Deliverable 2.1: An Integrated Framework of Ocean Energy Sector Challenges

Final Report

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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 TPOcean, 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 TPOcean 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>
<thead>
<tr>
<th>Category</th>
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</tr>
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<tbody>
<tr>
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<td></td>
<td>Implementing adaptive management systems</td>
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</tbody>
</table>

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

TPOcean 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.

TPOcean 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 TPOcean’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.

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

<table>
<thead>
<tr>
<th>Authoring Organisation</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPOcean</td>
<td>Strategic Research Agenda for Ocean Energy</td>
<td>2016</td>
</tr>
<tr>
<td>Foundation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SI Ocean</td>
<td>Ocean Energy Technology: Gaps and Barriers</td>
<td>2013</td>
</tr>
<tr>
<td>European Energy Research Alliance (EERA)</td>
<td>Ocean Energy Description of Work, version 2</td>
<td>2015</td>
</tr>
<tr>
<td>European Commission</td>
<td>Strategic Energy Technology Plan</td>
<td>2015</td>
</tr>
</tbody>
</table>
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.

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,

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

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4 Adapted from Wave Energy Scotland materials.
Figure 2 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.

![Figure 2: Development phases of ocean energy devices and arrays with corresponding TRLs](image)

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 TPOcean. 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.

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<table>
<thead>
<tr>
<th>Priority</th>
<th>Challenge</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Developing novel concepts for improved power take-offs (PTOs)</td>
<td>Work to improve the performance, reliability and cost of PTOs will help maximise energy capture.</td>
</tr>
<tr>
<td></td>
<td>Increasing device reliability and survivability</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Investigating alternative materials and manufacturing processes for device structures</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Investigating novel devices before moving towards convergence of design</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Defining and enforcing standards for stage progression through scale testing</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Developing and implementing optimisation tools</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Building on existing guidelines and standards for third-party verification and testing</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Developing improved, more cost effective mooring and foundation systems</td>
<td>Mooring and foundation systems (particularly their installation and maintenance) currently represent a very significant portion of overall project costs.</td>
</tr>
<tr>
<td></td>
<td>Implementing suitable condition monitoring systems</td>
<td>Condition monitoring allows for condition based maintenance systems, streamlining O&amp;M and delivering high reliability.</td>
</tr>
<tr>
<td></td>
<td>Improving the efficiency and cost-effectiveness of electrical subsystems and power electronics</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Optimising offshore operations and maintenance missions</td>
<td>Manned offshore O&amp;M missions are expensive, risky and time consuming. Periods of suitable weather conditions for O&amp;M missions can be short and infrequent, potentially leading to extended downtime for array components. Remote O&amp;M systems may mitigate such issues.</td>
</tr>
<tr>
<td></td>
<td>Developing dedicated vessels and tools</td>
<td>Tools and vessels tailored to the specific needs of ocean energy O&amp;M missions will allow more optimal use of limited weather windows.</td>
</tr>
<tr>
<td>B</td>
<td>Developing expertise related to the manufacture of ocean energy technologies</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Scaling up from single device deployments to arrays</td>
<td>Significant cost reductions can be achieved through economies of scale while utility scale developments are of greater commercial appeal.</td>
</tr>
</tbody>
</table>
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*  

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.

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<table>
<thead>
<tr>
<th>Priority</th>
<th>Challenge</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Providing warranties and performance guarantees</td>
<td>Warranties and guarantees 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.</td>
</tr>
<tr>
<td></td>
<td>Linking stage-gate development processes to funding decisions</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Maintaining grant funding for early TRL technologies</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Establishing long term revenue support</td>
<td>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.</td>
</tr>
<tr>
<td>B</td>
<td>Maintaining investment support</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Advancing engagement with insurance providers</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Improving cost models for ocean energy developments</td>
<td>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.</td>
</tr>
<tr>
<td>C</td>
<td>Ensuring stable policy, regulation and legislation</td>
<td>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.</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Priority</th>
<th>Challenge</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Enhancing social impact and acceptance</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Minimising negative environmental impacts</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Facilitating knowledge transfer and collaboration</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Implementing adaptive management systems</td>
<td>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.</td>
</tr>
<tr>
<td>B</td>
<td>Implementing training programmes</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Expanding research infrastructures</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Improving resource assessment and site selection techniques</td>
<td>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.</td>
</tr>
</tbody>
</table>
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>
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<td></td>
<td></td>
<td>Implementing adaptive management systems</td>
</tr>
<tr>
<td>B</td>
<td>Technology</td>
<td>Building on existing guidelines and standards for third-party verification and testing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Developing improved, more cost effective mooring and foundation systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implementing suitable condition monitoring systems</td>
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<td></td>
<td>Improving the efficiency and cost-effectiveness of electrical subsystems and power electronics</td>
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<td>Implementing training programmes</td>
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<tr>
<td></td>
<td></td>
<td>Expanding research infrastructures</td>
</tr>
<tr>
<td>C</td>
<td>Technology</td>
<td>Developing expertise related to the manufacture of ocean energy technologies</td>
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<td>Scaling up from single device deployments to arrays</td>
</tr>
<tr>
<td></td>
<td>Financial</td>
<td>Ensuring stable policy, regulation and legislation</td>
</tr>
<tr>
<td></td>
<td>Environmental and socio-economics</td>
<td>Improving resource assessment and site selection techniques</td>
</tr>
</tbody>
</table>

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
TPOcean 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. TPOcean 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.

TPOcean 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 TPOcean 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, TPOcean 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 TPOcean 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 TPOcean 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>
<thead>
<tr>
<th>Technology</th>
<th>Finance</th>
<th>Socio-economics &amp; Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge 1 (e.g. Control Systems)</td>
<td>Challenge 2 (e.g. Stable Support Mechanisms)</td>
<td>Challenge 3 (e.g. Environmental Permitting)</td>
</tr>
<tr>
<td>Challenge 4</td>
<td>Challenge 5</td>
<td>Challenge 6</td>
</tr>
<tr>
<td>Challenge 7</td>
<td></td>
<td>Challenge 8</td>
</tr>
<tr>
<td>Challenge 9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Assessment Criterion</th>
<th>Description</th>
<th>Weighting (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector urgency</td>
<td>How important is it to the sector that the challenge is tackled rapidly?</td>
<td>14</td>
</tr>
<tr>
<td>Cost reduction potential (impact on CAPEX)</td>
<td>What impact will tackling the challenge have on ocean energy project CAPEX?</td>
<td>10</td>
</tr>
<tr>
<td>Cost reduction potential (impact on OPEX)</td>
<td>What impact will tackling the challenge have on ocean energy project OPEX?</td>
<td>12</td>
</tr>
<tr>
<td>Cost reduction potential (installation, deployment and retrieval)</td>
<td>What impact will tackling the challenge have on ocean energy installation, deployment and retrieval costs?</td>
<td>10</td>
</tr>
<tr>
<td>Impact on technical risk and survivability</td>
<td>What impact will tackling the challenge have on the technical risk and survivability of ocean energy systems?</td>
<td>12</td>
</tr>
<tr>
<td>Level of adaptation required</td>
<td>How much adaptation would be required to apply existing solutions in other sectors to the ocean energy sector?</td>
<td>8</td>
</tr>
<tr>
<td>Performance improvement</td>
<td>What impact will tackling the challenge have on the performance of ocean energy systems?</td>
<td>12</td>
</tr>
<tr>
<td>Array development and assessment</td>
<td>What level of progress in array development will result from tackling the challenge?</td>
<td>14</td>
</tr>
</tbody>
</table>
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 TPOcean project is also determined. In a similar manner as an “Importance” score is awarded, each challenge is awarded a “Fit-to-TPOcean” score, according to the criteria and weightings laid out in Table 9. The same criteria are applicable across all themes.

<table>
<thead>
<tr>
<th>Assessment Criterion</th>
<th>Description</th>
<th>Weighting (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPOcean additionality</td>
<td>How much impact can the TPOcean programme have in tackling the challenge?</td>
<td>40</td>
</tr>
<tr>
<td>Fit with TPOcean objectives</td>
<td>To what degree would tackling the challenge contribute to the goals of TPOcean?</td>
<td>30</td>
</tr>
<tr>
<td>Value of a cross-European approach</td>
<td>To what degree would collaboration and coordination across member states aid the tackling of the challenge?</td>
<td>30</td>
</tr>
</tbody>
</table>

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.

The challenges falling into the upper priority regions of these plots will go forward to form the content of TPOcean knowledge exchange and education activities. The final priorities given here are the priorities with which a challenge should be tackled within TPOcean. 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 TPOcean 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 TPOcean project.
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