ETIPOCEAN

European Technology & Innovation Platform for Ocean Energy

An Integrated Framework of Ocean Energy Sector Challenges

Final Report

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 727483.

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1. Executive Summary

The ETIP Ocean project provides a hub for knowledge exchange and collaboration within the emerging ocean energy sector. It develops activities that are rolled out through ETIP Ocean, the European Technology and Innovation Platform for Ocean Energy, an existing and established network of ocean energy professionals, stakeholders and experts.

1.1 14 Priority Challenges for Ocean Energy Development

This document identifies 29 challenges that need to be overcome for the ocean energy sector to move to commercialisation. The challenges are categorised as related to either technology, finance or environment & socio-economics, and prioritised according to importance to the sector and the ability of ETIP Ocean to contribute to solutions.

Fourteen of the 29 challenges identified are considered to need more urgent address. Six are technological, four relate to finance and four are socio-economic or related to the environment.

Table 1: Fourteen priority challenges

Category	Challenge
Technology	Developing novel concepts for improved power take-offs (PTOs)
	Increasing device reliability and survivability
	Investigating alternative materials and manufacturing processes for device structures
	Investigating novel devices before moving towards convergence of design
	Defining and enforcing standards for stage progression through scale testing
	Developing and implementing optimisation tools
Financial	Providing warranties and performance guaranties
	Linking stage-gate development processes to funding decisions
	Maintaining grant funding for early TRL technologies
	Establishing long term revenue support
Environmental and socio-economics	Enhancing social impact and acceptance
	Minimising negative environmental impacts
	Facilitating knowledge transfer and collaboration
	Implementing adaptive management systems

The remaining 15 identified challenges cannot be overlooked, but may be tackled with less urgency.

2. Table of Contents

3. Introduction

Ocean energy has the potential to significantly contribute to Europe's energy requirements in an environmentally friendly, low cost and secure manner. The European wave and tidal energy sectors alone could deploy 100GW of capacity by 2050[1], meeting 10% of the EU's power demand[2].

This represents a significant portion of potential global capacity. The International Energy Agency's Ocean Energy Systems (IEA-OES) estimates that 337GW of capacity could be installed worldwide by 2050[3]. However, the ocean energy sector is currently emerging and its successful commercialisation remains dependent on a variety of challenges being overcome.

3.1 The ETIP Ocean Network

ETIP Ocean (the European Technology and Innovation Platform for Ocean Energy) is a project funded under the European Commission's Horizon 2020 research and innovation programme.

Using the existing TP Ocean and European Energy Research Alliance (EERA) Ocean Energy Joint Programme (JP) networks, it is tasked with providing a hub for knowledge sharing and collaboration amongst a diverse set of stakeholders in the ocean energy sector. ETIP Ocean is a network of ocean energy professionals, researchers and academics. It is officially recognised by the European Commission as a stakeholder in the Strategic Energy Technology (SET) Plan.

The ultimate goal of the project is to reach a common vision for the accelerated development of ocean energy on the path to commercialisation.

ETIP Ocean will, therefore, host knowledge exchange events including workshops and expert-led webinars to facilitate a pan-European, multi-stakeholder discussion on the key challenges facing the sector. As a conclusion to the project, an integrated strategy for the sector will be published. It will detail a concise framework of actions required to overcome the identified challenges and accelerate the development of the sector.

ETIP Ocean will also dedicate significant resource to education and engagement activities, ensuring that wider civil society is aware of the potential benefits of ocean energy and that the young workforce is well prepared to contribute to the sector as it expands.

3.2 A Basis for Knowledge Exchange

The purpose of this document is to provide the basis for ETIP Ocean's forthcoming knowledge exchange and collaboration activities. Through review of key ocean energy roadmap and strategy documents, this report highlights the challenges that are seen as the most critical to overcome in the pursuit of sector commercialisation.

Challenges will be analysed and categorised as related to either:

- Technology,
- Finance or,
- Environment and socio-economics.

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[1] Ocean Energy Europe, 2013. *Industry Vision Paper.*

[2] Ocean Energy Forum, 2016. *Ocean Energy Strategic Roadmap: Building Ocean Energy for Europe.*

[3] International Energy Agency – Ocean Energy Systems, 2012. *An International Vision for Ocean Energy.*

A number of the identified challenges will be particularly relevant to a specific technology (wave, tidal, OTEC, salinity gradient) and this will be accounted for when designing materials for knowledge sharing and engagement activities. Similar consideration will be given to the different operating zones (i.e. onshore, near-shore and offshore) of various technologies.

3.3 Data Sources

In identifying the key challenges reported in this document, several significant roadmap and strategy studies were reviewed. As shown in Table 2, six works in total have been analysed.

Two documents were the recent outputs of TPOcean or the Ocean Energy Forum (an initiative in which TPOcean was fully involved) and built upon the foundations set by four other key studies to provide the most up-to-date sector analysis available.

Table 2: Review of sector challenges - source reports

	Authoring Organisation	Title	Date
Recent	TPOcean	Strategic Research Agenda for Ocean Energy	2016
	Ocean Energy Forum (OEF)	Ocean Energy Strategic Roadmap: Building Ocean Energy for Europe	2016
Foundation	SI Ocean	Ocean Energy Technology: Gaps and Barriers	2013
	International Energy Agency Ocean Energy Systems (IEA-OES) Initiative	International Ocean Energy Technologies: Synergies with Other Industrial Sectors	2016
	European Energy Research Alliance (EERA)	Ocean Energy Description of Work, version 2	2015
	European Commission	Strategic Energy Technology Plan	2015

4. Technology Challenges

This chapter looks at the technological aspects of ocean energy development which need to be addressed to present a commercially attractive and viable energy solution. Ocean energy technologies, including energy conversion devices and balance of plant, can generally be said to be progressing through the lower-to-mid Technology Readiness Levels (TRLs), with further development required to reach operationally proven designs.

Error! Reference source not found. Figure 1, below, outlines the Innovation Pathway at the heart of the Wave Energy Scotland funding programme. Tied to TRLs, it outlines the activities that may take place at each stage of development for ocean energy technologies, including devices and subsystems. In a similar manner,

Figure 1: The Wave Energy Scotland (WES) Innovation Pathway - development stages and associated TRLs for ocean energy technologies [4]

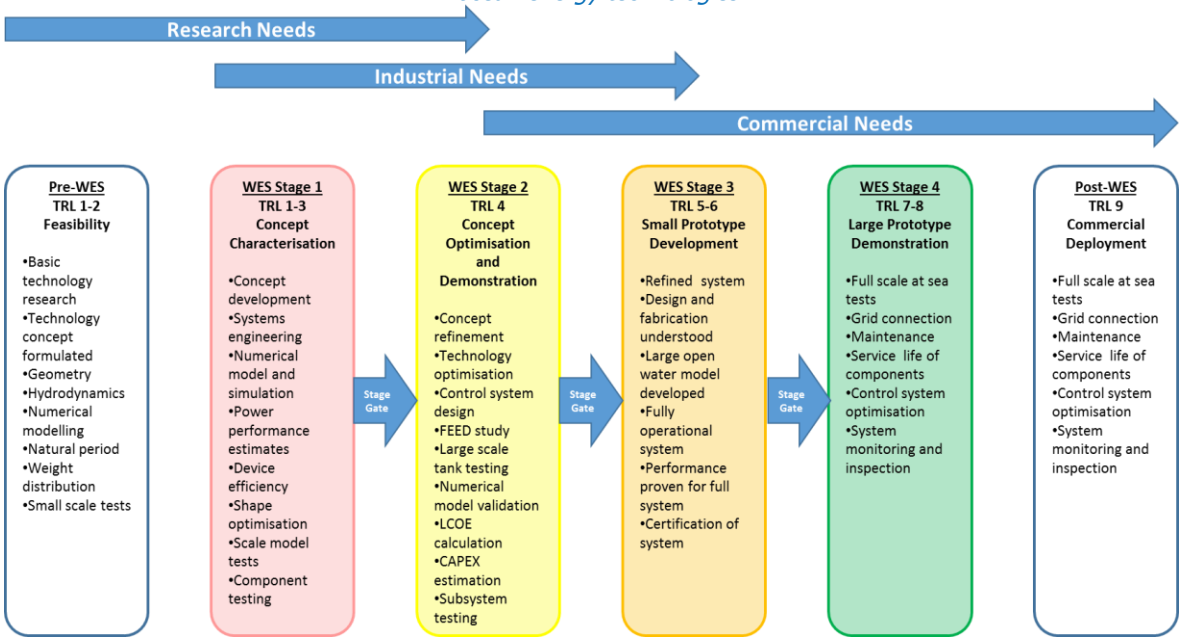
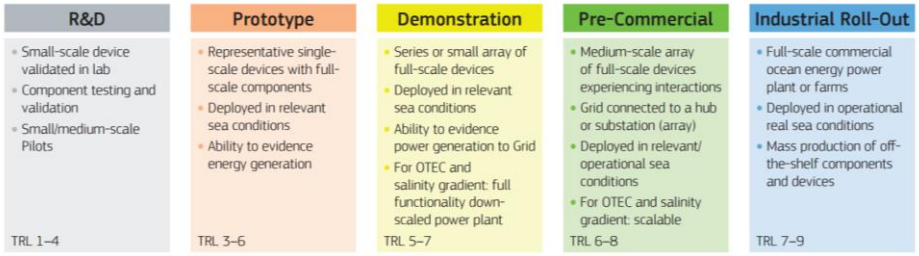


Figure 22 ties TRLs to phases of development for ocean energy devices and arrays, from initial R&D to full industrial roll-out.

Effective stage-gate development processes require standardised and commonly understood performance indicators to allow monitoring and comparison of development between technologies.

[4] Adapted from Wave Energy Scotland materials.

Figure 2: Development phases of ocean energy devices and arrays with corresponding TRLs [5]



Review of the literature listed in Section 3.3 has highlighted a variety of technological challenges that need to be tackled in the pursuit of sector commercialisation. All identified challenges have been prioritised (Table 3 below).

Rankings are given according to the importance with which a challenge must be overcome to further sector development and the degree to which a solution can be facilitated by ETIP Ocean. A rating of "C" does not indicate that a challenge is of low importance, simply that it may be tackled with less urgency than challenges with higher ratings.

A full methodology for the prioritisation of challenges can be found in Appendix I of this document.

[5] Ocean Energy Forum, 2016. *Ocean Energy Strategic Roadmap: Building Ocean Energy for Europe.*

Table 3: Identified and prioritised technology challenges

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

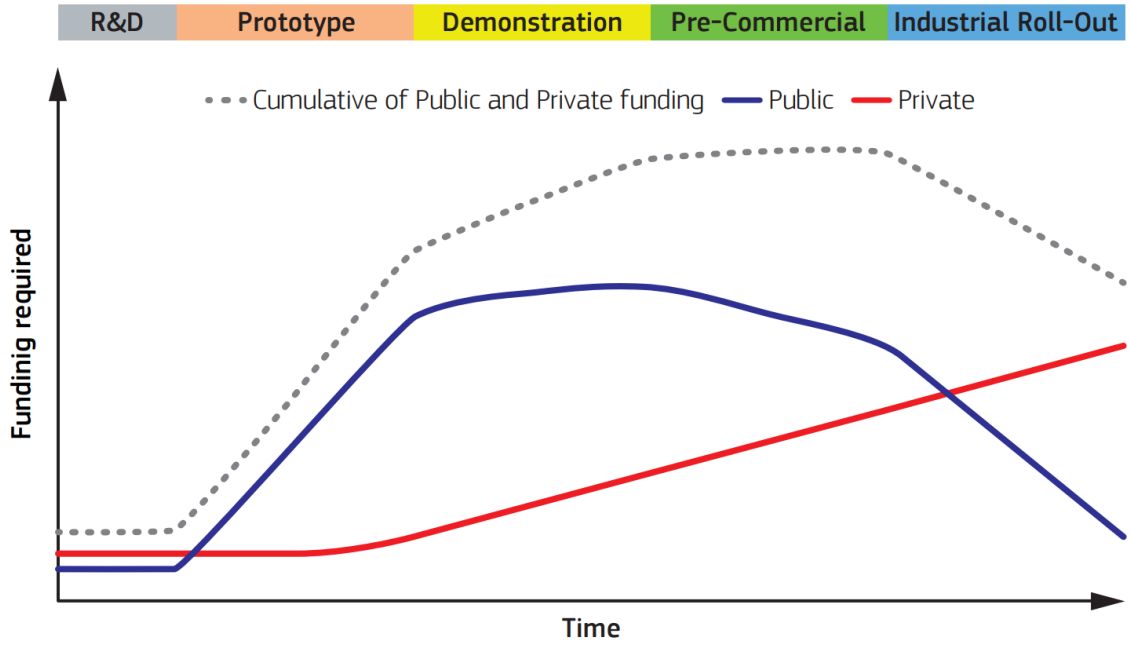
5. Financial Challenges

The ultimate goal of ocean energy support schemes, to achieve full commercialisation of the sector, is defined in financial terms. A commercial sector is one which has the potential to be sustained solely on the basis of private investment by offering a sufficiently attractive investment opportunity. This requires a strong demonstration of return on investment and acceptable risk profiles.

To reach full commercialisation and achieve commercial traction, developing technology sectors such as ocean energy typically require public support. Different forms of support are required at different stages of development and involve different mixes of upfront investment (pushing technology development) and revenue support (pulling the technology closer to market).

Figure 3 shows how a combination of public and private investment is required throughout the development process, with private investment gradually taking over from public support. Grant schemes are necessary at early stages, gradually giving way to investment support schemes before revenue support and private investment take a lead role.

Figure 3: Indicative share of private and public funding for an ocean energy concept per development phase [6]



In a similar manner to the analysis of technology challenges in Section 4, the financial challenges identified through literature review are outlined and prioritised in Table 4 below. Each of these challenges must be tackled to progress the sector from relying on public support to attracting private investment.

[6] Ocean Energy Forum, 2016. *Ocean Energy Strategic Roadmap: Building Ocean Energy for Europe.*

Table 4: Identified and prioritised financial challenges

Priority	Challenge	Description
A	Providing warranties and performance guaranties	Warranties and guaranties will reduce risk profiles for potential investors, particularly when dealing with first generation devices and components which do not yet have an established track record.
	Linking stage-gate development processes to funding decisions	Stage-gate development processes are used to ensure that innovative technologies develop fully and at a suitable rate. Such processes can be valuable in deciding whether a given technology is worthy of continued financial support.
	Maintaining grant funding for early TRL technologies	Grant funding is required to enable early stage technologies to progress to a point where revenue can be generated and investment support schemes become appropriate. A variety of grant funding schemes are available and it is vital that these remain accessible to the ocean energy sector.
	Establishing long term revenue support	Revenue support schemes serve to offer a guarantee that the electricity produced by ocean energy technologies will be sold at an acceptable price over a given time frame, thus reducing investor risk. This is seen as a critical first step in ensuring overall stable policy, regulation and legislation, as detailed below.
B	Maintaining investment support	Investment support is normally required until a technology reaches industrial roll-out, at which point revenue support schemes and private investment may take over. If investment support ceases too soon, technologies might not be mature enough to take advantage of revenue support.
	Advancing engagement with insurance providers	The provision of suitable insurance will increase investment attractiveness but typically requires appropriate certification standards, risk mitigation methods and codes of best practice to be in place.
	Improving cost models for ocean energy developments	Cost models, including Levelised Cost of Energy (LCoE) analysis, serve to inform decision making regarding investment and can improve public support. Reducing the uncertainty involved in such models offers greater confidence in decision making.
C	Ensuring stable policy, regulation and legislation	A stable commitment to ocean energy technologies from government organisations and funding bodies allows confidence in long-term planning and reduces risk profiles for investors.

6. Environmental and Socio-economic Challenges

As with any developing technology, a variety of impacts, both positive and negative, will become apparent during the development process. Greater understanding of all current and potential impacts can be of great value. Whilst knowledge of positive impacts can be useful in improving public acceptance and investor appetite, study of negative impacts is vital to ensure that appropriate mitigation measures are put in place.

Ocean energy has the potential to provide low cost, environmentally friendly and secure energy. The sector also promises economic growth and job creation in coastal regions that are often most in need of invigoration. However, there is potential for negative impacts on marine ecosystems and much public support will be required to bring the sector to a position where it can deliver all anticipated benefits.

As in previous chapters, Table 5 identifies and prioritises the challenges related to socio-economics and the environment which must be tackled to accelerate the development of ocean energy.

Table 5: Identified and prioritised environmental and socio-economic challenges

Priority	Challenge	Description
A	Enhancing social impact and acceptance	Ocean energy has the potential to be of great benefit to society, not least by providing clean, low cost, secure energy and being a source of employment and economic growth. Improving awareness of these benefits will increase public acceptance of the sector.
	Minimising negative environmental impacts	Although the environmental benefits of ocean energy in terms of emissions reductions are understood, the negative impacts that developments may have on the environment require further investigation to allow sufficient mitigation measures to be put in place.
	Facilitating knowledge transfer and collaboration	Given the limited resources available to ocean energy in terms of funding and personnel, knowledge transfer, technology transfer and collaboration (both within the sector and with other sectors) can aid in avoiding duplication of effort and making the most efficient and effective use of resources. Markets outside Europe may provide alternative challenges and opportunities which can offer significant learning.
	Implementing adaptive management systems	Ocean energy technology developments lend themselves well to adaptive management techniques, whereby development activities are recursive, incorporating lessons learnt during previous cycles. These lessons learnt can also be valuably fed back to regulators and funders.
B	Implementing training programmes	An expanding ocean energy sector will require ever greater numbers of skilled workers and instigating training programmes as early as possible will ensure sufficient skills are available as the sector grows.
	Expanding research infrastructures	Many world-class research organisations operate in the European ocean energy sector. Improving links between these organisations will ensure that the highest quality research outputs are generated in the most efficient manner.
C	Improving resource assessment and site selection techniques	Higher quality methods of assessing wave and tidal resource values will assist in selecting the most appropriate sites for a development and in allowing better modelling of future yields and returns on investment.

7. Conclusions

7.1 Priority Challenges

Table 6 summarises the sector challenges identified in Sections 4, 5 and 6. They are sorted by priority level and categorised as either technology, finance or environment & socio-economics.

Table 6: Summary of priority sector challenges

Priority	Category	Challenge
A	Technology	Developing novel concepts for improved power take-offs (PTOs)
		Increasing device reliability and survivability
		Investigating alternative materials and manufacturing processes for device structures
		Investigating novel devices before moving towards convergence of design
		Defining and enforcing standards for stage progression through scale testing
		Developing and implementing optimisation tools
	Financial	Providing warranties and performance guaranties
		Linking stage-gate development processes to funding decisions
		Maintaining grant funding for early TRL technologies
		Establishing long term revenue support
	Environmental and socio-economics	Enhancing social impact and acceptance
		Minimising negative environmental impacts
		Facilitating knowledge transfer and collaboration
		Implementing adaptive management systems
B	Technology	Building on existing guidelines and standards for third-party verification and testing
		Developing improved, more cost effective mooring and foundation systems
		Implementing suitable condition monitoring systems
		Improving the efficiency and cost-effectiveness of electrical subsystems and power electronics
		Optimising offshore operations and maintenance missions
		Developing dedicated vessels and tools
	Financial	Maintaining investment support
		Advancing engagement with insurance providers
		Improving cost models for ocean energy developments
	Environmental and socio-economics	Implementing training programmes
		Expanding research infrastructures
C	Technology	Developing expertise related to the manufacture of ocean energy technologies
		Scaling up from single device deployments to arrays
	Financial	Ensuring stable policy, regulation and legislation
	Environmental and socio-economics	Improving resource assessment and site selection techniques

Several of the challenges identified above could in fact be categorised under more than one of the three themes. For example, "improving resource assessment and site selection techniques," could be considered an environmental issue or a technological one. For the

purposes of this document, challenges have been categorised under the closest fitting theme. However, discussion during knowledge sharing activities will not be restricted to a single theme, allowing thorough investigation of each challenge by the broadest possible range of stakeholders.

7.2 Addressing the Challenges

ETIP Ocean will host a range of knowledge exchange activities with topics based on the priorities identified in this report. Each activity will facilitate discussion, knowledge exchange and collaboration amongst a diverse group of stakeholders. ETIP Ocean will encourage stakeholders to share all facets of their knowledge and experience, noting that the sharing of negative experiences and lessons learned can be of great value.

The results of these activities will be synthesised and the final output of the project will be an integrated strategy for the ocean energy sector. This strategy document will identify methods of overcoming the challenges faced by the sector, mapping a pathway for the accelerated development and commercialisation of ocean energy.

ETIP Ocean will also endeavour to identify the stakeholders (e.g. industry bodies, research organisations, governments) best suited to tackle each priority challenge, along with the geographical scale (e.g. EU-wide, member state, regional or local authority) at which each challenge should be addressed. At this point in the ETIP Ocean project it is assumed that each challenge is best tackled at an EU-wide level and through collaboration across a broad range of stakeholders. This assumption will be investigated and refined in the course of upcoming knowledge exchange activities.

In parallel to this study of sector challenges and strategy, ETIP Ocean will engage in activities targeted at engagement with civil society and educating the next generation of ocean energy workers. This will enhance social acceptance of ocean energy technologies and help ensure that an appropriately skilled workforce is in place to allow the continued expansion of the sector.

7.3 A Concise Summary of Challenges Facing the Ocean Energy Sector

In preparing this document, a variety of highly regarded ocean energy roadmap and strategy documents were reviewed, with a particular focus on previous ETIP Ocean and Ocean Energy Forum outputs. Commonly highlighted challenges to sector development were extracted from these studies and have been summarised. Furthermore, a custom scoring methodology was applied to ascertain the relative importance of the challenges and assign a priority to each.

This report provides a concise summary of the challenges faced by the ocean energy sector in the pursuit of commercialisation and will form the basis of all forthcoming ETIP Ocean activities.

8. Appendix I – Methodology

The purpose of this methodology is to synthesise a large number of challenges to sector development, identified from a broad range of sources, allowing for their prioritisation and the selection of the most crucial.

Each challenge is classified as related to one of three topics: technology, finance or socio-economics & environment, as shown in Table 7.

Table 7: Challenges to sector development categorised by Theme

Technology	Finance	Socio-economics & Environment
Challenge 1 (e.g. Control Systems)	Challenge 2 (e.g. Stable Support Mechanisms)	Challenge 3 (e.g. Environmental Permitting)
Challenge 4	Challenge 5	Challenge 6
Challenge 7		Challenge 8
Challenge 9		

Each challenge is given a score corresponding to the importance with which it must be overcome to suit the needs of sector development. Each challenge is assessed according to criteria similar to those laid out in Table 8, which gives example criteria for the Technology theme.

For each challenge, a score of 1, 2 or 3 is awarded to each criterion, and each criterion is further weighted to represent the relative importance of each.

Table 8: Technology theme - challenge assessment criteria

Assessment Criterion	Description	Weighting (%)
Sector urgency	How important is it to the sector that the challenge is tackled rapidly?	14
Cost reduction potential (impact on CAPEX)	What impact will tackling the challenge have on ocean energy project CAPEX?	10
Cost reduction potential (impact on OPEX)	What impact will tackling the challenge have on ocean energy project OPEX?	12
Cost reduction potential (installation, deployment and retrieval)	What impact will tackling the challenge have on ocean energy installation, deployment and retrieval costs?	10
Impact on technical risk and survivability	What impact will tackling the challenge have on the technical risk and survivability of ocean energy systems?	12
Level of adaptation required	How much adaptation would be required to apply existing solutions in other sectors to the ocean energy sector?	8
Performance improvement	What impact will tackling the challenge have on the performance of ocean energy systems?	12
Array development and assessment	What level of progress in array development will result from tackling the challenge?	14

Commonality	To what degree will overcoming the challenge be useful in sectors other than ocean energy (e.g. offshore wind)?	8

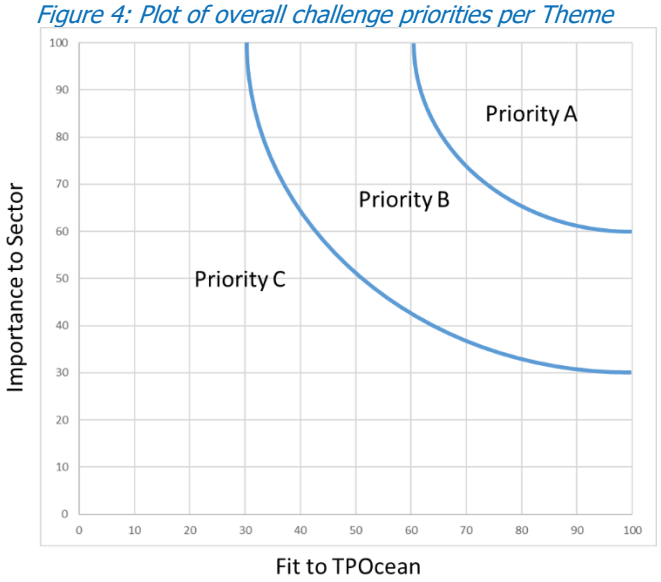
The degree to which the tackling of each challenge can be facilitated by the ETIPOcean project is also determined. In a similar manner as an "Importance" score is awarded, each challenge is awarded a "Fit-to-ETIPOcean" score, according to the criteria and weightings laid out in Table 9. The same criteria are applicable across all themes.

Table 9: Fit to ETIP Ocean - challenge assessment criteria

Assessment Criterion	Description	Weighting (%)
ETIP Ocean additionality	How much impact can the ETIP Ocean programme have in tackling the challenge?	40
Fit with ETIP Ocean objectives	To what degree would tackling the challenge contribute to the goals of ETIP Ocean?	30
Value of a cross-European approach	To what degree would collaboration and coordination across member states aid the tackling of the challenge?	30

The "Importance" and "Fit" scores are normalised to 100 for each challenge, and are plotted on charts similar to the one shown in Figure 4 where the "Fit" score provides the x-axis value and the "Importance" score provides the y-axis value. One chart is produced for each of the three themes.

Figure 4: Plot of overall challenge priorities per Theme



The challenges falling into the upper priority regions of these plots will go forward to form the content of ETIP Ocean knowledge exchange and education activities. The final priorities given here are the priorities with which a challenge should be tackled within ETIP Ocean. This is not necessarily the same as the priority of a challenge in the sector as a whole as consideration is given to how well-equipped the ETIP Ocean project is to assist in tackling a given challenge.

This methodology therefore identifies the challenges to sector development which:

- are of greatest importance to the sector,
- can be tackled more effectively with the aid of the ETIP Ocean project.

9. Appendix II – Allocated Priority Scores

Figures Figure 5 to Figure 7 provide an overview of the scores allocated to each challenge through application of the methodology described in Appendix I. The challenges appearing in the upper region of these charts have been designated "Priority A" and are those which have been selected for further investigation over the course of the ETIP Ocean project.

Figure 5: Technology theme priority scores

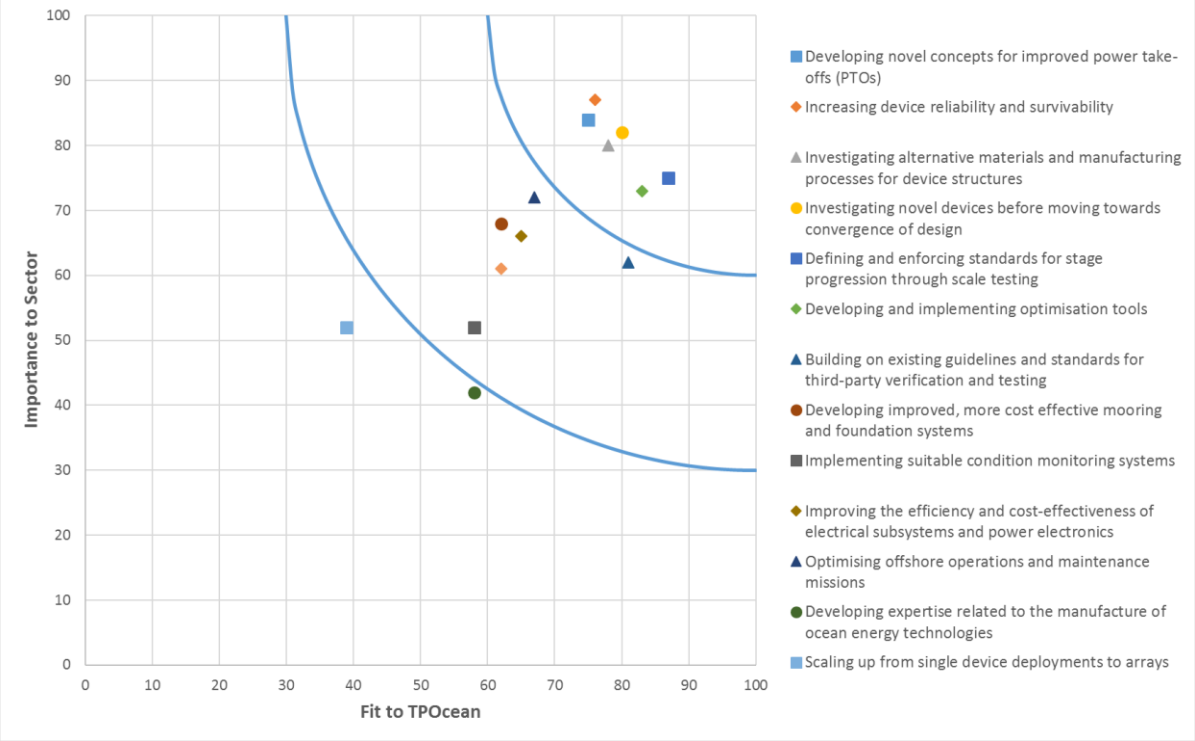


Figure 6: Finance theme priority scores

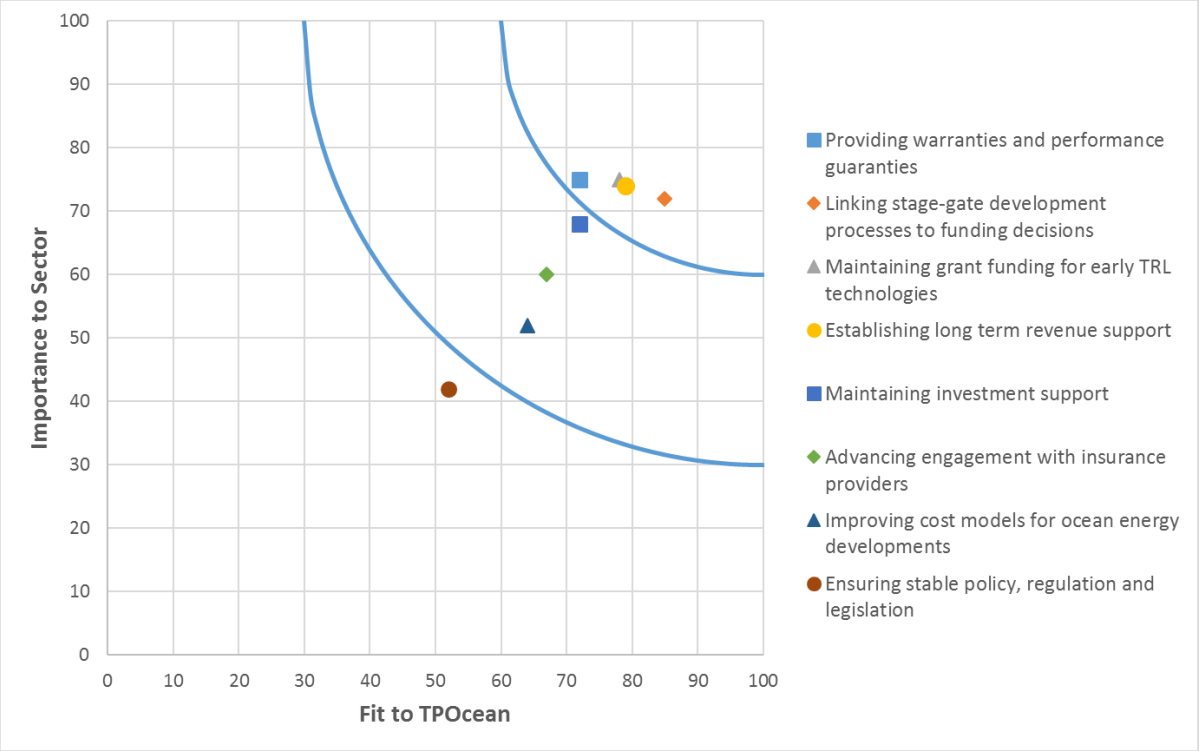
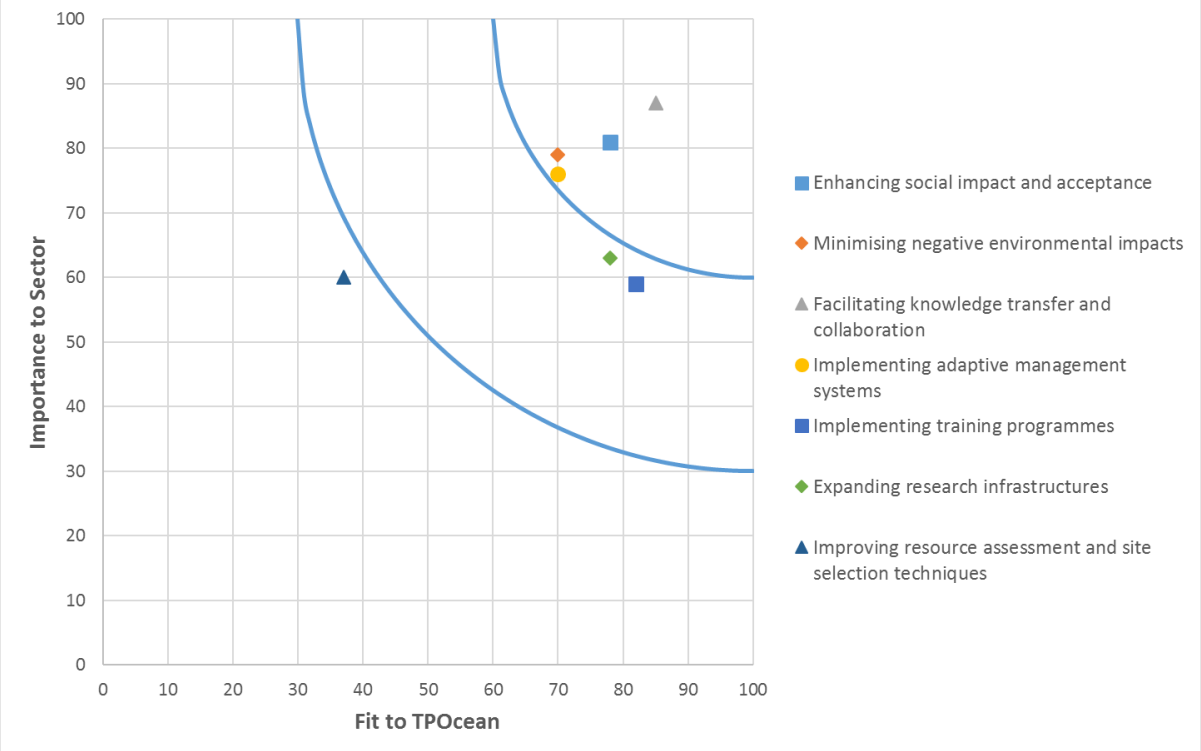


Figure 7: Environment and socio-economics theme priority scores



10. Appendix II - List of Figures

11. Appendix III - List of Tables