unfair bias against companies starting small."*

There was also concern expressed about the suitability of certain funding mechanisms and their ability to realistically provide a genuine impact to the necessary MW scale deployments needed within the ocean energy sector as a whole.

> *"MEAD [The UK's Marine Energy Array Demonstrator funding programme] is a technology [or, more accurately a deployment] accelerator – getting projects in to the water. The Saltire prize, although a good "Hollywood" motivator, is not realistically helping to accelerate project deployment."*

The Scottish Government have, however, incentivised development work to produce reliable and robust technology, as there are now understood to be five entrants vying for the £10 million Saltire prize.

3.1.5. Economic

As was discussed in the SI Ocean Cost of Energy Report [2], the current cost of ocean energy is too high, and the cost of energy must come down in order for the technology to be able to compete with other alternatives. Device developers are aware of this imperative, and there is recognition of the need to compete with 'competitors' such as offshore wind.

> *"The technology used in ocean energy needs to be competitive with offshore wind. Projects need to be commercially attractive to utility companies procuring the device."*

While not competing in terms of resource, the wave and tidal energy sector views utility companies as core customers of the product that they are developing. Utility companies have to make the investment decision on how they will fund clean energy projects. If a greater return on investment can be made from offshore wind than from ocean energy, then there will be a struggle to compete with the requirements of satisfying a drive to increase shareholders' return on investment. As a result, wave and tidal energy costs need to progress down the cost curve and demonstrate an ability to actively compete economically with offshore wind.

There is however, a balance required. In order to meet deployment targets, then deployment activity *must* take place. Cost reduction has historically been seen to occur as a function of deployment, and not a function of time. Although not competitive at current prices, there is a need for deployment of technology to allow learning by doing effects to take place, and this requires action at a European level to create attractive incentives to allow the first deployments to take place.

"To reach the [European ocean energy deployment] target you must do something. Someone needs to put money in to the sector."

The term 'investment' could relate to different funding processes and different sources, with investment being made at a technology level, or investment made at a project level. Both types of investment are necessary, but different investment is required at different stages in the development process.

Investment into technology developers could come through private shareholding, relating to equity in a company; this funding would help the early stage technical development of a project, and allow early prototyping to take place. Investment into projects could come through public funding, for example the Marine Energy Array Demonstrator fund in the UK (MEAD), which is driving commercial readiness, or the European NER300 array demonstration funding; this funding is required to help meet the vast investment costs and risks associated with developing an array of technologies. Once technology developers reach the stage of having a full-scale prototype, it is very difficult to find investors who are willing to take on the financial risk of the next step – deploying arrays of devices.

Regardless of whether a technology is seeking private or public funding, there is a temptation for developers to over-claim, causing potential damage to the reputation of the industry if promises are not delivered; however, there is also the dilemma that if investors or governments can't be convinced that there is likely to be significant outputs in a reasonable timescale, the funding will go elsewhere to technologies that can deliver (and make a return) in a shorter timescale.

There was some discussion surrounding the means by which companies are assessed for suitability in investment rounds and public funding calls.

"Device developers have to maintain a level of finance that implies that they are further ahead, or more capable, than they actually are. Often to reach the next funding level, the metrics of device scale, and level of progress towards a 'full-scale' commercial demonstrator take precedence, with device developers prematurely claiming to be capable of more than they are."

As has already been discussed, a mismatch exists between the expectations placed on the ocean energy sector, and the levels of funding that has been made accessible to the sector to date - whether it is through investment, or through government support such as 'technology push' or 'market pull' mechanisms. Without access to vital funding, technology developers are unable to reach their own aspirations, or that of government deployment targets.

"The Feed in Tariff rates across Europe are too low to provide enough support to make a project bankable."

Although feed in tariffs are a vital market pull support mechanism, in and of themselves they are not sufficient to secure financial close of a project. However, stronger market pull support mechanisms will reduce the level of funding that must be found from alternative sources. Unless favourable support mechanisms can be ensured in the long-term, there is a real risk of projects failing to reach financial closure.

There is a potential mismatch between the investment mind-set of some of the sector investors and the technology development mind-set within the ocean energy sector. While most technology developers are aware of a long term development trajectory, some potential investors may be more concerned about short term profits and rapid deployment trajectories.

"[There is a] conflict of interest within the current [ocean energy] investment set up. Investors want a high ROI [Return on Investment] for a risky project, but within its very nature, high ROI affects the LCOE [Levelised Cost of Energy] negatively, increasing the cost."

Unless appropriate investor expectations can align with realistic technology predictions, there will be a disparity between the capabilities of the sector and the expectations of investors. There will not be investor appetite for large scale investment in technologies if there are reduced deployment targets, or if the technology cannot meet the short term aspirations of investors. Due to the scale of the funding required by technology developers to complete array projects, private investment is unlikely to be able to meet the deployment needs of the sector. It is crucial that public funding be directed appropriately in support of the early array deployment, as without this support there is a risk that no array projects would be constructed.

However, from an investor perspective, it has been recognised by investors that the requirements of the ocean energy sector are greater than the capabilities of traditional sources of funding.

"More funding is required by the marine energy sector than Venture Capital can provide. The Venture Capital market has developed around software rather than complex engineering."

"Large corporate companies are the natural owners for [marine energy] device companies - engineering partners who can provide funding and technical expertise."

Device developers agree that the large engineering firms have a lot to offer:

"It is very important to have a big owner. This brings a lot of trust and security. If they [a large engineering company] promise something, then you know they can deliver it."

"Large companies can bring real experience and good engineering practice."

However, there are a large number of devices under development – it would be unfeasible to suggest that all companies would receive attention from large engineering firms. While some large engineering companies have been taking active involvement in the sector at an early stage, it may be expected that other OEM companies would consider taking a bigger involvement once the technology is more mature and they can be convinced of its commercial suitability – this will drive design consensus.

It was felt by many technology developers that the investment community may be unable to see beyond a desire for short-term profit, and as such was placing pressure on the ocean energy sector to deliver results at a rate in which it may not be capable of achieving. The investment mind-set of making quick returns on investment does not suit the wave and tidal energy industry.

"The behaviour of investors can be damaging, either through expectation of short term profits creating unrealistic expectations, or for being unwilling to invest due to lack of return on investment."

Clearly, there is some conflict of interest between investor requirements and the needs of technology developers. Technology developers more readily recognise the long-term nature of the sector, both economically and politically, but investors have been a part of the ocean energy sector, and have themselves learned some lessons.

> *"There was repeated disappointment in the early stages with marine investments - technology didn't work or didn't reach cost targets. The natural sources of Venture Capital investment have been disappointed and won't invest again."*

High risk and low return is never going to be a desirable prospect for Venture Capital funds that are required to make returns for their investors. Because of the high risk of failure - which could mean losing most, or all, of the investment (not just getting low returns) - the expected returns from ocean energy projects will have to be very high so that successes can balance out failures.

At a European level, the NER300 funding support mechanism has been set up to establish a demonstration programme that will allow the construction and deployment of a range of leading Renewable Energy Systems projects and Carbon Capture and Storage projects. This mechanism will involve all Member States of the European Union. It is envisaged that the NER300 funding will also help to leverage further private investment and co-funding from national governments across the EU.

Within the ocean energy sector, NER300 applicants are required to develop an array of 5MW or greater. In the tidal energy sector this deployment eligibility criteria may be appropriate, as each individual device is capable of producing up to 1MW and 10MW array demonstration projects are already in the development pipeline; in the wave energy sector there is some concern that the set criteria are difficult for the sector to meet.

> *"In our opinion this [5MW requirement] is too large. A 2MW or 3MW requirement would have been ok."*

In a sector where devices or technologies have operational data spanning the order of weeks or months, it is difficult to provide long term power predictions to any significant degree of certainty. The step up from a single demonstration device to an array of 10 or more creates significant uncertainties in the estimates of the level of production that will be achieved.

The stipulation of the NER300 funding requires that technologies produce at least 75% of the electricity output that was predicted when making the application. If this production target is not met then NER300 will not pay out. The focus of this funding is on reliability, and the proving of reliable device and project operation. The penalty for failing to meet 75% of the original target is severe, and there is a significant technological challenge - especially given that, in some cases, there have been no examples of long term device operation and power production that could provide developers with confidence of performance.

All developers, across both wave and tidal energy technology, unanimously agree that at present there is not enough funding available to support the development needs of the sector. In order for extensive progress to be made in the sector there is a requirement for extensive investment, due to the extensive costs associated with deployment at an array scale. Customers of technology development companies, such as utilities, who can foot the present development bill do not exist, and as a result there is a need for alternative support mechanisms to enable the first generation of array deployments to take place.

> *"Technology development is expensive and private investors do not want to invest a lot of money for technology development, it is a risky business."*

> *"We are at the stage of going towards a small pre-commercial farm, but to find a customer who would pay the whole bill is impossible in practice. Financial support, like EU funding programs, is critically needed [for this sector to advance]."*

While funding is necessary in the early stages of technological development to allow a device to reach the proving stages, continued financial investment in a technology, whether it is through shareholder investment or through government support, should be targeted at technologies that are shown to perform reliably, with increasing levels of electricity generated cost-effectively. Technology progress needs to be tracked more accurately using quantifiable targets rather than device capacity, or Technology Readiness Level (TRL).

Across the sector, there is evidence to suggest that many companies are operating as if within a commercial marketplace. While there are advantages to a commercial attitude, such as a drive towards cost reduction, and forward planning for mass unit production, the attitude of acting commercially without actually being a commercial entity could be a danger to the sector. The commercial mind-set of device and technology developers may be harming development by slowing down the rate of progress and creating barriers to knowledge transfer, as has been expressed by project developers:

> *"There is a competitive commercial mind-set of the device developers, where there seems to be a commercial mode of operation, but without a commercial product. This unusual situation causes closed doors, and a lack of knowledge sharing. There is currently not a market for tidal energy: there is no market to protect – yet."*

By aiming to protect a perceived 'share of market', closed door operation and lack of transparency from technology developers could be stifling growth within the sector. Despite having access to public funding, very little information is made accessible to the public, on items such as electricity generation, or maintenance and downtime duration and cost.

To tackle the issue of knowledge sharing, Member States across the EU could implement common clauses within funding contracts that stipulate a requirement for sharing of certain information. Governments have a strong role in ensuring that the correct data is shared.

There is a different approach to funding in Denmark when compared to countries such as the UK, with requirements for regular reporting and transparency as conditions of funding within the ForskVE and ForskEL-programmes run by Energinet [4]. This approach to funding also creates much stronger collaboration links between industry and the research sector, and has been positively received by both the developer and the research institutes involved.

> *"The Energinet funding provides continual motivation to improve machine performance. Payments are made when a machine exceeds set targets. Documenting increased and*

improved performance is important in terms of proving the concept to the funders as viable for continued investment."

There are many challenges facing the ocean energy sector from an economic perspective, and while there will be a requirement for significant investment in R&D and project development, there may need to be changes to the conditions in which funding is awarded, creating more transparency and collaboration between different devices, technology, and project developers.

3.1.6. Environmental

The theme of environmental impact is recognised as a significantly important area within project and technology development. There are challenges, particularly surrounding the difficulty of obtaining permits for carrying out prototype testing prior to larger scale deployment. There are many issues within the topic of environment that are causing delay to projects, and the lack of an efficient mechanism to facilitate deployment of test devices or arrays is causing lengthy setbacks on a par with grid connection issues.

Of primary concern is the scale of environmental impact envisioned by project and technology developers. While it is understood that there is a need for environmentally responsible development, there is a distinct lack of perspective from environmental and regulatory bodies when it comes to the issue of prototype deployment. While large scale deployments should be required to carry out a full suite of environmental impact studies, it is felt that the requirements for solo devices are far too stringent, and expensive, potentially being a show-stopper for innovation.

> *"The existing environmental legislation is almost prohibitively expensive and is stifling innovation, and the progression of deployments. As long as there are no toxic substances, no oil leaks, and no hazard to human activity and shipping, then there should be some relaxing of legislation to allow prototypes to develop, and be refined. Upon reaching a more mature phase of deployment, when multi megawatt deployment is a reality for the device, more stringent legislation could be enforced"*

A number of device developers struggle to consolidate a need to fund technical R&D work with an ever increasing expense associated with environmental monitoring. By putting things into perspective there should be a more reasonable solution employed that can allow prototyping and device proving, without the environmental regulations causing too heavy a financial (and time) burden for developers, which are currently potentially causing the expenditure of funding and effort that could be more appropriately allocated to technology R&D.

Even when significant environmental work is undertaken at a site, the impacts (or lack thereof) are often ignored when there is a requirement to assess the environmental impact at a new site – with an entirely new suite of environmental works to be carried out. Environmental impact assessments have to start from scratch, creating new baseline information, despite significant findings at other locations being able to provide evidence that environmental impact is benign.

> *"Once EIAs have been done for several projects it would be useful to re-use relevant material for future sites rather than starting from scratch with every new application. The time and*

economic constraint [of having to start new environmental impact assessments from scratch at each new site] is delaying projects. There needs to be more efficiency"

Pooling of environmental impact data and information should be more widely adopted, particularly at the nascent stages of device development to improve efficiency. Similarly, evidence at existing sites should be considered relevant for the environmental impact at new sites, as information on the environmental impact of a device or technology that is installed has significant value when compared to perceived or estimated environmental impact of a device that has not yet been installed.

"The smaller the impact that a particular device has on the environment, the harder you have to look/work to detect an impact - Therefore the more you need to spend"

"Quasi-quantitative and pseudo-scientific environmental assessment techniques are of limited benefit to the development of ocean energy technologies at this stage in the development process. Environmental legislation is a good thing, but only when appropriate situations and scenarios are considered. Significant cost savings could be made by relaxing the environmental regulations during the development process of conceptual devices"

Despite the concerns over cost and time, it was recognised that there have been improvements in the way that process is handled, particularly in Scotland with the 'one-stop-shop' approach in place with Marine Scotland. This could be used as a template for the licensing process in other regions across the EU.

"The single biggest support mechanism that has helped the wave and tidal sector is the Marine Scotland Licensing system. This system relieves developers of the administrative burden, and streamlines the consenting process significantly. The exceptional improvement in this system is thanks to the support of the Scottish Government. Previously there were 17 different stakeholders that a developer had to approach. Now Marine Scotland offer a one stop shop"

However, both inside and outside of Scotland there are still some challenges in the consenting process. The industry as a whole requires a consolidated and more straightforward permitting process. The difficulty in obtaining permits is cited by many as a hindrance to development and innovation.

"Consenting remains a challenge – [the] precautionary approach assumes there is an environmental impact until it is proved there isn't"

"The industry needs a much more simplified and straightforward consenting and permitting process, as this causes significant delays in projects"

With the ocean energy sector representing a new and emerging technology, there are often occasions where consultations are required with stakeholders that do not fully understand the nature of the technology. There needs to be a greater level of understanding, at a technological perspective, from those who are making the decisions on the permitting process.

> *"The permitting process is difficult due to the uncertainty of the product – permit authorities in certain EU countries had never heard of tidal stream turbines before an application was made. [It is] Difficult to deal with environmental groups who have little or no understanding of the technicalities of a specific ocean energy device"*

In order to improve the understanding of the environmental impact of the technology, there is no substitution for data that has been collected from an environmental monitoring programme – those responsible for the licensing and permitting of new technologies need to be able to apply appropriate and equitable environmental policies and regulations, otherwise there is a real risk of delaying, if not preventing, technology development and innovation.

There is an opportunity, therefore, to improve the sharing of environmental data across the sector, and improve the level of understanding of the environmental impact, both between device developers and regulatory bodies.

3.1.7. Engineering and Design Tools

Engineering and design tools have helped aid the development and progression of many sectors in the past, but a more direct comparison can be drawn up with the experience of the wind industry. In the early stages of wind energy development, several large capital projects created large MW scale wind turbines, that ultimately proved to be unreliable and beyond the capability of the early sector; the projects did, however, create engineering tools that improved the technical and scientific understanding of the interactions between the wind turbines and their operating environment [3].

Utilising both computational tools and structural and performance measurements, the understanding of machine performance in a given environment can be rapidly increased. The development of standards and guidelines from certification bodies will also help to enhance the level of understanding of the challenging operating conditions within the ocean environment.

However, caution must be advised. There is no quick fix to creating industry relevant modelling tools, and the use of wind industry software modified for fluid properties of water does not necessarily produce desirable outputs.

> *"Utilising wind turbine software and changing the fluid density does not take into account things like added mass and other dynamic effects that are experienced within the marine environment, but not in wind. The numerical simulation needs improving as models do not provide reliable representations of what is actually experienced at sea"*

There is a need for tool and strategy development to take place hand-in-hand with actual device deployment, such that the measurements taken from at sea deployment provide validation for the tools that are being developed for the sector. Validation based on a single device output at one specific location does not imply that the model will be valid for other deployment locations, and so multiple sources must be able to feed into the validation process before there can be a degree of certainty in the ability of the tools and strategies to provide adequate and credible results, and thus aid future development of projects.

For this to take place there needs to be buy in from multiple project and device developers. Waiting for the answers to fall into place without proactively doing any work to help provide the solutions is not an advisable approach, and this is becoming apparent to project developers.

> *"It is naïve for project developers to be passive and wait for others to do work and produce results, and they can't assume that results will just come to them. Project developers need to take an active role in research projects, guiding, shaping, learning, and sharing knowledge. The future growth of the industry could benefit greatly from less passivity and greater active engagement"*

There are existing databases in place that, although offering a good concept, were not providing the user with the ease of access that had been hoped. One developer commented on an existing knowledge sharing database tool [5], and the need to populate it with more data and information.

> *"The information bank does not have much data or information going into it. There needs to be an agreement as to what data should be shared by all developers. For example, ecology and environmental data should be shared [without infringing on anyone's technological patents or IP]."*

More needs to be done to engage the developing ocean energy sector, in a way that will bring cooperation from all technology developers, rather than just a select handful. This may require step changes in thinking from technology and/or project developers, but there is a stark warning from one developer to all technology and project developers, to warn against complacency and fear of change. The wave and tidal sector to date has promised much, but achieved little in terms of cumulative deployment. Progress has been much slower than anticipated, with a significant risk of being unable to meet deployment targets. This is causing re-evaluation of the deployment targets, such as in the UK where the 2020 deployment target has been adjusted from 1300MW to 130MW (see Figure 5). There is a requirement for the sector to improve on what has been achieved to date.

> *"This unique window of opportunity may not deliver."*

If the wave and tidal sector wants to be taken seriously, then it must produce results, it must be more transparent, and it must be realistic about what can and cannot be achieved. The IEA Vision Document has forecasted that a global capacity of 337GW [6] wave and tidal energy is possible by 2050, so there is plentiful opportunity for development; however, it is only with collaboration, and much greater levels of proactive cross-sector engagement, that such a large target can be met.

3.2. Sector Engagement Workshop

The workshop and supply chain event was an enabler in bringing together three key parties in ocean energy development and deployment – technology developers, supply chain companies, and utilities. Between presentations from industry, significant scope for discussion presented itself, revealing some of the most challenging and pressing issues facing the industry. While there is a real sense of urgency in the need to get the emerging ocean energy sector off the ground, there are conflicting viewpoints and priorities that must be resolved in order for the sector as a whole to reach consensus and allow a structured approach to the removal of barriers. While the European ocean energy sector is well placed to capitalise on first mover advantage, there is a real risk that this unique window of opportunity may not deliver if complacency and lack of appropriate action fail to produce tangible outputs and progression that demonstrate a maturing ocean energy sector. This section will identify and discuss some of the findings from the SI Ocean workshop.

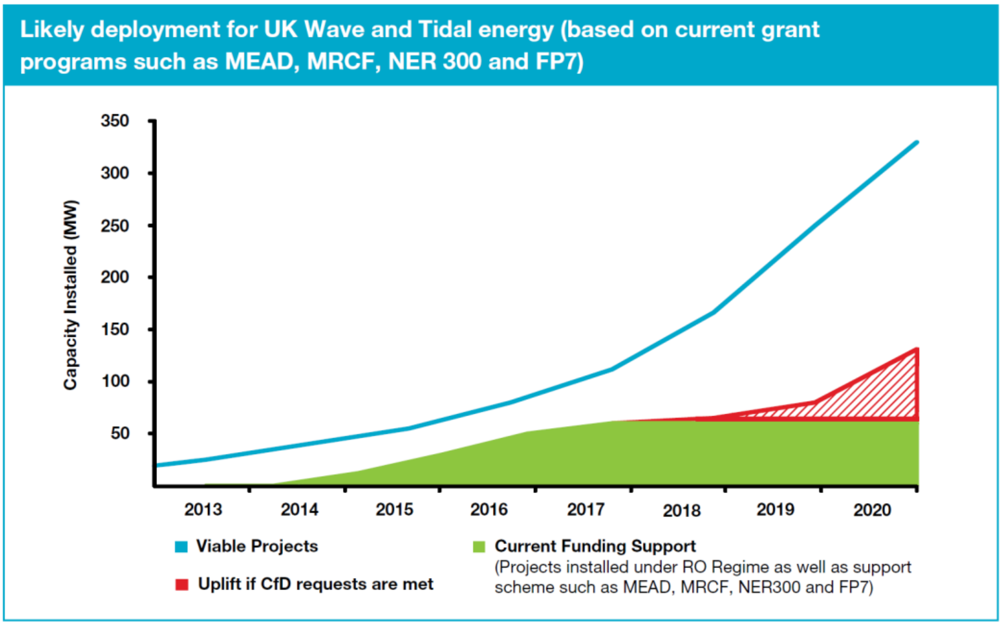

Figure 5: UK Likely Deployment (Source: RenewableUK)

3.2.1. Urgency

The UK is currently leading the rest of the EU in terms of ocean energy deployment. While the trajectory identified in Figure 5, above, is likely to be replicated in other EU countries with an ocean energy resource, the initiation of deployment in locations outside of the UK will be at a later date.

There is a great sense of unease amongst supply chain and technology companies, and a real sense of urgency in the need to get the fledgling ocean energy sector off the ground and into the water. A key source of the unease and a driver for urgency is the revised assessment of the 2020 ocean energy deployment target within the UK. The UK National Renewable Energy Action Plan[2] (NREAP) created in 2009 projected a deployed capacity for wave and tidal energy technologies of 1300MW. In 2013, RenewableUK reassessed the deployment targets, based upon projects currently under development within UK waters, and advised that a more likely deployment trajectory could see only

[2] National Renewable Energy Action Plan for the UK, Article 4 of the EC Renewable Energy Directive https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47871/25-nat-ren-energy-action-plan.pdf

130MW of cumulative wave and tidal energy deployment by 2020[3]. This revised scenario represents a share of 10% of the original deployment target. While a portion of the original estimated £5 billion investment would incentivise any supply chain company to add value to a growing industry, the more realistic forecast has resulted in a scenario where the supply chain feels that there is *"not enough likely installed capacity to make a business case*".

The lack of drivers for supply chain investment mean that companies with the capability of building prototypes or solutions to the challenges faced by the sector are not able to deliver; there is no ability to make a commercial return from such a development. A poignant warning for the ocean energy sector, issued by one of the supply chain companies present at the workshop, now exists:

> *"[It is] paramount that the latest predictions [of installed capacity] are met – if they are missed this time around, the industry will not get the backing of the supply chain.*"

3.2.2. Innovation vs. Commonality

The wave and tidal energy sector suffers technological fragmentation, with many stakeholders working on individual in-house developed solutions for a wide range of activities along the supply chain. With every new design and technology there is a significant engineering requirement in Non-Recurring Engineering (NRE). NRE, design work, is a one-time technical effort made for the innovative design and development of a new product or service. The cost of design for a new product will inherently result in high costs compared to a product that is the result of standardisation.

The chart shown in Figure 6 displays an example of costs attributed to the creation of a certain hypothetical product. The cost of the initial product will contain the development costs associated with the design, and also the manufacturing cost.

Within this product, design costs will occur at the beginning of the project and product lifecycle. Once completed, the design should not require significant further engineering work, and so the cost of future products to the same design will be lower than the cost of the initial product.

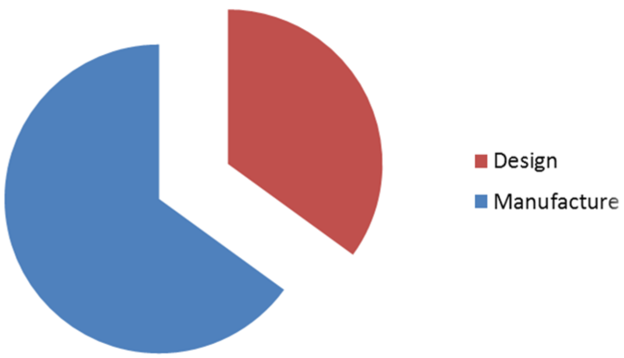

Figure 6: Innovation or Standardisation? NRE Costs in Design

[3] Wave and Tidal Energy in the UK, Conquering Challenges, Generating Growth, RenewableUK (February 2013)

Within wave and tidal energy, there has been continued requirement for NRE within device designs. Despite the high costs associated with initial pre-commercial demonstration units, there is a significant level of NRE effort associated with each design iteration.

There is a need for greater levels of commonality in order to reduce the cost of energy, and allow for a greater market potential if a new product solution was to be developed. There are certain areas that could utilise commonality across a range of technology developers, such as foundation or mooring design, or design of nacelle quick connections and latching systems (for tidal). Reducing the level of NRE needed for ocean energy systems will help to significantly reduce the overall cost of the product. This needs the buy in from multiple technology and project developers, and component suppliers - it will not work without collaborative effort.

Indications from the supply chain suggest that there is a change in focus of the business strategy from a market based strategy (how big is the market? How much value is there in developing products for this market?) towards a product based strategy, whereby development of a product that could serve multiple sectors - including, but not limited to, the wave and tidal sector - will be of more interest in the longer-term than bespoke pieces of equipment with high NRE. This suggests that the supply chain could consider developing strategies and enabling technologies for the ocean energy sector by identifying markets for these potential future products within established industry markets.

Device developers are generally small scale companies, and IP power is very important to them; they are reluctant to give up IP as it is seen as important to keep the information in house. However, a balanced approach needs to be taken.

On the whole, there is agreement within the sector that collaboration is desirable, but there needs to be progression from 'talking about collaboration' to actually carrying out collaborative projects. The biggest barrier to collaboration is Intellectual Property (IP) and arguments over ownership of generated IP. While the nature of IP needs to be respected, barriers that slow or hinder the progression of the ocean energy sector are undesirable. At present there is an over-protective attitude towards IP, one which causes a breakdown in collaboration. The focus should not be on generating IP for personal gain, but more compromise on producing solutions that benefit the sector as a whole.

There will, of course, be strategic areas in which developers are not willing to collaborate, as private investors will generally insist on some IP protection in order to protect their investment and prevent anyone from copying their idea, however, these need to be considered carefully so that they do not hinder the overall development of the sector.

3.2.3. Enabling Technologies for Array Deployment

A stalemate situation arose regarding the topic of the best strategies for deploying the first arrays – the enabling technologies that will aid the development and deployment of devices. The sector knows how to install single devices, but there are still a large number of unknowns when it comes to array deployment. While it is necessary to have the correct equipment, technologies, strategies, and tools to allow safe and efficient deployment and development of the ocean energy sector, at present the wave and tidal sector does not have access to the optimal strategies to facilitate bankable deployment: What the industry has at present may not be the most effective route to build out projects. This is a catch 22 situation: To develop the correct strategies we need an industry; to build an industry we need the correct strategies.

Industry enabling technology may result from early adoption to get devices *"into the water"*, which has already identified some drawbacks and limitations to existing technology – such as ROVs, current designs of which are not suitable for use in tidal stream environments. While there may be complex solutions to the challenges, the industry needs to start simple by getting technology into the water that works.

On the other hand, a rush to install and deploy devices could be a threat to the sector, as this was seen by some as akin to trying to "*run a long distance marathon before we can walk"*. By developing technology in tandem with projects, some of the focus on the technology development is lost, potentially inhibiting innovation –a potentially risky strategy.

It was pointed out that the early offshore wind sector utilised onshore turbines mounted on a suitable offshore foundation. Problems resulted, and offshore specific turbine technology is now developing in tandem with offshore projects. Learning by doing is facilitating the growth of the correct deployment strategies in the offshore wind sector.

To resolve this barrier in the wave and tidal sector, there must be better engagement between the solution providers (the supply chain) and the end users of the equipment (wave/tidal technology developers and project developers); there are companies with the capability to design and build, given the appropriate level of commitment from potential customers. At present, there is a real risk that different developers could be asking the supply chain for their own unique bespoke equipment to resolve their own challenges. There is a real problem with this in the high NRE costs, as outlined in Section 3.2.2. More collaboration (at an early stage) between technology developers, project developers, contractors, and the supply chain is required in order to prevent multiple pieces of expensive bespoke solutions. In particular, some challenges that must be addressed by the sector include:

Maintenance intervals - what are *realistic* maintenance intervals, and can these maintenance intervals be guaranteed? The main limiting factors in selecting a maintenance interval must be acknowledged - demonstration of a greater awareness of Mean Time Between Failures (MTBF) for sub-components in use within the system, or making use of a failure database to log issues across the wider sector would help bring confidence in long maintenance interval projections.

Access for maintenance - this is fundamental for any retrieval and maintenance operation, and economic access solutions must become available in order to reduce the LCOE for array projects.

Design for maintenance - within individual technology types, design remains fragmented, with different options available from different technology developers. The most cost effective solutions may eventually see convergence from within the sector, but this needs to happen in short-term time scales through collaborative effort in order to maximise opportunity for supply chain involvement. The merits and drawbacks of each method may have to result in a compromise, as technology and environmental requirements may have differing priorities.

Vessels - these have, to date, divided opinion: while some developers have been happy with their chosen installation vessels, others have remarked that below-expectation flexibility and very high cost show that not all oil and gas vessels are optimum for the sector. While projects are underway to investigate the design and development of wave and tidal specific vessels and barges, there needs to be active collaboration between device developers and the technology solution providers to ensure that the outcome of these projects is what the industry requires. Additionally, certain developers are looking towards smaller scale or buoyant designs to remove the need for heavy lifting vessels altogether, utilising small multi-cat workboats that are less expensive than their larger installation vessel counterparts.

3.2.4. Responsibility for Risk

A hurdle facing the development of ocean energy is the burden of risk. As with any new and emerging technology, there is a risk associated with development and deployment. At present, there are few willing to take the risk for the construction of the first ocean energy small array projects. Investors are not willing to take the risk alone; technology developers cannot bear the cost burden and risk alone; it is difficult to find supply chain partners that are willing to take on the risk.

The industry needs to be careful, and cannot expect *"magic wands to be waved"*, resolving the issues of risk. To tackle risk, there cannot be a neutral stance: stakeholders can no longer sit in different corners and point fingers at one another, passing on risk to other players. At present, no one is taking the risk. There needs to be collaboration between the industry, public sector, and government to overcome this risk adversity.

There are opportunities for risk reduction before engaging in offshore activity, as there are several test centres and facilities across the EU where on-shore component and sub-system level testing can be carried out prior to off-shore deployment. Existing test facilities include drive train testing, blade testing, and electrical systems component testing. Test facilities are available for Accelerated Life Testing, and system integration testing, both of which could offer increased confidence in technology prior to deploying it in the offshore environment.

Another risk cited by project developers is the need for performance guarantees: The bankability of an ocean energy project is fundamental in allowing continued development and deployment, and performance and availability guarantees are fundamental requirements in wind farm projects. While few, if any, wave and tidal technology developers are in a position where they can financially or physically offer performance guarantees, the outcome of testing and deployment of pre-commercial demonstrators should result in performance and availability proving. This information needs to be more transparent to the project developers who could utilise technology in sites under development, and is an area which must be improved upon.

With capital intensive equipment necessary for the preparation and installation process of device deployment, there was some question as to who should bear the responsibility for ownership of the equipment, and who bears the cost burden of the development. With the uncertainty about future market size, no supply chain company will invest in enabling technology development without the backing of a consortium of partners who can share the risk and cost burdens.

In the current state of play, many technology developers might benefit from focussing on their core technology, rather than trying to achieve system perfection through their own resources. This could share risk, and prevent re-inventing of the wheel, whereby different sub-components are developed through collaborations with the correct industry partners, creating more collaboration rather than stifling innovation.

3.2.5. Knowledge Transfer

As a renewable energy technology that has gone through a period of significant learning, there are lessons to be learned from the wind energy sector that are applicable to the wave and tidal industry. One particular warning was 'how not to engage the supply chain': An offshore wind supply chain gap analysis report, carried out in the UK in 2013 by The Crown Estate, identified sub-sea export cables as a high risk area in both installation and cable protection. According to leading companies within the sub-sea cable and cable protection field, they were not consulted for their input in suggesting a resolution to overcome the identified barrier, despite the wealth of offshore cabling experience available. The right people need to be approached, and appropriate guidelines implemented, to avoid a repetition of this supply chain scenario in wave and tidal.

As was discussed previously, the emerging offshore wind sector placed onshore wind turbines on offshore foundations, with severe reliability consequences. Much more work was required to marinise wind turbines than was initially thought, with current offshore turbines now having been engineered from the ground up as offshore specific. Caution must be advised to the offshore wave and tidal sector, as project developers perceived it to be unrealistic to think that wave or tidal energy technology could be brought to maturity quickly. With a more challenging operating environment, the wave and tidal sector will need to work harder than offshore wind in order to bring the costs down.

Figure 7: Beatrice Offshore Wind Demonstrator

Although offshore wind, and oil and gas industries are often referred to when the topic of learning from relevant industry is discussed, it must be remembered that wave and tidal energy technologies are very different to technologies developed for the oil and gas sector. Without the same capital spending ability as oil and gas, offshore renewable energy developments need to be more cost conscious, and there must be innovative new thought processes and ways of working together that recognise that the industry does not have high profit margins – the ocean energy sector cannot afford to follow in the footsteps of oil and gas.

Offshore oil and gas platforms often adopt bespoke applications or designs. The renewable energy sector must focus more heavily on commonality as opposed to bespoke systems and applications. The deployment of multiple similar devices will rely on common components, methods and procedures in order to maximise the efficiency of an accelerated deployment trajectory at a cost that is affordable to the sector.

4. Technology Development Activity Prioritisation

There are several themes and activities that require further research and development within the ocean energy sector in order to allow technology progression towards a more mature industry. However, there is not sufficient funding to be able to carry out each and every one of the necessary technology development activities in the short term; some activities are more urgent, and therefore necessary in the short-term, to allow cost effective systems and deployment. As a result, the list of activities that has been analysed and developed within this section of the report has been prioritised to identify those activities that must be addressed most urgently.

The technology themes and activities listed in Table 1 are the result of a blend of information from multiple sources including the technology and project developer interviews, the supply chain workshop, and feedback from the Advisory Board.

Following on from consultation with funding bodies involved in the support of ocean energy projects, a list of identified technology development themes (bold white text) and activities (*black italic text*) was drawn up to represent the current technology development needs of the wave and tidal sector, as shown in Table 1 below. Each technology theme contains a number of sub headings (activities), which could then be graded across a range of metrics in order to prioritise the most urgent technology development needs, and identify the responsible actors who are crucial in developing each activity in order to provide a solution.

Table 1: Technology Themes and Activities

Device & System Deployment	**Sub-systems**	**Design & Optimisation Tool Development**	**Arrays**
Performance Data Collection	*Control Systems*	*Design Optimisation Tools*	*Offshore Grid Design & Optimisation*
Knowledge Transfer & Dissemination	*Intelligent PMS (Predictive Maintenance Systems)*	*Device Modelling Tools*	*Array Electrical System*
Economic Installation Methods	*Power Take Off*	*Reliability Modelling Tools*	*Sub-sea Electrical System*
Economic Recovery Methods	*Power Electronics*	*Environmental Impact Assessment Tools*	*Array Interaction Analysis*
Connection / Disconnection Techniques	*Device Structure*	*Site Characterisation Techniques*	*Offshore Umbilical / Wet MV Connectors*
Pre-commercial Device Sea Trial	*Hydraulic Systems*	*Resource Analysis Tools*	*Reliability Demonstration*
Pre-commercial Array Sea Trial	*Cooling Systems*	*Array Design & Modelling Tools*	
Design For Maintenance	*Bearings*	*Techno-economic Analysis Tools*	
Novel System Concepts	*Foundations & Moorings*		
Sub-sea Preparation Work			
Vessels			
Reliability Demonstration (Device & Sub Component)			

The prioritisation allowed quantitative results to be acquired from qualitative descriptions. The assessment was robust and used evidence based information in order to justify the scoring allocation.

In order to assess the funding prioritisation, each activity was graded according to four sets of metrics. One set of metrics represented the needs of the ocean energy sector and how greatly the activity could impact a range of sector requirements; the remaining three sets of metrics represented the SI Ocean identified enablers, or key actors, who could deliver the identified activities:

Government: The activities that can only proceed with funding interventions at a Member State or EU level;

Industry (Technology Developers and Supply Chain)**:** The activities best suited for technology developers and/or supply chain leadership;

Research Facilities: The activities that require fundamental underpinning research using the skills, facilities and capabilities of research institutes.

Although various actors have been identified, ***there is a duty for governments to ensure that the industry and research sectors are adequately resourced to take on their responsibilities*.**

Scoring each activity on the above metrics resulted in four overall values for each activity: a "Fit to Industry Need" score and three "Enabler" scores covering Government, Industry and Research. The score for each activity was normalised to give a value out of 100 in each metric. By plotting the "Enabler Score" as an x-axis value and the "Fit to Sector Need" as a y-axis value, each activity could be visually represented as a point on a 2D chart. The location of each data point on the chart identifies whether the activity falls within Attention Area A, Attention Area B, or Attention Area C, as explained in Figure 8 below.

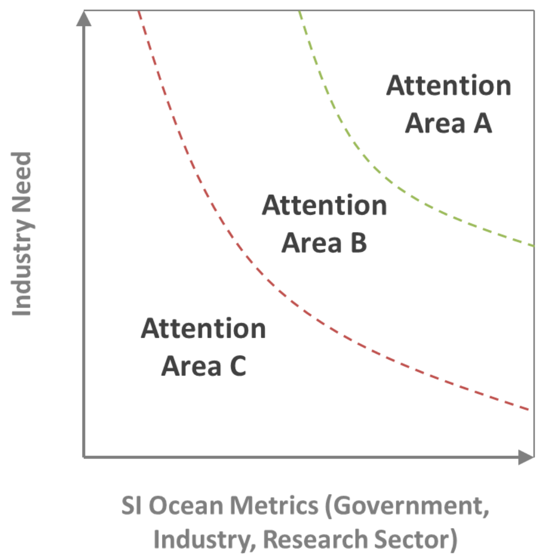

Figure 8: Technology Prioritisation

- “Attention-Area-A” represents activities that should be targeted as highly suitable for intervention;
- “Attention-Area-B” represents activities that are of medium suitability for intervention;
- “Attention-Area-C” represents activities that, while still important for meeting the development needs of the sector, are not immediately suitable for intervention by a particular actor in the short-term.

Scoring was carried out for all activities within each of the technology themes, and for each actor (Government, Industry, Research), resulting in the graphs identified in the following sections of the report.

The prioritisation, in essence, reveals the stakeholders who must engage in order to progress and advance the knowledge of each development activity. Certain activities may fall under the responsibility of one stakeholder, for example, performance data collection requires the industry to take responsibility for leading projects that capture appropriate measurements, and that these data are analysed to provide value and growth in knowledge and understanding. Other activities, for example economic recovery methods, require both buy in from industry (acknowledging a need, initiating collaboration) and government (to provide the necessary financial and policy support that will facilitate development of this activity).

A number of charts will be shown on each of the following pages. The charts are arranged in sets of three, and will be in order of:

- **Government;**
- **Industry;**
- **Research**.

Each ‘set’ represents one of the technology themes:

- **Device & System Deployment;**
- **Sub Systems;**
- **Design & Optimisation Tool Development;**
- **Arrays**.

The charts will identify which activities should be targeted by each of the actors for intervention, and a brief summary overview will be provided after each set of charts.

Device and System Deployment

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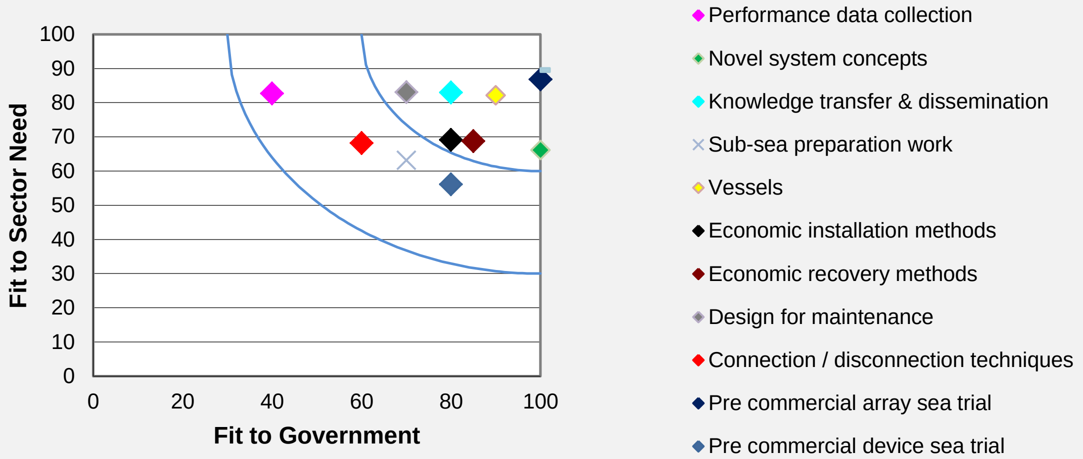

Figure 9: Device & System Deployment – Government

INDUSTRY:

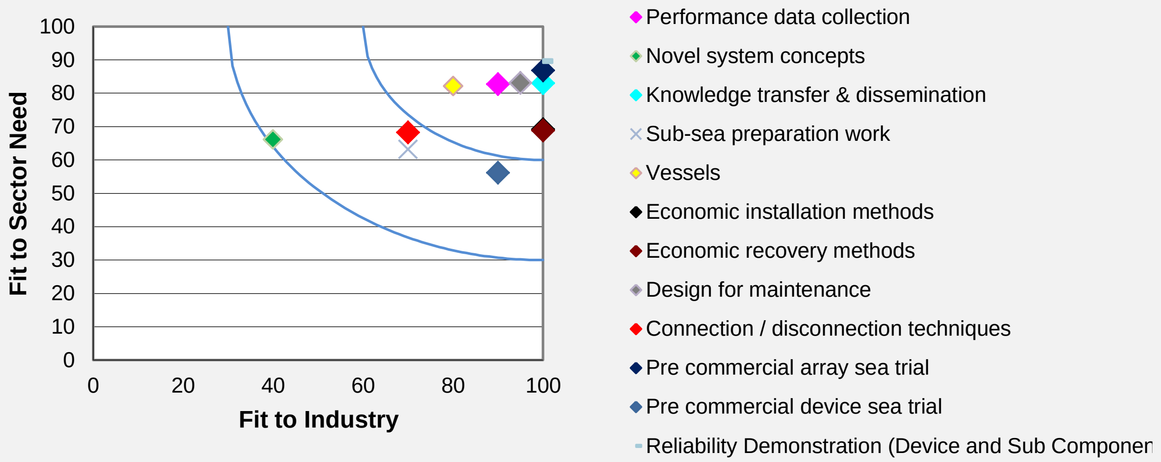

Figure 10: Device & System Deployment – Industry

RESEARCH:

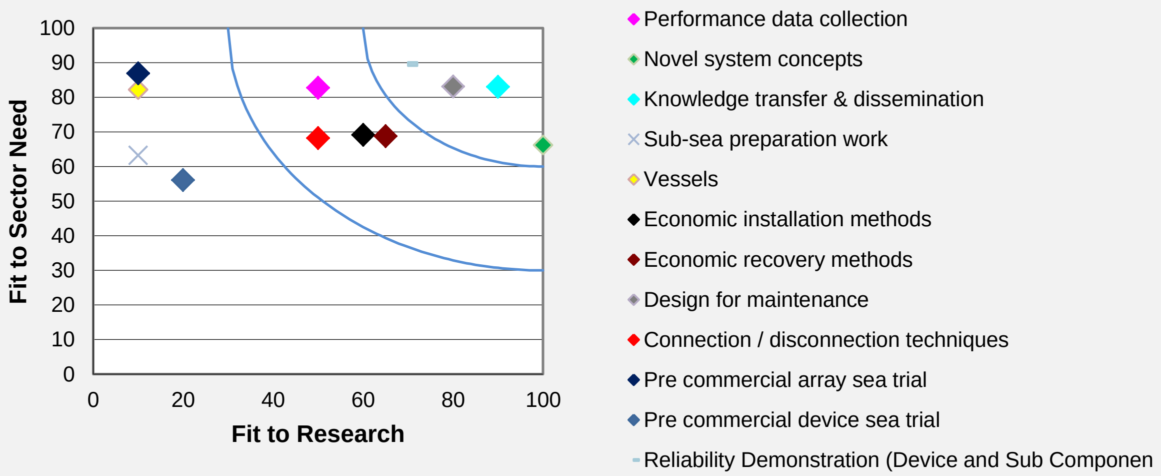

Figure 11: Device & System Deployment – Research

Device and System Deployment

Device and system deployment contains a suite of activities that will benefit the sector in a number of ways, positively impacting the cost of energy through reduction of CAPEX and OPEX costs, or improving the performance (and measurement thereof), or creating optimised enabling technology to facilitate the future growth of the sector in a progression towards array deployment. With an aim to identify the relevant actors in developing each of the activities, the three graphs will be summarised to extract relevant information.

The **government** chart identifies that all activities within the device and system deployment theme are either high or medium priority for funding support – that is to say that all the activities within this theme, to a greater or lesser extent, will require investment stimulus from EU level, Member State, or local government in order to advance knowledge in the area. The most urgent priorities for government support cover the activities of:

- ***Pre-commercial array sea trial;***
- ***Reliability demonstration***.

Topics such as knowledge transfer & dissemination, design for maintenance, economic installation/retrieval techniques, vessels, and novel system concepts also reveal that there would be significant benefit from government funding to stimulate investment in solutions for these challenges.

The **industry** chart reveals a closely nested cluster of activities in the high priority region. The most urgent priorities for industry leadership cover the activities of:

- ***Pre-commercial array sea trial***;
- ***Reliability demonstration;***
- ***Knowledge transfer & dissemination;***
- ***Design for maintenance;***
- ***Performance data collection***.

Closely linked topics such as economic installation/retrieval methods and vessels also score highly in the requirement for industry leadership.

Four topics were identified as high priority in the **research** prioritisation:

- ***Reliability demonstration;***
- ***Design for maintenance***;
- ***Knowledge transfer & dissemination;***
- ***Novel system concepts***.

In the identified areas, the research sector has the skills, resources, and infrastructure to help increase knowledge and state of the art.

Topics that scored highly in all three Device & System Deployment charts include **knowledge transfer & dissemination**, **design for maintenance**, and **reliability demonstration**. These topics would be suited for significant cross-sector collaborative opportunities.

Sub Systems

GOVERNMENT:

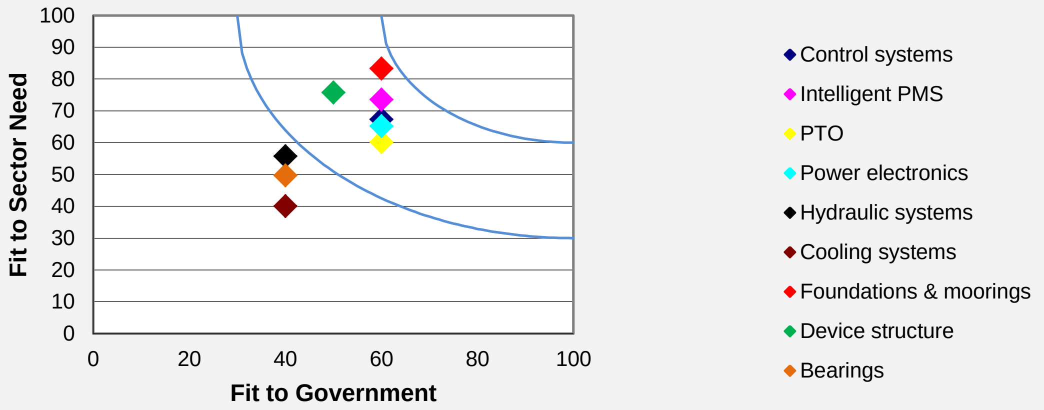

Figure 12: Sub Systems – Government

INDUSTRY:

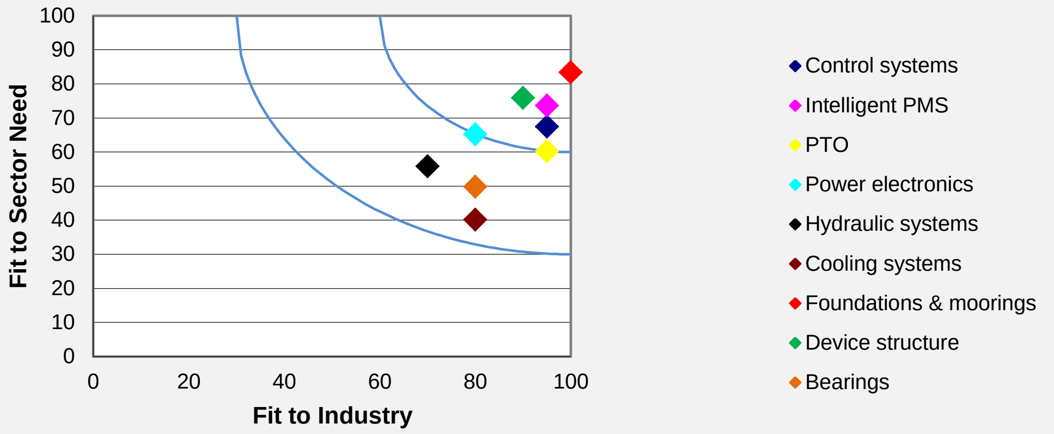

Figure 13: Sub Systems – Industry

RESEARCH:

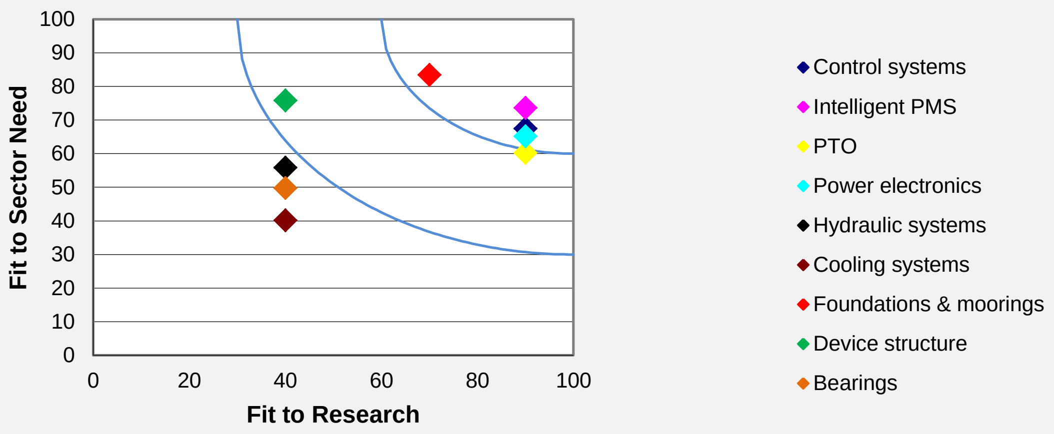

Figure 14: Sub Systems - Research

Sub Systems

Sub systems or sub-components within an overall system have a significant impact on overall system performance and reliability. The optimisation of several sub systems within a device could provide improved capability.

The **government** chart identifies that all activities within the device and system deployment theme are either medium or low priority for funding support, suggesting that the advancement of state of the art in these areas requires the industry or research centres to drive projects forward. This does not mean that these topics are unimportant for public funding, but that funding may be better directed elsewhere, leaving the industry to develop leading solutions through deployment and learning by doing.

The **industry** chart reveals the following high priority activities:

- **Foundations & Moorings;**
- **Intelligent Predictive Maintenance Systems;**
- **Device Structure;**
- **Control Systems;**
- **PTO;**
- **Power Electronics.**

While ***foundations and moorings*** score highest, identifying that there is perhaps a need for greater collaboration and commitment from the technology developers and supply chain to reach a solution that can work for a number of technologies. It was noted in the stakeholder consultation that a variety of different options exist, but it was felt that the industry would probably converge upon the optimum solution. By proactively seeking collaboration in this respect, an optimum solution will become apparent more rapidly. ***Intelligent Predictive Maintenance Systems***, ***device structure***, ***control systems***, ***PTO***, and ***power electronics*** also all scored high in the industry category, falling into the high priority banding, meaning that industry leadership is a crucial element of finding solutions for these topics. The industry needs to be able to develop sustainably, and there are a large number of development activities that fall under the responsibility of the industry itself. The ocean energy sector needs to take initiative in creating the sustainable development.

Five topics were identified as high priority in the **research** prioritisation, activities in which research facilities can help to drive forward knowledge:

- **Intelligent Predictive Maintenance Systems;**
- **Control systems;**
- **Power electronics;**
- **Foundations & moorings;**
- **PTO.**

Design Optimisation and Tool Development

GOVERNMENT:

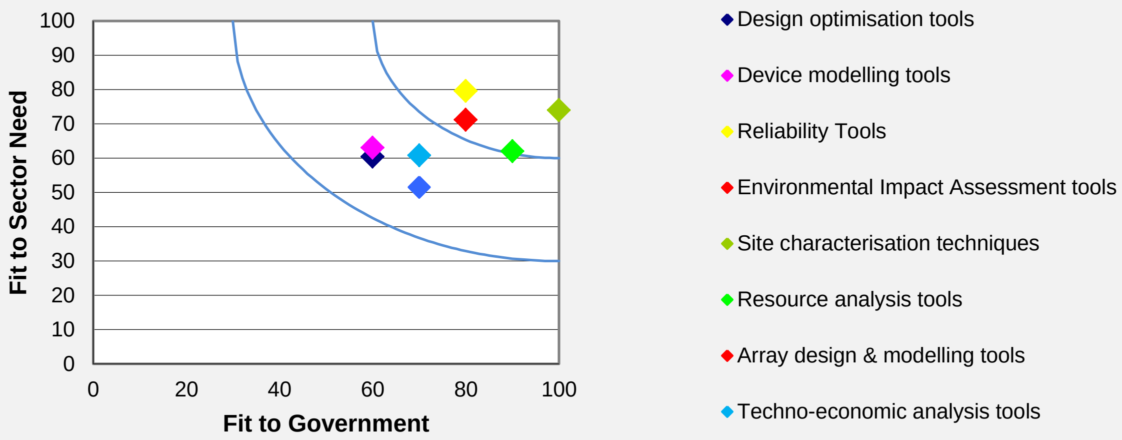

Figure 15: Design Optimisation and Tool Development - Government

INDUSTRY:

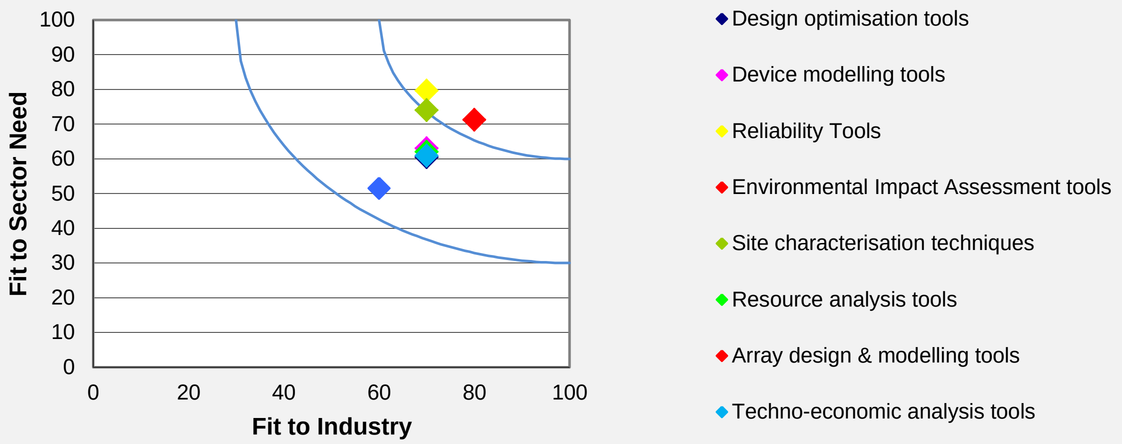

Figure 16: Design Optimisation and Tool Development - Industry

RESEARCH:

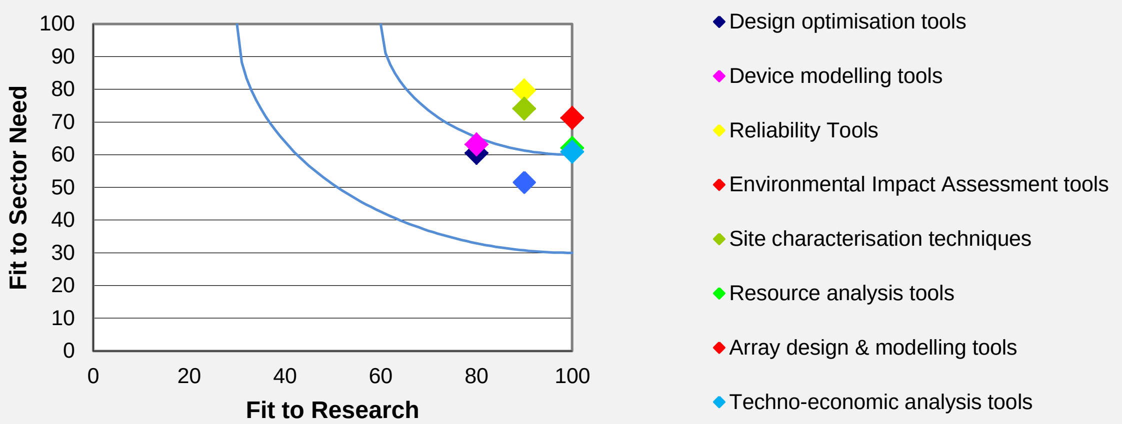

Figure 17: Design Optimisation and Tool Development - Research

Design Optimisation and Tool Development

Design optimisation and tool development is aimed at identifying and addressing some of the tools and optimisation processes that will help aid future design, development, and deployment of ocean energy technologies.

The **government** chart identifies four high priority areas:

- **Site characterisation techniques**;
- **Reliability tools**;
- **Environmental impact assessment tools**;
- **Resource analysis tools**.

There is a requirement for government support both in both economic and policy fields, to assist in the creation of standardised procedures for ensuring that there is a common baseline for every project – regardless of location. At present, there is fragmentation and a lack of clear consensus and guidance in the correct suite of assessment needs that are appropriate for the wave and tidal sector.

The **industry** chart identifies three high priority areas:

- **Site characterisation techniques**;
- **Reliability tools**;
- **Environmental impact assessment tools**.

Again, this points to the need for agreement within the sector as to common practice and standardisation for these tools.

While all activities scored relatively highly in the **research** prioritisation, high priority activities were identified as:

- **Reliability tools**;
- **Site characterisation techniques**;
- **Array design & modelling tools**;
- **Resource analysis tools**;
- **Techno-economic tools.**

The above list represents areas in which research facilities can help progress the activity through dedication of research effort and resources – with particular need for close collaboration with industry in order to achieve industry relevant outputs.

Topics that scored highly in all three Design Optimisation & Tool Development charts include **reliability tools**, **site characterisation techniques**, **environmental impact assessment tools**, and **array design and modelling tools**. These topics would be suited for significant cross-sector collaborative opportunities and could be identified as suitable topics for Joint Industry Programmes.

Arrays

GOVERNMENT:

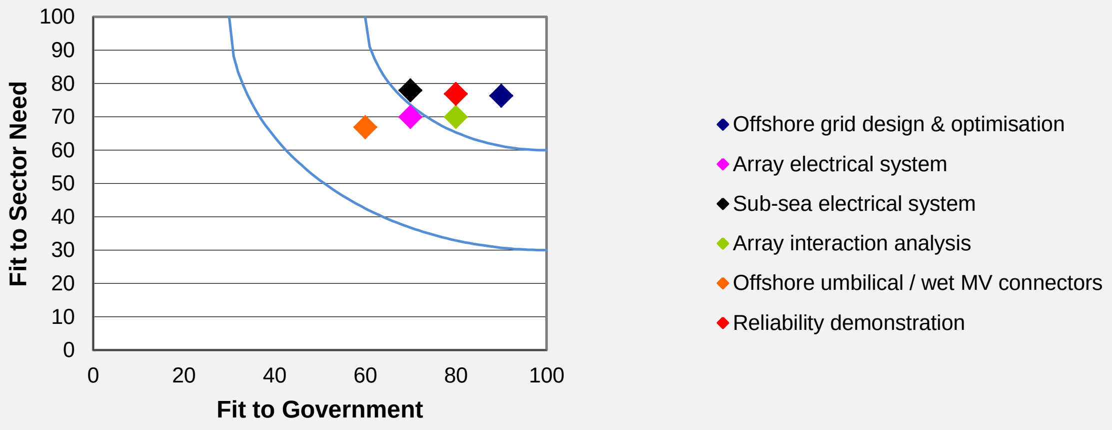

Figure 18: Arrays - Government

INDUSTRY:

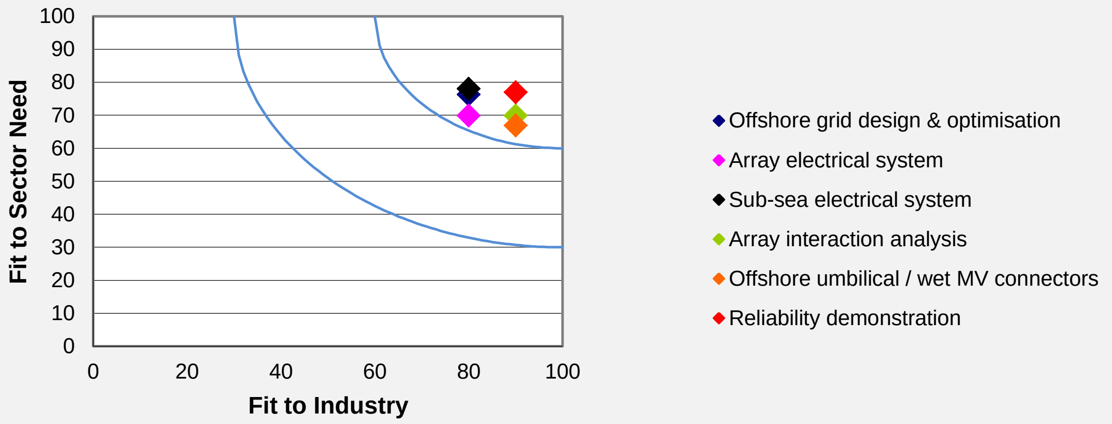

Figure 19: Arrays - Industry

RESEARCH:

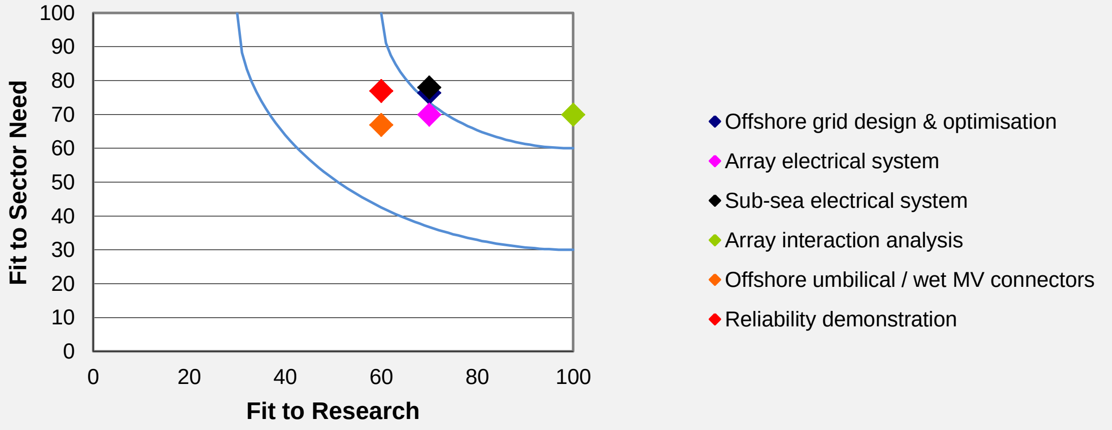

Figure 20: Arrays - Research

Arrays

The **arrays** theme presented some of the pressing issues that are present in the sectors' move from single device deployment to multiple device arrays.

Within the **government** chart for Arrays, four activities present themselves as high priority:

- **Offshore grid design & optimisation**;
- **Reliability demonstration**;
- **Array interaction analysis**;
- **Sub-sea electrical systems**.

There is a need for shift in focus towards reliability demonstration of devices and arrays, proving that the technology deployed is capable of surviving long-term in the marine environment. Furthermore, the development of sub-sea electrical systems and offshore grid design are fundamental to large scale deployment of ocean energy technologies. This high risk and high cost activity would benefit from economic and political support to enable swift action to address the current challenges.

The **industry** chart identifies that all activities within the Arrays theme are high priority areas for industry leadership:

- **Offshore grid design & optimisation**;
- **Array electrical system**;
- **Sub-sea electrical system**;
- **Array interaction analysis**;
- **Offshore umbilical / wet mate MV connectors**;
- **Reliability demonstration**.

All activities are urgent priority for the build out of arrays, but industry and supply chain must take leadership in identifying the solutions, leading initiatives with the research sector to ensure that the outcome is driven by industry.

The activities that scored highly in the **research** prioritisation include:

- **Array interaction analysis**;
- **Sub-sea electrical system**;
- **Offshore grid design and optimisation**.

While these topics may be best led by industry, there is significant opportunity for collaboration with research facilities across Europe that may have technical expertise in electrical system modelling and optimisation or with significant ability in CFD analysis of multiple device array interaction. These facilities should be used by the sector to enhance the state of the art in array deployment.

Topics that scored highly in all three Array charts include array interaction analysis; **sub-sea electrical system**; and **offshore grid design and optimisation**. These topics would be suited for significant cross-sector collaborative opportunities and could be identified as suitable topics for Joint Industry Programmes.

5. Challenges and Opportunities

While there have been several prototypes deployed at sea utilising existing test facilities, there is still a need for many devices to prove long term reliability and successful autonomous operation. There is already a ‘valley of death’ facing technology developers on the route to technology commercialisation: There is a significant funding gap between producing and proving device viability at model scales through applied research, and manufacturing a full scale prototype for reliability demonstration at a commercial scale. The industry now faces a second hurdle, that of addressing the funding gap existing between the proving full scale operation of a single device, and of deploying a commercially viable array project. Little work has been done to assess the impact that this second hurdle is having on the development of the ocean energy sector. It is clear, however, that there is much work to be done in order to gain confidence in the sector and build out the projects that will meet the EU ocean energy deployment targets. The existing barriers that have been discussed within this report consist of both technical and non-technical challenges, both of which will be summarised in the following sections of this report.

5.1. Technology

While it is accepted that there are a diverse range of ocean energy technology concepts, and that there is IP locked in to designs, there are elements of ocean energy devices that could benefit from wider cross sector engagement to identify optimum common techniques without infringing on any perceived IP, such as cost effective installation and deployment processes. This would unlock greater interest from the supply chain, which would have an increased market with multiple technologies, rather than sole devices.

5.2. Installation, Operation & Retrieval

There are substantial prospects of reducing the cost of installation, deployment and retrieval if joined up thinking between different device developers can come together to optimise the installation process. Device testing has not yet led to significant O&M optimisation, but in time, this will play a part of future innovation work, and knowledge transfer and dissemination will play a key role in facilitating convergence on an appropriate design solution.

5.3. Innovation vs. Commonality

There are arguments for and against the issue of commonality within the wave and tidal sector, and while it is obvious that lack of design consensus in the wave sector will prevent convergence of major components, there is certainly scope for greater design commonality to be achieved in the future. The tidal sector, with greater convergence upon a horizontal axis turbine, offers significant scope for commonality of components than the more fragmented wave energy sector.

There is a difficulty in the supply chain getting involved in the solution and resolution of the technology challenges without the key ingredients: Funding, and a market - guaranteed end users. A commitment from the industry to use products that could be delivered through the supply chain will allow supply chain companies to give more effort to R&D and solution finding. Commonality between multiple devices and sectors creates a larger market for the supply chain, increasing the appetite for development of new products or solutions suitable for the wave and tidal sector.

While there may be concern that commonality may reduce the freedom of design to a certain extent, it has been made clear within the supply chain that the wave and tidal sector alone does not have significant market demand for the generation of individually appropriate solutions. The investment in terms of time and money for development of several unique solutions does not exist.

There is an opportunity for a reassessment of IP, and an identification of areas in which collaboration will benefit enabling technologies for the sector. Identifying areas for achieving commonality would enhance the growth of the wave and tidal industry. There must be greater levels of collaboration and design convergence within the ocean energy sector in order to enable a larger demand from supply chain companies. Already certain players within the supply chain have indicated that they will only look at developing enabling strategies or technologies if there is a wider market beyond the ocean energy sector.

5.4.Enabling Technologies for Array Deployment

There are elements of core technology operation that have yet to achieve demonstration over long periods of operation. Current installation practices and procedures are sub optimal, in terms of safety, practicality, and in cost. There is a catch 22 situation of the requirement for the correct enabling technologies to allow efficient project development, and the need for project development to facilitate the advance of optimised strategies for enabling future array deployment.

In the first instance, it may be necessary for compromises to be made: project deployment may need to take place with *sub-optimal* deployment strategies and enabling technologies in order to facilitate the development of the *optimal* deployment strategies and enabling technologies. Governments and funding bodies must be made aware of the opportunity for funding to support the development of the right enabling technology solutions.

5.5.Infrastructure

Without secured access to a grid connection point, ocean energy project development will slow significantly. Grid upgrades have been delayed across several parts of the UK, and the timescales for ocean energy projects have been negatively affected. There is an urgent need to ensure that adequate grid connection is available in a timely manner, and that grid connection application processes are made more transparent. Although resource may be identified in a particular area, if there is no means by which to connect the technology to the grid, then there will be a significant delay to project construction. The development and strengthening of grid network in the areas of significant resource should be a priority for all countries where a wave or tidal resource exists.

Other EU member states must take heed of the significant time and cost delays that are associated with limited grid connectivity, and take action as appropriate in preparation for any proposed or planned deployment. The expense, the lack of transparency, and the disparity of grid connection costs are choking a sector that is at a make or break point. Action is needed to end this stalemate.

5.6.Policy

The key challenge for policy makers is to level the playing field for ocean energy technology developers, allowing appropriate incentives to make early projects more attractive, and making the route to access suitable sites more transparent.

5.6.1. Innovation Funding

The evidence also suggests that there is a need for continued technology push support mechanisms as well as the large scale deployment and market-pull support schemes that are currently in place. It is essential that the right support reaches the right projects at the right time. While the industry recognises the need for large utility scale deployments as an essential part of meeting the EU ocean energy deployment targets, enhanced technology push support will help address the continued requirement for earlier stage ocean energy R&D funding in the EU that will facilitate technologies and sub-systems that may play a future role in cost reduction and performance improvement within ocean energy technologies.

5.6.2. Site Leasing and Assessment

A suitable solution for mitigating the challenges surrounding acquisition and characterisation of appropriate development sites could be for governments to take responsibility for centralised leasing zones, whereby site characterisation is carried out by a centralised government body that will bear the risk of identifying the resource characteristics. Subsequently, sections of the site could be leased out to project or technology developers at a capacity according to their development needs or abilities. This would be particularly pertinent for technology developers who are also becoming project developers in order to create a market for, or find a suitable site for the deployment of, their device. By government organisations taking an active role in site development, technology developers can focus on their core research and development area of producing reliable devices.

5.7. Economic Expectations

Providing justification, to governments or investors, of the progress being made by a specific technology needs a common metric that can be used across the sector, and that will not show bias to a particular technology type, or technology scale. Metrics that judge performance should be reliability, total generation output in GWh, and current technology cost (CAPEX, OPEX, and LCOE in c/kWh - using current costs and actual electricity generated to grid).

It is necessary to bridge the divide between investor expectations and the technology development mind-set. There is a need to align the expectations with realistic deployment trajectories that are within the capabilities of technology developers, and the sector as a whole. Ultimately, if the desired large scale deployment projections are to be achieved then the level of funding provided for the sector, whether that is through public or private sector finance, needs to be appropriate.

5.8. Environmental

While the industry accepts there is a need to deploy in an environmentally sensitive manner, the effect of legislation in environmental impact is currently stifling the innovation of the sector, resulting in decisions that are not appropriate given the development state of the sector.

There is at present, as identified by many stakeholders during the consultation process, a real sense of frustration at the strict and uncompromising environmental legislation that is in place; the situation and scenarios associated with environmental impact need to be appropriate with the level of development being undertaken – at present this is not seen to be the case.

There is a significant opportunity for an ‘adaptive management’ approach to be utilised in the ocean energy sector, as there is a greater value in learning the real impact of a technology through deployment, rather than speculating the possible impacts of a non-deployed technology. Adaptive management, such as ‘deploy, monitor and mitigate’ techniques could have binding stipulation in place that could require mitigation activity if a certain threshold is perceived to be reached, or even removal if breached. The conditions would need to be fully agreed and approved by any regulatory bodies prior to the construction and deployment of a given project, and continual monitoring would take place until sufficient evidence has been gathered to demonstrate that there is no longer a risk associated with continued device operation.

5.9. Timescale and Targets

With recent alterations to the 2020 deployment targets across various Member States of the EU, deployment trajectories for the ocean energy sector have reduced by an order of magnitude compared to earlier 2020 targets. Ocean energy technology must deliver on the updated targets; otherwise there is a real risk that the sector could lose credibility amongst supply chain companies and policy makers. It is essential that there is a renewed attitude of urgency in order to ensure that deployment targets are met; deployment activity must take place to ensure the future viability of the sector.

5.10. Risk Management

There is a need for deployment funding of megawatt-scale array projects to ensure that deployment targets are met, but there is also a need for continued technology push funding for those at an earlier stage of development. The technology push funding is also an essential requirement for the next generation of systems and sub-systems that could allow step change cost reductions and performance improvements to be made.

At present, there is not an obvious attitude of responsibility within the ocean energy sector for *sharing* risk. The lack of firm supply chain contracts suggests that utility scale projects may be deemed 'too risky' in the current economic and political climate. The current deployment pathway of wave and tidal energy technology appears to be taking a technological jump that is larger than the economic will (or ability) of the investors. Risks need to be managed appropriately, and this requires careful management in order to achieve the desired outcomes. Routes for facilitating risk-sharing must be identified and acted upon.

5.11. Knowledge Transfer

Across Europe there are a wealth of engineering skills from industries outside of ocean energy that could provide relevant input and expertise into the wave and tidal sector. While the oil and gas sector has a wealth of offshore engineering expertise, it must be remembered that ocean renewable energy does not have the same capital spending ability as oil and gas, therefore bespoke solutions and applications found in the oil and gas sector cannot become commonplace in the ocean energy sector.

Lessons have already been learned in the wind energy sector that costs would not come down as quickly as initially anticipated. It is unrealistic to think that nascent wave or tidal energy technology could be brought to maturity quickly without the expertise and knowledge gained through sharing of best practices, and from consultation with other industrial sectors or industries. In order to maintain a focus on improving the commonality of design, there needs to be a continued effort at knowledge transfer and sharing of best practice both internally within the ocean energy sector, and externally beyond the field of renewable energy.

The transfer of knowledge, whether that be shared learning from deployment of generic technology components (such as failure data, foundation designs, or moorings) or from cross-transfer of knowledge and understanding from other engineering sectors, offers significant opportunity for improvement within the ocean energy sector.

There is an opportunity for greater government to government agreement as to what information should be shared across developers internationally, and ensuring that this information is provided by all technology developers and parties involved.

6. Summary and Conclusion

While this report does not present solutions to the gaps and barriers, it has laid the foundations for the forthcoming Strategic Technology Agenda and future Market Deployment Strategy (MDS). The MDS will outline the policy recommendations to help facilitate accelerated solutions to the identified problems, enabling the right support to reach the right technologies at the right time.

The Gaps and Barriers report has presented the findings of the SI Ocean stakeholder engagement programme, and has identified significant barriers to deployment. While many of the barriers presented are not directly associated with enabling technology in the engineering sense, the barriers presented all have an impact on the ability to deploy, demonstrate, and optimise technology.

While there is some disappointment in the revised deployment targets that are now in place amongst some of the key early adopter Member States, there must be a renewed sector push to ensure that these revised deployment targets are met, to safeguard investor confidence and develop supply chain appetite.

This document has highlighted the barriers that exist and are hindering the development of wave and tidal energy technology. The key actors in overcoming these barriers (Governments; Industry; Research) all have roles to play in the provision of solutions to overcoming the barriers. This has been discussed within the report, and recommendation of prioritisation provided.

The next phase of the SI Ocean project will consider and document the technical obstacles, and the routes by which these barriers can begin to be addressed. This will be presented in the Strategic Technology Agenda, which will consider some of the interventions that will help accelerate delivery of commercial technologies – ensuring that the ocean energy sector is able to meet future deployment targets and continue growth out to 2030, 2050, and beyond.

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8. Annex A: Strategic Research Agendas for Other Developed Technologies

An important step for the development of the wave and tidal sector is to look at the knowledge gathered by other renewable energy sectors, and compare important lessons on how gaps and barriers were overcome. The progression of the offshore wind sector is often used as a metric for the development of the wave and tidal sector in terms of technology development, supply chain and licensing procedures. However, important lessons could also be imported from the experience gained by the solar Photovoltaic (PV) sector, which, in common with wave and tidal, offers a wide range of conversion mechanisms and reveals diversity in the types of technology being investigated and developed.

In the last decade both the offshore wind and the PV sectors have seen an increased amount of research, and Strategic Research Agendas (SRA) and Strategic European Industrial Initiatives (SEII) have been implemented to consolidate and reinforce their market share and reduce the overall LCOE. The establishment of the EU wind[4] and photovoltaic[5] platforms are aimed at consolidation of policies and development of strategies for meeting the Europe 2020[6] agenda. An overview of historical activities undertaken for the development of the wind energy and PV sectors is presented in Figure 21.

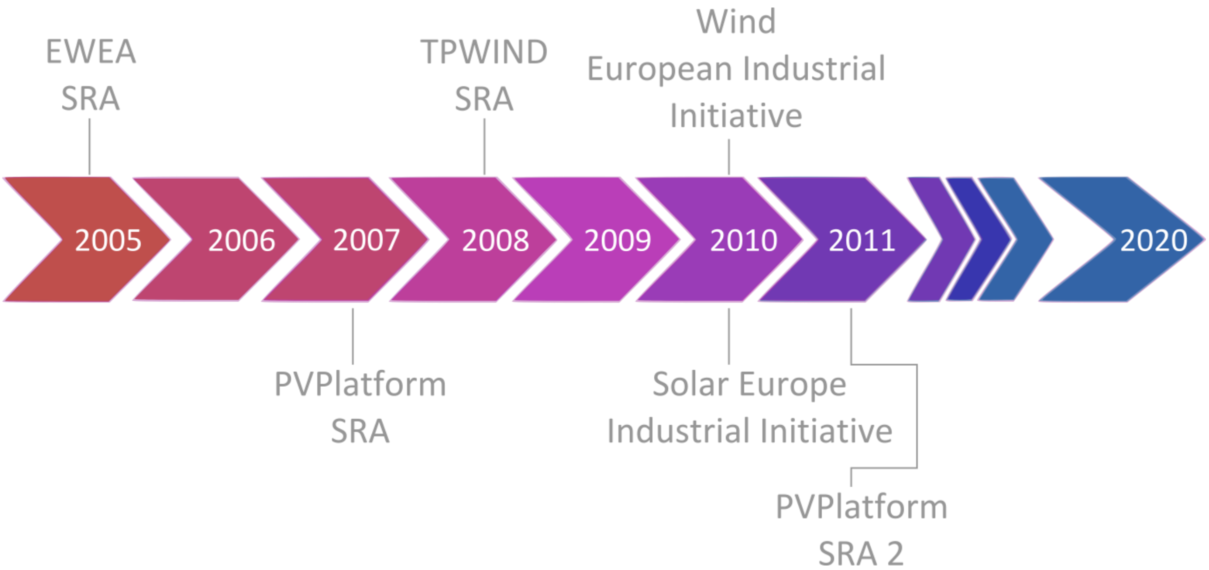

Figure 21: Timeline of actions and initiatives developed for the wind energy and PV sectors at European level

8.1. Key Objectives and Performance Indicators

Despite the significant differences between solar PV and Wind energy, their respective SRAs and SEIIs focus and address common areas for improvement and continuous research. The main objective of the documents is to achieve cost-reduction in the generation of electricity to maintain or increase competitiveness with other conventional and renewable forms of energy. Different areas for specific research have been identified in the SRAs and SEII, which can be summarised as follows:

[4] European Wind Energy Technology Platform, http://www.windplatform.eu/, including offshore wind development
[5] European Photovoltaic Technology Platform, http://www.eupvplatform.org
[6] http://ec.europa.eu/europe2020/europe-2020-in-a-nutshell/targets/index_en.htm

- Conversion technology and components: research aimed at increasing energy yields and identifying new conversion technology that could be more cost-effective;
- Grid integration: integrating the electricity generated in the wider grid, by smoothing peaks and providing remote-grid connections;
- Supply chain and balance of systems: focussing on standardisation methods and cost-reduction through mass-production and installation systems;
- Resources, environmental, socio-economic and planning aspects: focussing on implementing the Life Cycle Assessment of technology, improving forecasts and resource assessments.

Similarly, SRAs and SEIIs identified key performance indicators (KPIs) against which the progress of technology and the effectiveness of research activities can be measured. Within the framework of the SET-Plan and the implementation of European Industrial Initiatives, the levelised cost of electricity (LCOE) has been identified as the overarching KPI. As outlined in previous SI-Ocean work, the LCOE represents the lifetime cost of electricity for a given farm, considering capital costs and investment, operation costs and the annual energy yield. In addition to LCOE, priority-specific KPIs associated with the identified area of research have been developed. The following subsections provide an overview of the key points outlined in the SRAs and SEIIs for Wind and PV energy, and how they represent an opportunity for the ocean energy sector.

8.2. Wind and Offshore Wind Energy

The development of the offshore wind energy sector is often taken as a reference for the wave and tidal energy industry, due to the many similarities that exists in terms of environment (harsh and saline conditions), support infrastructure needed (vessel, cables, suitably equipped harbour), and licensing requirements. Offshore wind represents an expansion of the wider wind energy sector, and although it has gained much attention of late, research objectives and priorities between onshore and offshore wind often coincide. The Wind SEII published in 2010, identifies four main areas for research and industrial activity within the wind sector:

- New turbines and components
- Offshore technology
- Grid integration
- Resource assessment and spatial planning

A comparison of the above priorities with those presented by the 2005 and 2008 SRAs indicates that the primary focus has moved towards the development of new concepts (turbines and supply chains) for offshore installation. This development is in line with the wind sector's ambitious objective to generate 10% of European electricity using offshore wind by 2030[7].

8.2.1. New Turbines and Components

The wind sector is looking at exploiting higher resource locations by moving turbines offshore. As a consequence, there is the ability to develop and test larger scale wind turbines, at a greater scale than would be permissible onshore, in the range of 10-20 MW. Additionally, increasing the reliability

[7] TPWind '2030 Wind Energy Vision', 2007

of components by using new material, employing advanced rotor designs and improving control and monitoring systems is a key focus. Improvements can be achieved by developing a cross-industrial cooperation and demonstration programmes, aiming at the progressive development and testing of 5-10 MW demonstration projects.

8.2.2. Offshore Technology

Moving to offshore environments further away from the coastline does not only require the development of larger and more reliable turbines, but also a shift in installation techniques and manufacturing processes. The implementation of more rigid standards especially in terms of safety, education and environment is needed to insure the overall life-cycle of the farm is cost-competitive. The current research agenda focus is on developing and proving technology for water depth >50m, whilst consolidating the experience for offshore technology up to 50m depth. This goal is not only achieved by looking at new concepts, but also through the improvements in the life expectancy of structures, building appropriate installation and assembly infrastructure, implementing grid connection, and optimising O&M. In particular, focus is given to methods for building stackable and replicable substructures, and developing floating turbines; inducing demonstration programmes for mass-manufacturing of proven systems, as well as testing new concepts in site-representative at-sea conditions.

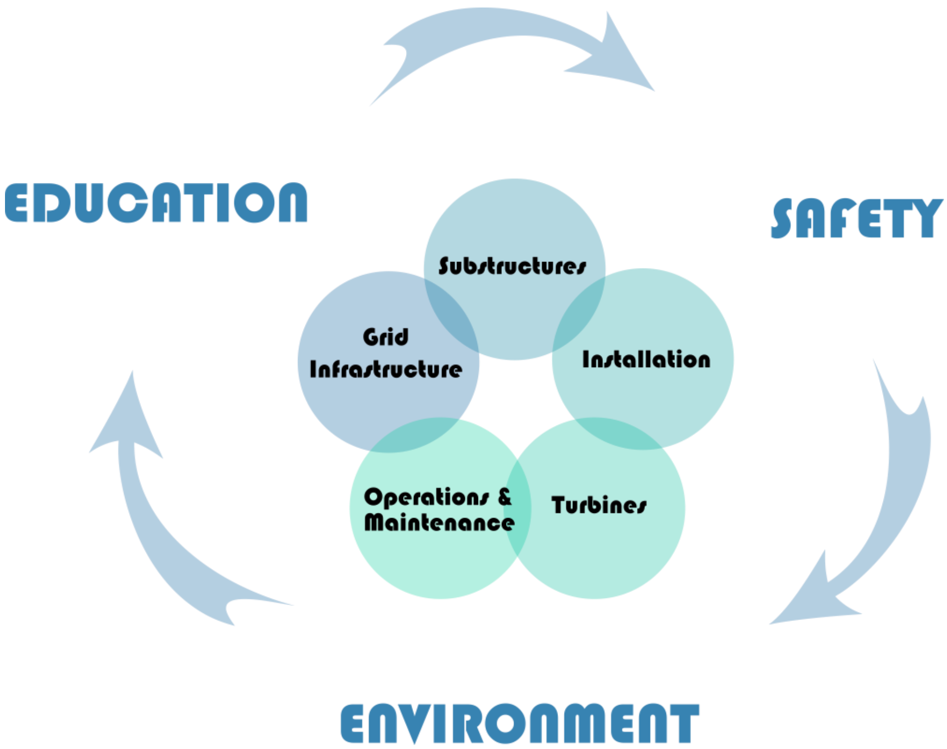

Figure 22: Offshore wind SRA priorities

8.2.3. Grid Integration

Grid integration, including the provision for infrastructure for remote areas and smoothing of peaks is a key priority for the development of wind energy in Europe. The importance of the topic is proportional to the cumulative capacity installed. It can be expected that the wave and tidal energy sector will experience similar requirements in terms of grid connection and integration, and therefore sharing of knowledge and cross-sector standards will be beneficial.

8.2.4. Resource Assessment and Spatial Planning

One of the main objectives of the 2008 wind SRA is to reduce uncertainties in wind energy forecast to less than 3% by 2030. The importance of more accurate predictions resides in a reduced risk for investors which are presented with a more reliable value of Annual Energy Production. Implementing resources assessment techniques, by means of more detailed campaigns, and development of databases and atlases, allows for correct siting and improved control of the wind farm. In particular, focus is given in mapping offshore areas and complex terrain to increase accuracy.

8.3. Solar & Solar Photovoltaic

The development of the photovoltaic industry and the associated strategic agendas and initiatives is not frequently associated or used as a metric for assessing the progress of the wave and tidal sector. However, the PV industry reveals some commonalities with the wave and tidal sector, especially with regards to the number of different cell technologies that have been developed over the years (technology fragmentation). Whilst silicon based PV are the most commonly known, other conversion technologies include thin-film silicon, Copper Indium Gallium Sulphur-Selenide (CIGSS), Cadmium Telluride (CdTe), organic PV and concentrated solar. In order to ensure the constant progress and innovation of the industry, without undermining its current market prospective, the various SRAs and SEIIs developed for the PV industry applied a "Non-exclusivity" principle. The principle allows the inclusion of the many different PV technologies within the one SRA; however each technology is allocated different targets and priorities. Such an approach ensures that no technology is discarded, even if the technology readiness will be far from commercialisation in the short term, but that all technologies can be considered for future development.

8.4. Learning from Other Strategic Research Agendas – Lessons for Wave and Tidal

The Strategic Research Agendas for Wind and Solar PV technologies provides a wealth of information on how gaps and barriers have been overcome in comparable renewable energy sectors.

8.4.1. Wind - New Turbines and Components

The SI-Ocean technology and Supply Chain workshop indicated that there is the need for the industry to find a convergence of technology, and achieve support from the supply chain by creating a market for technology solutions - which could lead to reduce costs. While the wind sector looks at new turbines and components, the wave and tidal sector should focus on reaching commercialization (TRL>9) of demonstration prototypes, and provide evidence of reliable technology operation. There are a number of wave (15[8]) and tidal (5) test centres that have been developed around Europe, but only a few of them have been used for testing programmes, particularly within the wave energy sector.

8.4.2. Wind - Offshore Technology

There is a large margin for knowledge transfer between the priorities in developing competitive offshore wind energy and the nascent ocean energy sector. The offshore wind industry, is looking to

[8] SOWFIA, catalogue of wave energy experience to date.

reduce costs through adopting mass-manufacturing, but is also developing an incremental step-process in terms of installation at increasing water depth and more energetic resource sites. This allows for the consolidation of a mature design (and establishment of a standardised supply chain) whilst research activities are undertaken at improving and optimising design. Such a sequential approach ultimately increases the learning rate of the industry reducing the LCOE.

8.4.3. Wind - Resource Assessment & Spatial Planning

The correct estimate of annual energy production (AEP) and of wind conditions that can be exploited at a site are fundamental in obtaining project funding and determining the return that an investor can expect on the investment made. Wave and tidal energy resource assessments present higher accuracies compared to those from wind, however, limited information is presented in terms of wakes and external constraints (such as environmental and social) that could inform correct site selection. A particular issue for wave energy systems is related to the availability of high accuracy short-term forecast data to inform and implement control systems for maximum energy output.

8.4.1. Solar

The convergence of technology is not something that has been observed in the wave energy sector to date, although the tidal energy sector has largely converged upon a horizontal axis turbine design. At the current stage in development it is possible to highlight ocean energy technologies that have reached a higher stage of development, whilst other technologies will require further research and development to achieve commercial breakthrough. As with solar energy, the definition of a differential scale of targets based on specific technology would greatly benefit the wave and tidal sector, which still needs to demonstrate long-term reliability in the generation of electricity. Targets could be based upon core technology – for example wave or tidal. The targets and objectives could also be more specific, setting targets to the specific technology types within the category of wave or tidal energy – for example Oscillating Water Column or Oscillating Wave Surge Converter (near-shore wave), attenuator or point absorber (offshore wave), horizontal axis or vertical axis (tidal), etc.

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