ETIPOCEAN

European Technology & Innovation Platform for Ocean Energy

Deliverable 2.1

Report on the prioritisation of research, technology and innovation

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1. Executive Summary

The European Technology and Innovation Platform for Ocean Energy (ETIP Ocean) is funded by the European Commission to define research and innovation priorities for the ocean energy sector and promote solutions to the industry, European and national policy makers.

This report outlines a prioritised list of updated technology challenges to commercialisation of wave and tidal energy, alongside the prioritisation methodology and scoring criteria employed to prioritise this list. The purpose of this report is to serve as a list of key technology development requirements in the ocean energy sector. This deliverable provides a summary of a wide range of material containing prioritised challenges, therefore summarising technological challenges found, through prior work, to be of a high priority to the sector, under a number of criteria.

Building on the content of the Strategic Research Agenda for Ocean Energy (2016), this deliverable will be used in the creation of the Strategic Research and Innovation Agenda (SRIA). The SRIA will further the work carried out in this report by outlining technological priority areas, objectives and actions that will encourage the commercialisation of ocean energy in Europe.

Key technology development requirements for the advancement of a commercial ocean energy sector will be produced in the SRIA, making reference to the list contained in this report. Concurrently, an assessment of industry progress against each challenge has been made. Examples of European effort against the challenges are presented in this report, making reference to industrial updates such as that contained within the IEA-OES Annual Report 2018.

The key findings presented in this report comprise 61 challenges within 11 challenge areas. The challenges underwent prioritisation on two criteria by the ETIP Ocean consortium, to establish their overall importance to the sector. This prioritisation process, coupled with engagement with the ETIP Ocean Technology Working Group (TWG), validated the finding that the vast majority of challenges identified are of a high priority to the sector on the metrics of the level of dependence of the sector's progression on the challenge being overcome, and the opportunity offered Europe to overcome each challenge.

This report will feed into the creation of the SRIA, for delivery in early 2020, which will define specific objectives and actions to carve the path towards ocean energy commercialisation.

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Acronyms

BEIS	Department for Business, Energy and Industrial Strategy
EINA	Energy Innovation Needs Assessment
ETIP Ocean	European Technology and Innovation Platform for Ocean Energy
FORESEA	Funding Ocean Energy through Strategic European Action
HV	High Voltage
IEA-OES	International Energy Agency – Ocean Energy Systems
MaRINET2	Marine Renewables Infrastructure Network for Enhancing Energy Technologies
MEA	Marine Energy Alliance
PTO	Power Take Off
TWG	Technology Working Group
SC	Steering Committee
SRIA	Strategic Research and Innovation Agenda
WaTERS	Wave and Tidal Energy Research Sites

2. **Introduction**

The European Technology and Innovation Platform for Ocean Energy (ETIP Ocean) is funded by the European Commission to define research and innovation priorities for the ocean energy sector and promote solutions to the industry, European and national policy makers.

Work package 2 of ETIP Ocean focuses on the technological research and innovation priorities. This report outlines a prioritised list of up-to-date technological challenges to commercialisation of wave and tidal energy, alongside the prioritisation methodology and scoring criteria which was employed in prioritising this list.

Key technology development requirements for the advancement of a commercial ocean energy sector will be produced through prioritisation of the list contained in this report. This will be used in the creation of the ETIP Ocean Strategic Research and Innovation Agenda (SRIA). The SRIA will further the work carried out in this report by outlining technological priority areas, objectives and actions that will encourage the commercialisation of ocean energy in Europe.

This report furthers the work carried out to produce the list of technology challenges within D2.1 of ETIP Ocean's first iteration, *An Integrated Framework of Ocean Energy Sector Challenges* [1]*.* Compiled and prioritised in 2014, this list provides a solid base, however the sector has progressed in the interim years so revision of this list and its compilation and scoring methodologies is necessary. The list content now derives from a wide range of reports and roadmaps released since the publication of [1], such as the Joint Research Centre's (JRC) *Ocean Energy Status Report*, 2016 [2] and ETIP Ocean's *Deliverable 8.5: Report on presentation of stakeholder engagement results workshop* [3]. One significant source was *Energy Innovation Needs Assessment (EINA) Workshop Report (2019)* [4], by the Carbon Trust in association with the Department for Business, Energy and Industrial Strategy (BEIS).

Concurrently, an assessment of industry progress against each challenge has been made through review of the State of the Art (SOA) of wave and tidal energy technologies and progress updates by technology development firms. Exemplary European efforts against the challenges have been identified, making reference to industrial updates such as that contained within the IEA-OES Annual Report 2018 [5].

2.1 Stakeholder Engagement

The list and scoring methodology presented in this report underwent review and validation by ETIP Ocean platform stakeholders, specifically the TWG, according to the criteria outlined in Section 4.1.

The TWG was consulted on the list of challenges and the scoring methodology applied in their prioritisation. Their feedback was gratefully received and implemented, and it is this revised list and methodology that is contained within this report.

The newly-reformed TWG has 63 members including device developers, project developers, OEMs, funders, regulators, research community and academia. The TWG is comprised of the range of roles described in Table 1.

Table 1 Composition of TWG

Organisation type	Number of members
Research	19
Technology Developer	14
Supply Chain	12
Test site	7
Utility	4
Manufacturer	1

Engagement provided valuable insight gained from knowledge and expertise of the TWG. Following their feedback, three new challenges were added, seven challenges were reworded for clarity and 20 scores were adjusted.

The results of this prioritisation exercise were also presented to the ETIP Ocean Steering Committee (SC) in order to add additional value to the work produced, from a policy perspective.

The primary qualitative feedback received concerned the scoring of the challenges. Some feedback was received which raised the question that, if everything is 'high priority', then nothing is. This was addressed through clarification that, given that the source material had already been validated, the scoring task served more to validate the continuing high priority of the content of the new list of challenges, than to rank the challenges relative to each other. Other, positive, feedback was also received, stating approval of the scoring criteria and exercise.

Further qualitative feedback suggested rephrasing certain challenges which were phrased as actions. This list is intended as a spotlight on difficulties which must be overcome by the sector, and does not specify the actions that must be taken to do so. This feedback has been implemented.

3. Compilation of Technology Challenges

The original list of challenges outlined in *An Integrated Framework of Ocean Energy Sector Challenges* [1] has been rewritten to reflect the interim progress of the sector towards overcoming those challenges. A number of industry, policy and academic sources have been consulted for these updates. Table 2 itemises the source material referenced for both the original and updated lists of technology challenges. The *Updated List* rows contain publications contributing to this report, while the *Original Challenges* rows contain material fed into the original list, which therefore remains the backbone of the new list. One significant source referenced was *Energy Innovation Needs Assessment (EINA) Workshop Report (2019)*, delivered by the Carbon Trust in association with Department for Business, Energy and Industrial Strategy (BEIS) [4]. This tidal-focused list was expanded to include equivalent wave technology challenges, adapted to suit the needs of the ETIP Ocean platform, and augmented with recently published content. The 'innovation opportunities' within the EINA workshop report have been adapted to instead describe technology challenges to commercialisation, as per the requirement of the SRIA and to foster continuity with the original list format.

Table 2 Source material consulted for the previous and updated prioritised lists of technology challenges

	Author	Title	Year
Updated challenges	Carbon Trust	Energy Innovation Needs Assessment (EINA) Workshop Report [4]	2019
	Joint Research Council (JRC)	Ocean Energy Status Report [2]	2016
	ETIP Ocean	D8.5 Report on presentation of stakeholder engagement results workshops [3]	2018
	Wave Energy Scotland (WES)	Landscaping topics [6]	2016 - 2019
	Supergen ORE Hub	Research Challenges [7]	2019
Previous Challenges	TPOcean	Strategic Research Agenda for Ocean Energy [8]	2016
	Ocean Energy Forum (OEF)	Ocean Energy Strategic Roadmap: Building Ocean Energy for Europe [9]	2016
	SI Ocean	Ocean Energy Technology: Gaps and Barriers [10]	2013
	International Energy Agency-Ocean Energy Systems (IEA-OES)	International Ocean Energy Technologies: Synergies with Other Industrial Sectors [11]	2016
	European Energy Research Alliance (EERA)	Ocean Energy Description of Work, v2 [12]	2015
	European Commission (EC)	Strategic Energy Technology (SET) Plan [13]	2015

4. Prioritisation Methodology

This section outlines the approach to be taken to test the validity of the high-priority status of the technology challenges to commercialisation listed in this report, based on the extent to which each challenge is crucial to the development of the sector and presents opportunity to Europe. The purpose of this exercise is to compile a comprehensive list of the technology challenges to overcome as the ocean energy sector moves towards commercialisation, before conducting thorough analysis and validation to confirm that the content of the list of challenges remains robust and relevant in terms of sector need and opportunity offered to Europe in overcoming each challenge.

4.1 Prioritisation of Challenges

The challenges are prioritised according to both the level to which they are currently an obstacle to the development of the sector and the extent of opportunity offered to Europe to overcome the challenges. Each challenge on the list was therefore scored on two axes, receiving a score of 1 to 5 (from low to high) for each criterion, producing a final scale of challenges from highest to lowest. The scoring criteria of both axes are further weighted to represent their relative priority to overcoming the challenges.

The challenges were scored from 1 to 5 on questions within two criteria: the dependence of the sector on this challenge being overcome, and the opportunity afforded Europe to play a significant role in overcoming the challenge. Sub-criteria on which each challenge should be assessed were identified and weighted according to their contribution to the overall criteria score. These sub-criteria are explored in more detail in 4.1.1 and 4.1.2. Corresponding questions on which to score each challenge between 1 and 5 were developed. Finally, the weighted scores from the respondents were averaged out to give a single score for each challenge.

The weighting of each criterion has been adapted from the original deliverable, D2.1 of ETIP Ocean's first iteration, on which this list is based. The original weightings underwent validation by the ETIP Ocean platform. The subsequent, amended scoring criteria presented in this report, has again been validated through engagement with the TWG.

4.1.1 Dependence of Sector Development on Resolution of Challenges

The horizontal axis maps the level to which the progression of the sector is depending on the challenge being overcome. Table 3 shows the scoring criteria for assessing the importance of each challenge to sector development.

Table 3 Criteria for assessing the importance of the challenge to sector development

Assessment Criterion	Description	Weighting (%)
Sector urgency	How important is it to the sector that the challenge is tackled rapidly?	20
Cost reduction potential (impact on CAPEX)	What impact will tackling the challenge have on ocean energy project CAPEX?	20
Cost reduction potential (impact on OPEX)	What impact will tackling the challenge have on ocean energy project OPEX?	20
Impact on performance (energy yield and efficiency)	What impact will tackling the challenge have on the energy yield and efficiency performance of ocean energy systems?	15
Impact on reliability, technical risk and survivability	What impact will tackling the challenge have on reliability, technical risk, and survivability of ocean energy systems?	15
Cross-cutting	How diverse is the range of other ocean energy technologies and other sectors that stand to benefit from the resolution of this challenge?	10

The criteria weighted the highest are: the urgency with which the sector needs to overcome the challenge; the cost reduction potential in resolving the challenge; and the impact on yield. A challenge will score highly for sector urgency if there is no alternative and the challenge is truly an impediment to the progression of the sector. Similarly, a high-scoring challenge for the cost reduction assessments offers the biggest cost savings by its resolution.

Rated as median importance is the impact of overcoming each challenge on the performance of the energy system, both in terms of energy yield and overall reliability and survivability. A challenge will score highly if overcoming it will achieve significantly improved energy yield from the ocean energy system, or achieve greater reliability and survivability in real-sea conditions.

Finally, the cross-cutting score assesses the applicability of the solution to other ocean energy technologies and, out with the industry, to other sectors.

4.1.2 European Opportunity to Overcome Challenges

These criteria are intended to assess the current opportunity offered to Europe to overcome the challenges; this opportunity is mapped on the vertical axis. By considering sector progress against the original list in terms of the application of funding and effort, and taking into account the capability within the European supply chain, each challenge is scored on the extent to which the European supply chain has the potential to resolve it.

Table 4 shows the scoring criteria for this assessment.

Table 4 Criteria for assessing the level of opportunity afforded to Europe to overcome each challenge

Assessment Criterion	Description	Weighting (%)
Dedicated funding stream	To what extent does this challenge require funding to be overcome?	33
European capability to deliver the solution	How well-placed is the sector in Europe to deliver the solution to this challenge?	33
Risk of duplication	To what extent is work not already being carried out to overcome this challenge?	33

4.2 Mapping the Prioritised Challenges

Once scored according to the methodology above, the challenges are plotted on charts such as the one shown in Figure 1. Here, the dependency of sector progression on the resolution of the challenge is scaled on the x-axis, and the extent of the opportunity afforded Europe in overcoming the challenge is scaled on the y-axis. All challenges have been plotted on one chart, Figure 1, providing a visual reference of the prioritised list.

The challenges have been plotted across each axis in Figure 1. In the top right sit challenges scoring highly on both axes. The sector depends strongly on solutions to these challenges being found in order to progress, and Europe is well-placed to deliver these solutions. The bottom left, therefore, is where challenges on which the sector is not depending for progression, and Europe would have less opportunity to solve in any case sit. The top left and bottom right are where one challenge scored highly on one axis and lower on the other would be found. Challenges in these two latter areas would be candidates for further, qualitative, analysis to assess their importance to the sector in more specific ways.

As evidenced in Figure 1, all challenges sit towards the top right-hand corner of the charts. This demonstrates that all the challenges identified in this piece of work are appropriate for further research and will require attention in the short and medium term. The reason for this lack of diversity in the scores is that they have all already undergone prioritisation in the authorship of the source material. Any low priority challenges have been eliminated at an earlier stage. The consistent scoring in this exercise demonstrates the continued validity of the source material.

The challenges mapped by Challenge Area are contained in [Annex I: Challenge areas](#).

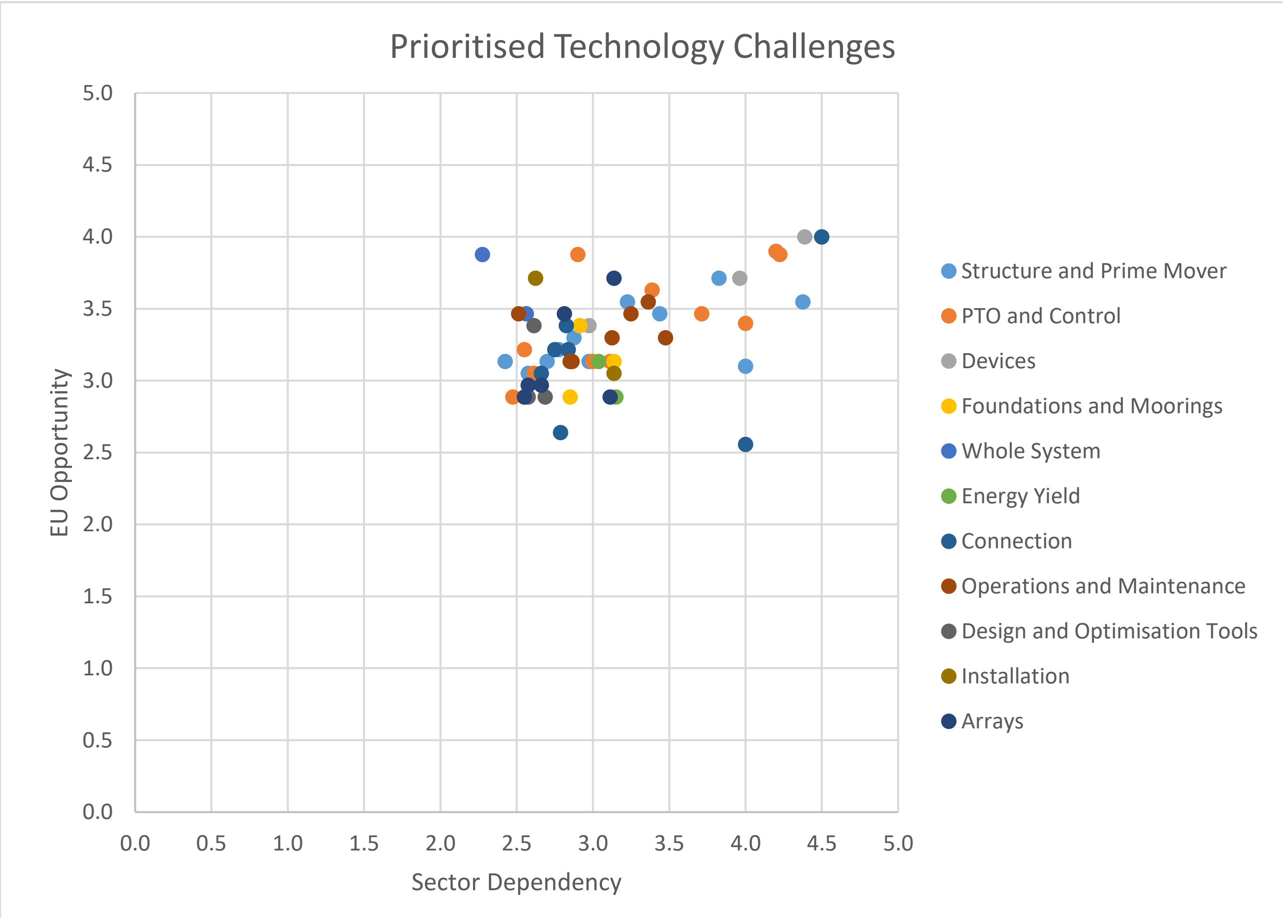

Figure 1 Prioritised Technology Challenges plotted across the two axes

As all of the challenges fall within, or within a small margin of, the highest scoring – and therefore high priority – area of the chart, they will form the content of stakeholder engagement and knowledge sharing activities throughout the duration of ETIP Ocean 2.

4.3 Prioritised List of Challenges

The list of challenges in Table 5 has undergone prioritisation by the consortium according to the scoring methodology outlined in 4.1, followed by validation by the ETIP Ocean Technology Working Group.

Table 5 Prioritised list of Structure and Prime Mover technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Structure and Prime Mover	Novel materials to reduce biofouling, corrosion and extend lifetimes.	Both	4.4	3.5
	Lack of common, recognised and open access dry and wet testing facilities	Both	4.0	3.1
	Development of novel and sustainable materials for device structure	Wave	2.8	3.7
	Development of novel and sustainable materials for device structure	Tidal	2.8	3.5
	Investigation of novel reaction system technology	Wave	2.9	3.3
	Advanced manufacturing and design processes	Wave	3.0	3.1
	Advanced manufacturing and design processes	Tidal	2.7	3.1
	Difficulty testing novel reaction system designs at part scale in relevant environment	Wave	2.8	3.2
	Lack of subcomponent validation and certification systems	Wave	2.4	3.1
	Lack of subcomponent validation and certification systems	Tidal	2.6	3.1
	Lack of new and improved tidal blade technology investigation	Tidal	3.2	3.5

Table 6 Prioritised list of PTO and Control technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
PTO and Control	Insufficient access to dry and wet test facilities	Both	4.2	3.9
	Lack of integrated design of control system within device as a whole	Both	2.6	3.1
	Demonstration and improvement of current PTO technology e.g. control systems, gearbox, direct drive, power electronic conversion	Wave	4.2	3.9
	Demonstration and improvement of current PTO technology e.g. control systems, gearbox, direct drive, power electronic conversion	Tidal	3.7	3.5
	Early stage research for disruptive PTO technologies	Wave	2.9	3.9
	Early stage research for disruptive PTO technologies	Tidal	2.6	3.2
	Improved control systems for wave energy devices, particularly for extreme conditions	Wave	3.4	3.6
	Lack of controls systems guidelines and specifications	Wave	3.0	3.1
	Lack of controls systems guidelines and specifications	Tidal	3.5	2.9
	Need for improved pitch and yaw technology investigation & demonstration	Tidal	4.0	3.1
	Investigation on PTO interaction with WEC operating modes	Wave	4.0	3.4

Table 7 Prioritised list of Devices technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Devices	Cost, performance and reliability improvements to existing devices	Both	4.4	4.0
	Development of novel devices at TRL 3-6 and investigation into alternative generation methods	Wave	4.0	3.7

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
	Development of novel devices and investigation into alternative generation methods	Tidal	3.0	3.4

Table 8 Prioritised list of Foundations and Moorings technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Foundations and Moorings	Advanced mooring development & demonstration	Wave	4.5	4.0
	Advanced mooring development & demonstration	Tidal	2.9	3.4
	Advanced foundation development & demonstration	Wave	2.9	2.9
	Advanced foundation development & demonstration	Tidal	3.1	3.1

Table 9 Prioritised list of Whole System technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Whole System	Improving integration with the wider energy system from the nascent design stage through to array deployment to provide added value.	Both	3.5	3.5
	Developing grid-level system balancing benefits from wave and tidal electricity generation	Both	3.5	3.5

Table 10 Prioritised list of Energy Yield technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Energy Yield	Wave resource modelling – Better near-field wave forecasting and measurement to improve controllability and yield of devices as well as survivability.	Wave	3.0	3.1

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
	Tidal resource modelling – its impact on yield as well as on reliability –blades and PTO loading	Tidal	3.2	2.9

Table 11 Prioritised list of Connection technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Connection	Installation of cables in challenging and high-energy seabed conditions	Both	4.0	2.6
	Improvements to wet mate and dry mate connectors	Both	4.5	4.0
	HV sub-sea hub	Both	3.8	3.4
	Standardised subsea hubs	Both	2.8	3.2
	Dynamic umbilical connection	Both	2.8	3.2
	Standardised electrical architecture & connections	Both	2.7	3.1
	Wave: Investigation on cable stability, repairability and survivability	Wave	2.8	2.6

Table 12 Prioritised list of Operations and Maintenance technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Operations and Maintenance	Development of bespoke support vessels	Both	2.5	3.5
	Design and demonstration of improved physical maintenance procedures	Wave	3.4	3.5
	Design and demonstration of improved physical maintenance procedures	Tidal	3.5	3.5
	Predictive maintenance techniques for wave devices	Wave	3.1	3.3

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
	Predictive maintenance techniques for tidal devices	Tidal	3.5	3.3
	Instrumentation for condition monitoring of wave devices	Wave	3.1	3.3
	Instrumentation for condition monitoring of tidal devices	Tidal	3.5	3.3
	Design and optimisation of systems to ease design for maintenance	Wave	2.9	3.1
	Design and optimisation of systems to ease design for maintenance	Tidal	3.5	3.1

Table 13 Prioritised list of Design and Optimisation Tools technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Design and Optimisation Tools	Limitations to research in gathering, distributing, employing and protecting data within tools	Both	2.6	3.4
	Need for development of fully integrated or coupled simulation design tools	Both	2.7	2.9
	Need for improved analytics in development and implementation of optimisation tools	Both	2.6	2.9

Table 14 Prioritised list of Installation technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Installation	Need for development of bespoke installation vessels	Both	2.6	3.7
	Need for new and improved installation techniques (e.g. devices, cabling, foundations, anchors)	Both	3.1	3.1
	Decommissioning	Both	3.0	3.0

Table 15 Prioritised list of Arrays technology challenges

Challenge Area	Technology Development Challenge	Tech.	Sector Dependence	EU Opportunity
Arrays	Understanding farm-level wave device interaction	Wave	2.8	3.5
	Array planning & modelling	Wave	2.6	3.0
	Array planning & modelling	Tidal	3.1	2.9
	Array design and impact on cable layout and avoided hub cost	Wave	2.6	2.9
	Array design and impact on cable layout and avoided hub cost	Tidal	2.7	3.0
	Turbulence intensity and wake effects investigation	Tidal	3.1	3.7

5. Industry Progress

This section presents the progress of the industry against each challenge identified as being a technological barrier to the commercialisation of wave and tidal energy generation technology. Industry progress was first assessed against the challenges, and a selection of key current and future targeted funding opportunities are listed, with a view to contextualising the list of challenges within the European industry.

5.1.1 Technology Innovation

A number of examples of European sector efforts to overcome each challenge thus far have been included in this section to provide context to the challenges. Industry progress is defined here as technological achievements at deployment or R&D stage. This content is not exhaustive and simply aims to provide a snapshot into the technological progress against a selection of challenges.

Structure and Prime Mover

The North Sea Solutions for Innovation in Corrosion for Energy (NeSSIE) project produced a Roadmap in 2018 outlining solutions to corrosion challenges facing the sector [23]. To research novel reaction system technologies, Artemis Intelligent Power Ltd.'s Hybrid Digital Displacement hydraulic PTO integrates its own hydraulic digital displacement technology into the ex-Pelamis PTO system. The systems offers continuous variability in control of loads in reaction to the device interaction with wave loads [17]. Concerning the development of novel and sustainable materials for device structure, through the WES-funded Structured Materials and Manufacturing Processes call, the following three projects serve as an example of progression to the highest stage against this challenge: [12] UK-based engineering and design firm ARUP is leading a WES-funded project, Concrete as a Technology Enabler (CREATE) to evaluate the potential for concrete to be used as the primary structural material for WECs. Swedish technology developer, Corpower Ocean will employ polyester and E-Glass in the final iteration of their HydroComp project.

Finally, the lack of common, recognised and open access dry and wet testing facilities is being addressed by FORESEA, whose 5th call for proposals launched in January 2019, and MaRINET2. Five testing facilities of various scales are available in France, and a quarter-scale test site is being developed in Galway, Ireland [15].

PTO and Control

Through the WES-funded PTO call, the following three projects serve as an example of progression to the highest stage in PTO improvement, having been supported through the programme from early stage development [14]. Artemis Intelligent Power Ltd.'s Hybrid Digital Displacement hydraulic PTO integrates its own hydraulic digital displacement technology into the ex-Pelamis PTO system [15]. The generator and prime mover of The University of Edinburgh Project Neptune's C-GEN generator led to increased relability and consequent availability, thanks to minimal moving parts [16]. Umbra Cuscinetti S.p.A's ReBaS generator integrates the recirculating ballscrew and a permanent magnet generator [17].

Devices

Novel devices are being explored in Italy, where the Resonant Wave Energy Converter (REWEC3), integrated OWC breakwater, is under construction [18]. In addition to this, Portugal's IST and Kymaner biradial self-rectifying air turbine, now with new fixed guide vanes, is undergoing testing within an OWC at BiMEP [19]. Similarly, a second new Portuguese self-rectifying WEC design comprising an internal U-shape OWC is being tested at Plymouth University with MaRINET2 [19].

Foundations and Moorings

Work is being carried out on foundations and moorings across Europe, namely by Magallanes Renovelables' floating platform, and SIMEC Atlantis' AR1500, whose gravity-held foundations require no seabed penetration. Sweden's UMACK project, which commenced in 2018, uses a connectivity scheme for its anchor, foundation and mooring system, that addresses affordability, survivability, reliability and installation challenges. [19]. Similarly, within the OPERA project, new elastomeric mooring tethers have been successfully deployed at BiMEP and Sweden's UMACK project, commenced in 2018, uses a connectivity scheme for its anchor, foundation and mooring system, that addresses affordability, survivability, reliability and installation challenges [19].

Design and Optimisation Tools

Danish consulting firm Ramboll lead a WEC modelling verification and validation project that drives primarily at assessing the accuracy of new and existing computational models and tools [19]. Similarly, Srikanth Narasimalu of Singapore coordinates an equivalent project for tidal device modelling verification and validation. Specifically, this project is devoted to the mapping of tidal resource, and has so far implemented an international network of experts in this arena [19]. DTOcean and DTOcean+ develop and demonstrate a suite of design tools for the identification, development and deployment of ocean energy systems [20].

Connection

Research into connections has been carried out by NKT of Sweden's research into dynamic low-voltage cables between buoy and floating hub in a marine energy system, and SIMEC Atlantis' AR2000 array, which uses a subsea connection hub with a single connection cable [23][14]. Software from CABILITY, France, led by Wood developed a set of industry guidelines on cable behaviour in the subsea and seabed environment [17]. Similarly, the Cable Analysis Software Tool (CAST) optimises subsea power cable routes [18].

Arrays

The Deployment Design Tools work of DTOcean+ models site characterisation and array-level energy capture [21]. The tool also focuses in part on the computation of system lifetime costs [22].

Whole System

In France, Guinard Energies has commenced operational sea testing of a 3.5kW hydrokinetic device co-located with solar panels and batteries. Also in France, the Sabella PHARES project collocates two turbines with a wind turbine, PV solar plant and storage capacity, for the purposes of serving an insular community of 2000 inhabitants. The system will be operational by 2020 [19].

5.1.2 Targeted Funding Opportunities

Across Europe, there are funding and development opportunities devoted to addressing a number of specific challenges outlined in Table 5 to 15. This section presents a selection of targeted funding opportunities available, set up with an express view to overcoming some or all of the challenges.

Marine Energy Alliance (MEA) launched its first call for applications in December 2018. The programme is aimed primarily at increasing reliability and resilience of early-TRL device during demonstration phases [24].

Funding Ocean Energy through Strategic European Action (FORESEA) launched its 5th call, aimed at improving access to real-sea test sites, in January 2019. FORESEA itself is funded by the Interreg North West Europe Programme [25].

Wave Energy Scotland (WES) hosts four stage-gate funding calls targeting technology areas requiring attention, namely Structured Materials and Manufacturing Processes, Power Take-Off, Novel Wave Energy Converter, and Materials and Manufacturing.

Sweden's National Energy Agency National Ocean Energy Programme devotes €10.2 million to R&D and demonstration of: improved reliability and durability; the development of systems, subsystems and components for cost-effective conversion of marine energy; technical solutions for cost-effective electrical systems; and improvements to installation and O&M strategies, among other non-technical objectives [19].

MaRINET2 follows MaRINET Infrastructures Network, has as a principle aim the connection of technology developers with testing facilities and accompanying processes. Results of MaRINET2's third call were announced in February 2019 [26]. Similarly, EMEC's International Wave and Tidal Energy Research Sites (WaTERS) Network fosters relationships between global test sights to progress the sector as a whole [27].

6. Next Steps

The list contained within this report is at a high granularity of detail. There is scope for further refinement of the list in preparation of the SRIA to reduce the overall quantity of challenges and render the list more manageable for future research. This future work is ongoing and not fully defined at publication, but may comprise a deep dive into each of the Challenge Areas, further aggregation of the challenges, and removal of any duplication across the challenges. The SRIA will investigate a reduced number (by some method) of challenges.

This report will feed into the creation of the SRIA, for delivery in early 2020, which will define specific objectives and actions to carve the path towards ocean energy commercialisation. Based on the identified priority areas in this report, a draft Strategic Research and Innovation Agenda will be developed. The SRIA will include objectives and actions focussed on the development of the key technology requirements. The SRIA will build upon existing documents such as TP Ocean's 'Strategic Research Agenda', and on lessons learnt from the industry working groups, webinars and workshops. The final Strategic Research and Innovation Agenda will be developed by integrating the results of a Validation Workshop to be held in late 2019. The report will outline the technological priority areas, objectives and actions to encourage the commercialisation of ocean energy in Europe. The SRIA will feed into policy recommendations, as well as the Ocean Energy Roadmap to be produced by ETIP Ocean 2.

7. References

[1] ETIP Ocean, "An Integrated Framework of Ocean Energy Sector Challenges," ETIP Ocean, Brussels, 2014.

[2] JRC, "JRC Ocean Energy Status Report 2016 Edition," European Commission, Brussels, 2016.

[3] ETIP Ocean, "Deliverable 8.5: Report on presentation of stakeholder engagement results workshop," ETIP Ocean, Brussels, 2018.

[4] Carbon Trust, "Energy Innovation Needs Assessment: Tidal Stream," Carbon Trust, London, 2019.

[5] International Energy Agency Ocean Energy Systems (IEA-OES), "Annual Report 2018," IEA-OES, Lisbon, 2018.

[6] Wave Energy Scotland, "Progress Report," Wave Energy Scotland, Inverness, 2016.

[7] Supergen ORE Hub, [Online]. Available: https://www.supergen-ore.net/.

[8] TP Ocean, "Strategic Research Agenda for Ocean Energy," TP Ocean, Brussels, 2016.

[9] Ocean Energy Forum, "Ocean Energy Strategic Roadmap: Building Ocean Energy for Europe," Ocean Energy Forum, Brussels, 2016.

[10] SI Ocean, "Ocean Energy Technology: Gaps and Barriers," SI Ocean, 2013.

[11] IEA-OES, "International Ocean Energy Technologies: Synergies with Other Industrial Sectors," IEA, Edinburgh, 2016.

[12] EERA, "Description of Work (DoW) v2," EERA, Brussels, 2015.

[13] EC, "The Strategic Energy Technology (SET) Plan," EC, Brussels, 2015.

[14] NeSSIE, "Roadmap for Anti-Corrosion Solutions in the Offshore Renewable Energy Sector," NeSSIE, Brussels, 2018.

[15] WES, "Hybrid Digital Displacement hydraulic PTO," WES, 01 01 2019. [Online]. Available: https://www.waveenergyscotland.co.uk/programmes/details/power-take-off/hybrid-digital-displacement-hydraulic-pto-for-wave-energy/. [Accessed 25 04 2019].

[16] WES, "Structured Materials and Manufacturing Processes Projects," WES, 01 01 2019. [Online]. Available: https://www.waveenergyscotland.co.uk/programmes/details/materials/. [Accessed 24 04 2019].

[17] IEA-OES, "Annual Report 2018," IEA-OES, Lisbon, 2018.

[18] WES, "Power Take-Off Projects," WES, 01 01 2019. [Online]. Available: https://www.waveenergyscotland.co.uk/programmes/details/power-take-off/. [Accessed 25 04 2019].

[19] WES, "Project Neptune," WES, 01 01 2019. [Online]. Available: https://www.waveenergyscotland.co.uk/programmes/details/power-take-off/c-gen-direct-drive-pto/. [Accessed 25 04 2019].

[20] WES, "ReBaS Project," WES, 01 01 2019. [Online]. Available: https://www.waveenergyscotland.co.uk/programmes/details/power-take-off/rebas-generator-reciprocating-ball-screw-generator/. [Accessed 25 04 2019].

[21] Wavenergy.it, "REWEC3," 01 01 2017. [Online]. Available: http://www.wavenergy.it/documents/leaflet_weavenergy%20GB.pdf. [Accessed 25 04 2019].

[22] DTOcean+, "The Project," DTOcean+, 01 01 2019. [Online]. Available: https://www.dtoceanplus.eu/. [Accessed 25 04 2019].

[23] [Online]. Available: https://www.nkt.com/media/press-room/news-report/news/nkt-testing-innovative-cables-for-wave-power. [Accessed 02 01 2019].

[24] Marine Energy Biz, "Collaborative project gets to the bottom of cable stability issues," Marine Energy Biz, 26 February 2018. [Online]. Available: https://marineenergy.biz/2018/02/26/collaborative-project-gets-to-the-bottom-of-cable-stability-issues/. [Accessed 19 04 2019].

[25] Mojo Maritime, "Cast - Cable Analysis Software Tool," Mojo Maritime, 01 01 2019. [Online]. Available: http://mojomaritime.com/en/rd/cast/. [Accessed 19 04 2019].

[26] DTOcean+, "WP5 - Deployment Design Tools," DTOcean+, 01 01 2019. [Online]. Available: https://www.dtoceanplus.eu/Project-Structure/WP5-Deployment-Design-Tools. [Accessed 25 04 2019].

[27] DTOcean+, "WP6 - Assessment Design Tools," DTOcean+, 01 01 2019. [Online]. Available: https://www.dtoceanplus.eu/Project-Structure/WP6-Assessment-Design-Tools. [Accessed 25 04 2019].

[28] Marine Energy Alliance, "Marine Energy Alliance opens first call for applications," 17 December 2018. [Online]. Available: https://marineenergy.biz/2018/12/17/marine-energy-alliance-opens-first-call-for-applications/. [Accessed 19 04 2019].

[29] EMEC, "Press Release: FORESEA launches end-of-project call for proposals," EMEC, 07 01 2019. [Online]. Available: http://www.emec.org.uk/press-release-foresea-launches-end-of-project-call-for-proposals/. [Accessed 25 04 2019].

[30] MARINeT2, "About MARINeT2," MARINeT2, 01 01 2019. [Online]. Available: http://www.marinet2.eu/about/. [Accessed 25 04 2019].

[31] EMEC, "About International WaTERS," EMEC, 01 01 2019. [Online]. Available: http://www.internationalwaters.info/. [Accessed 25 04 2019].

[32] Marine Energy Biz, "Marine data gets £500,000 boost," 1 November 2018. [Online]. Available: https://marineenergy.biz/2018/11/01/marine-data-gets-500000-cornish-boost/. [Accessed 19 04 2019].

[33] EMEC, "Press Release: EMEC Metocean Data Open for Innovation Challenge," EMEC, 8 August 2018. [Online]. Available: http://www.emec.org.uk/press-release-emec-metocean-data-open-for-innovation-challenge/. [Accessed 19 04 2019].

[34] SIMEC Atlantis, "AR1500 Tidal Turbine Brochure," SIMEC Atlantis, 2016.

[35] O. C. J. G. J. A. P. Barambones, "A real time sliding mode control for a wave energy converter based on a wells turbine," *Ocean Engineering,* vol. 163, pp. 275-287, 2018.

[36] Arup, "Arup to investigate alternative materials to advance wave power," Arup, 05 04 2017. [Online]. Available: https://www.arup.com/news-and-events/arup-to-investigate-alternative-materials-to-advance-wave-power. [Accessed 22 04 2019].

[37] Wave Energy Scotland, "WES awards £1.4m to three Materials projects," WES, 19 07 2018. [Online]. Available: https://www.waveenergyscotland.co.uk/news-events/wes-awards-14m-to-three-materials-projects/. [Accessed 22 03 2019].

[38] DTOcean+, "WP7 - Integration and Demonstration of Design Tools," DTOcean+, 01 01 2019. [Online]. Available: https://www.dtoceanplus.eu/Project-Structure/WP7-Integration-Demonstration-of-Design-Tools. [Accessed 25 04 2019].

[39] Wave for Energy, "R&D Development," Wave for Energy, 01 01 2019. [Online]. Available: http://www.waveforenergy.com/tech/iswec. [Accessed 25 04 2019].

8. Annex I: Challenge Areas

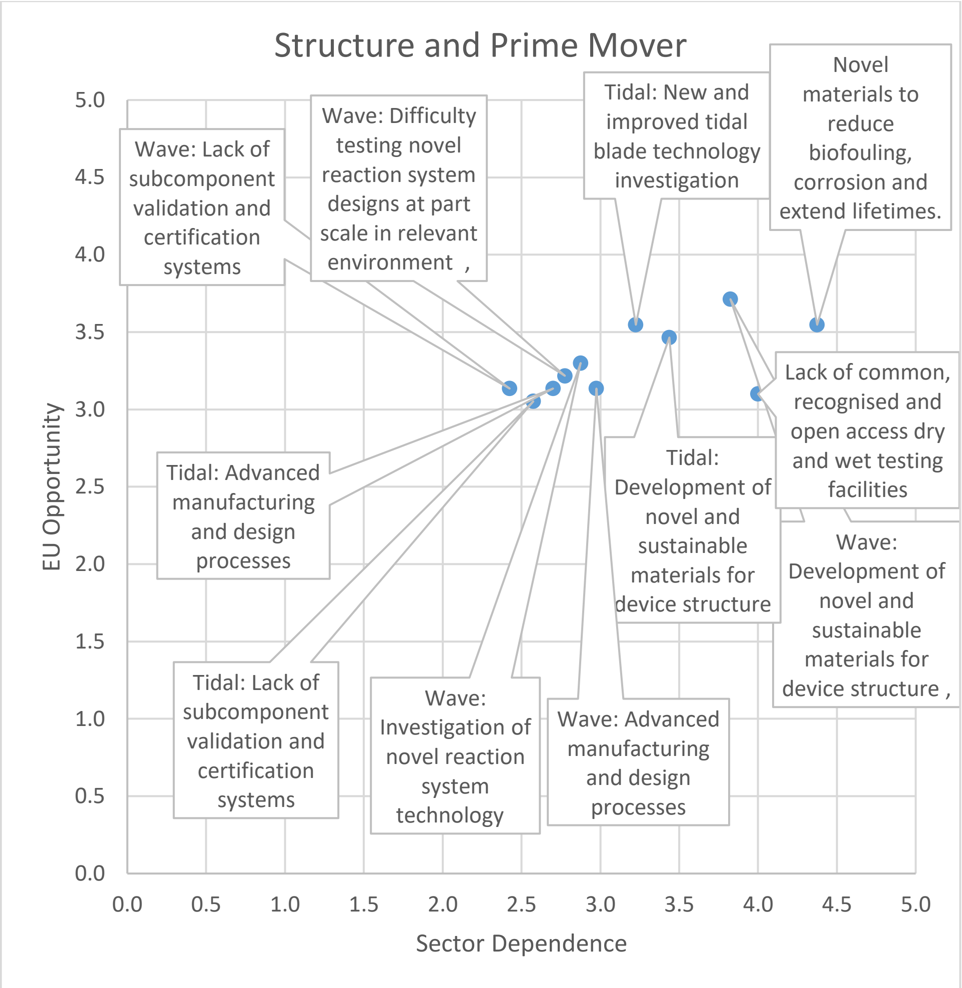

Figure 2 Structure and Prime Mover challenges

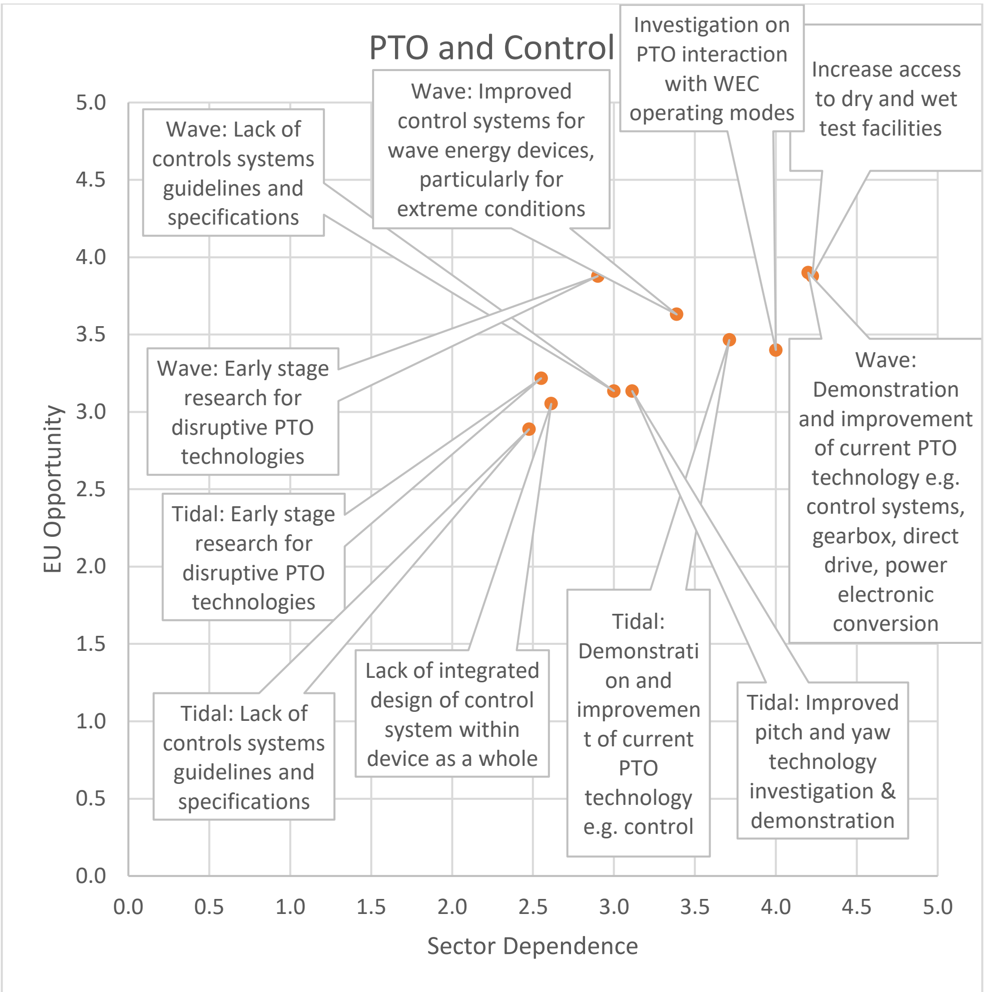

Figure 3 PTO and Control challenges

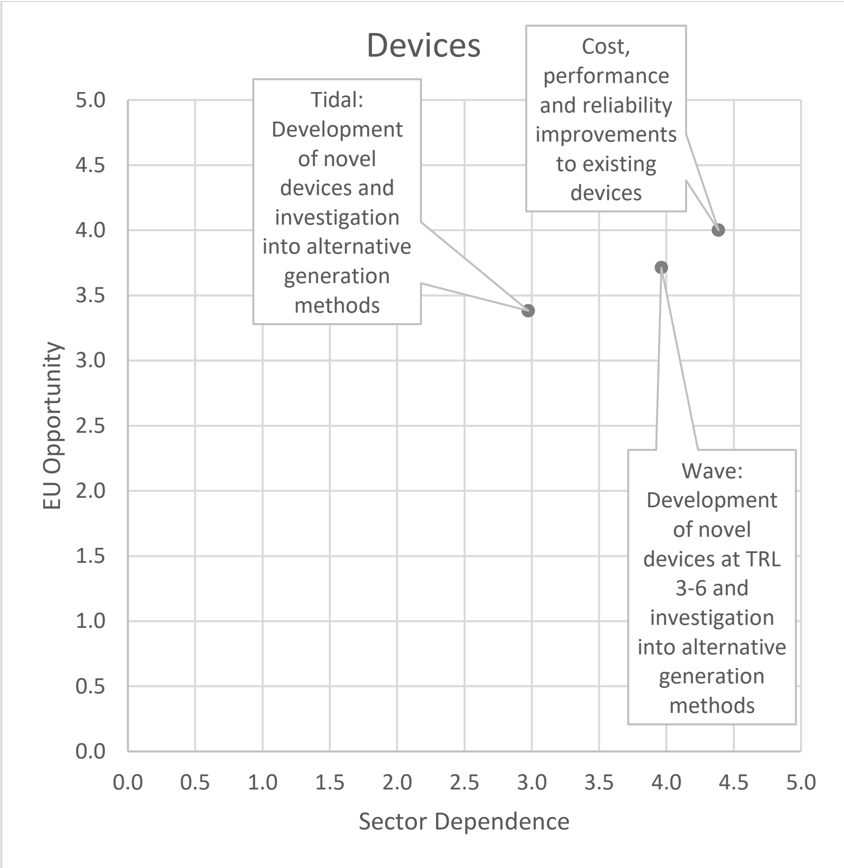

Figure 4 Devices challenges

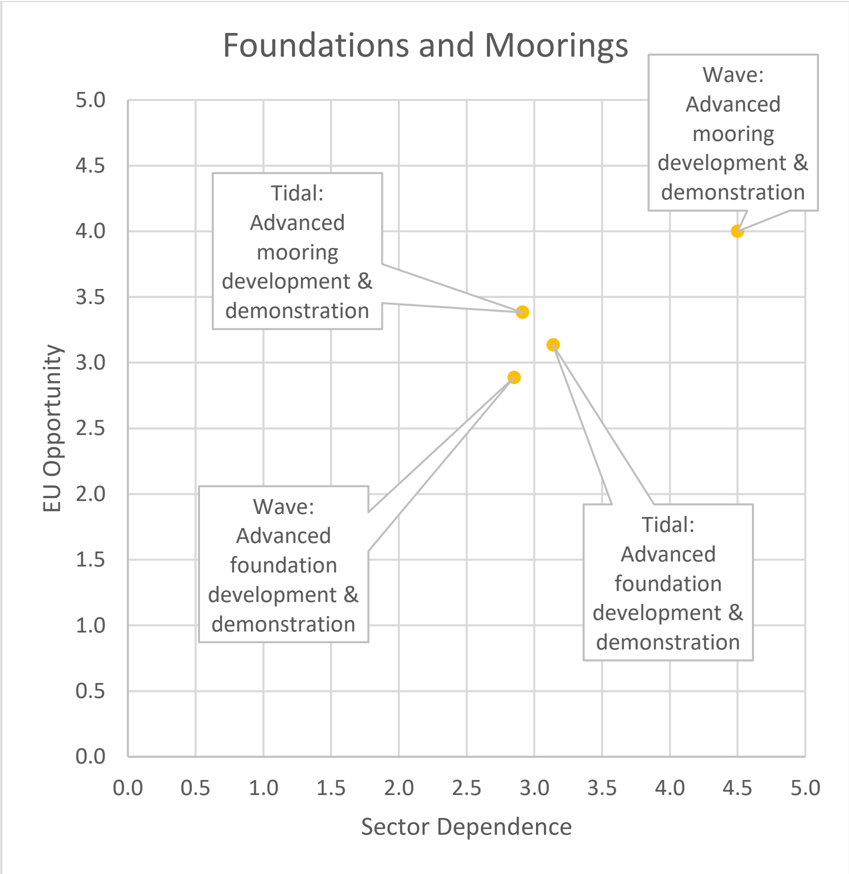

Figure 5 Foundations and Moorings challenges

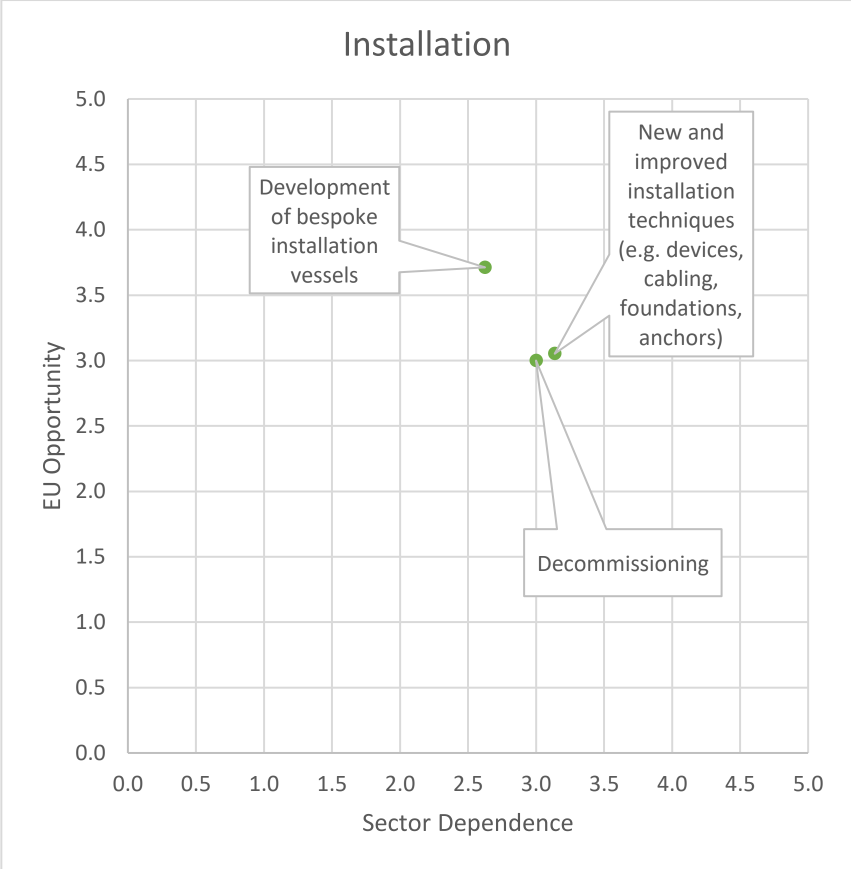

Figure 6 Installation challenges

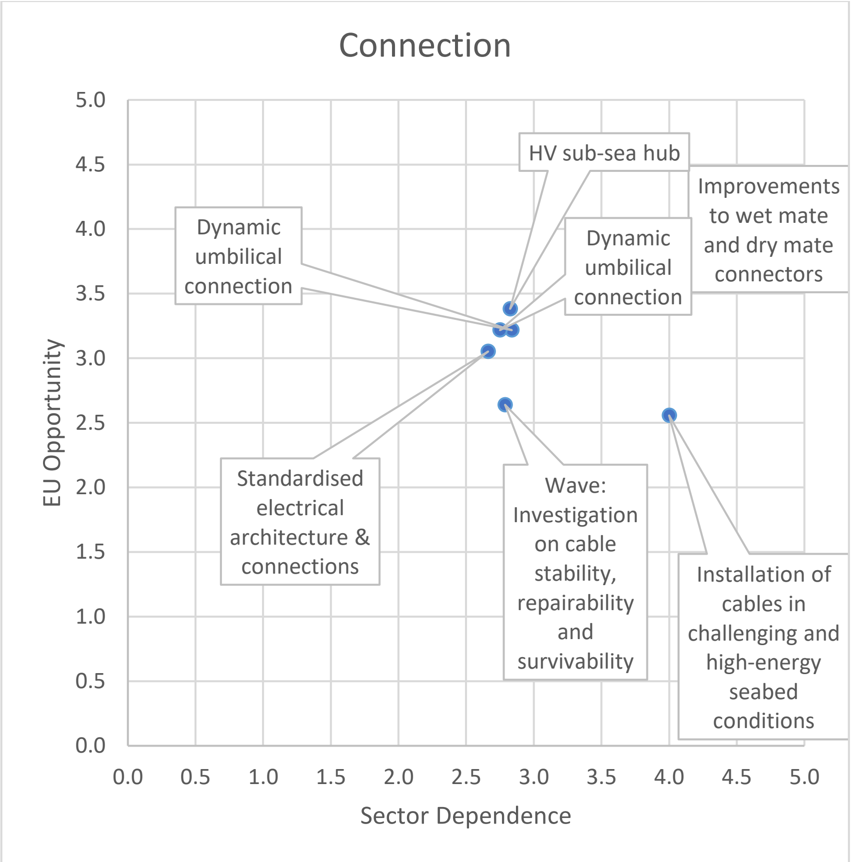

Figure 7 Connection challenges

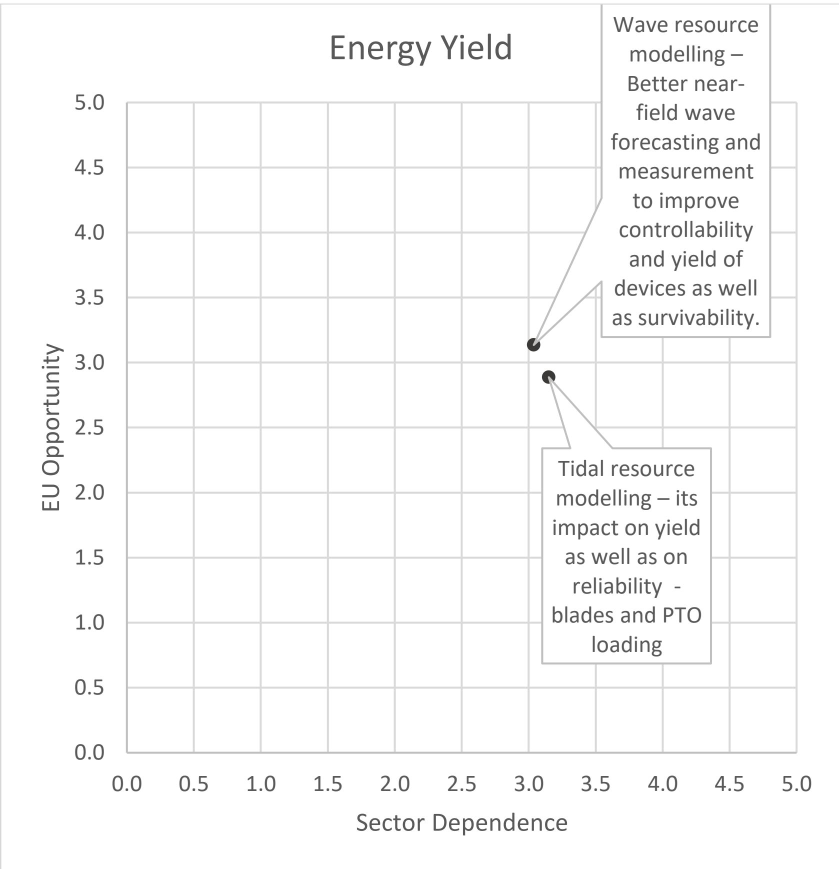

Figure 8 Energy Yield challenges

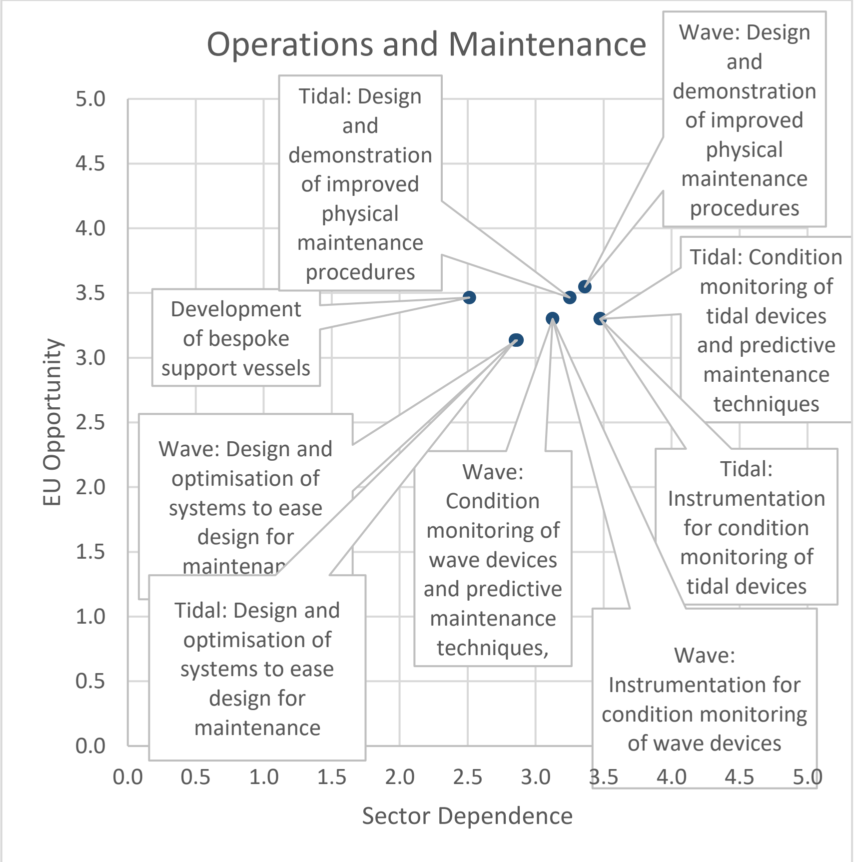

Figure 9 Operations and Maintenance challenges

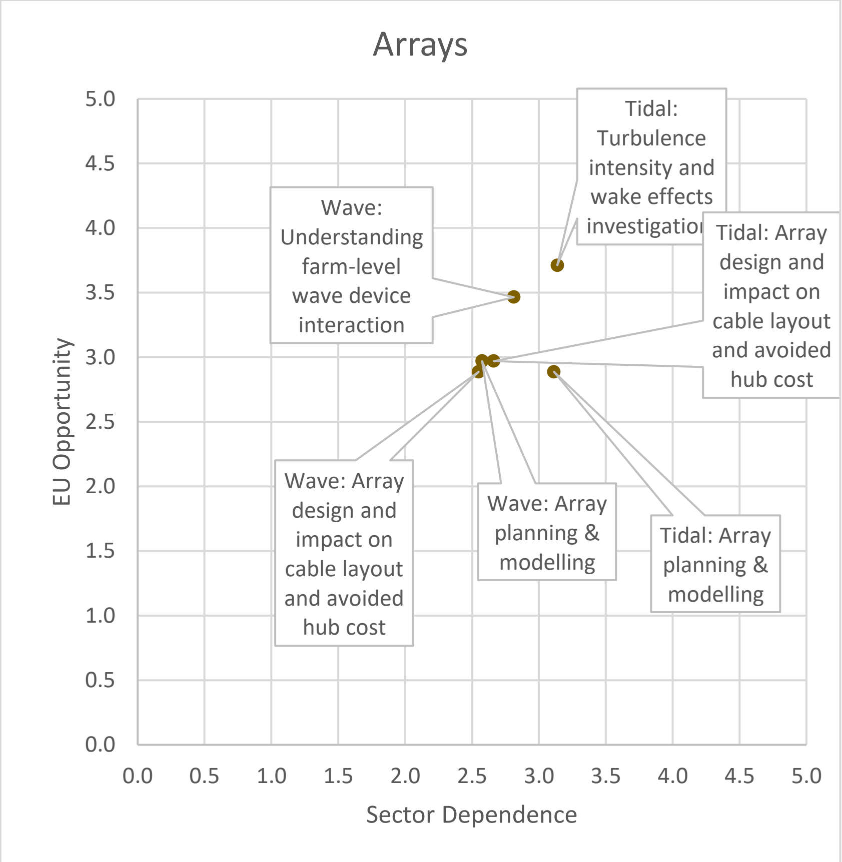

Figure 10 Arrays challenges

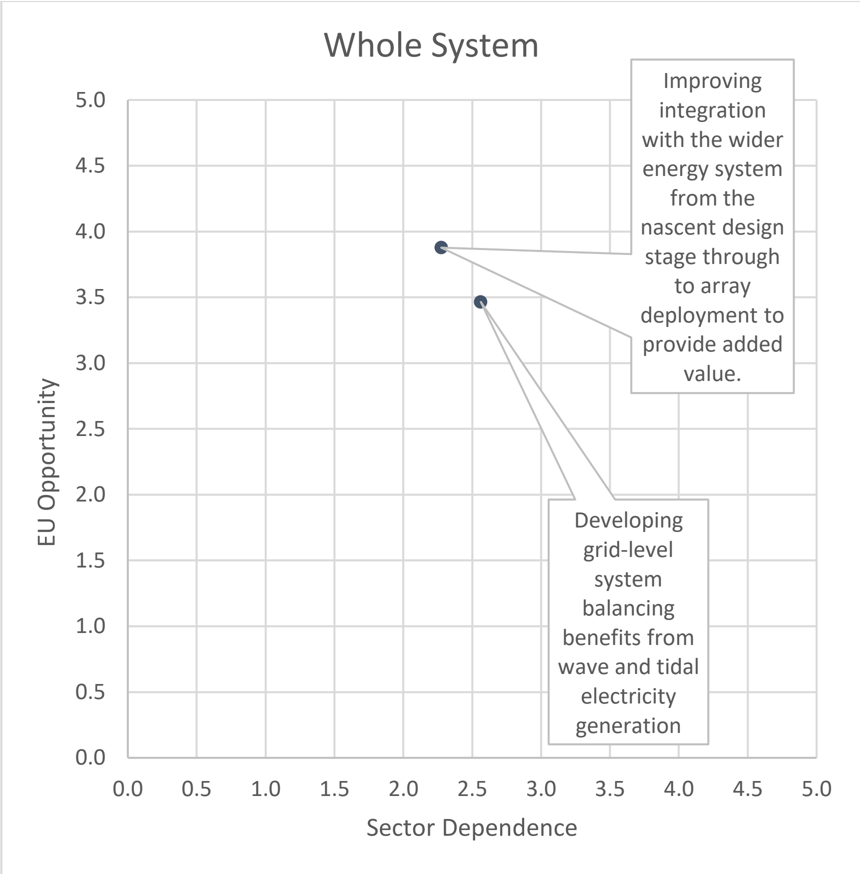

Figure 11 Whole System challenges

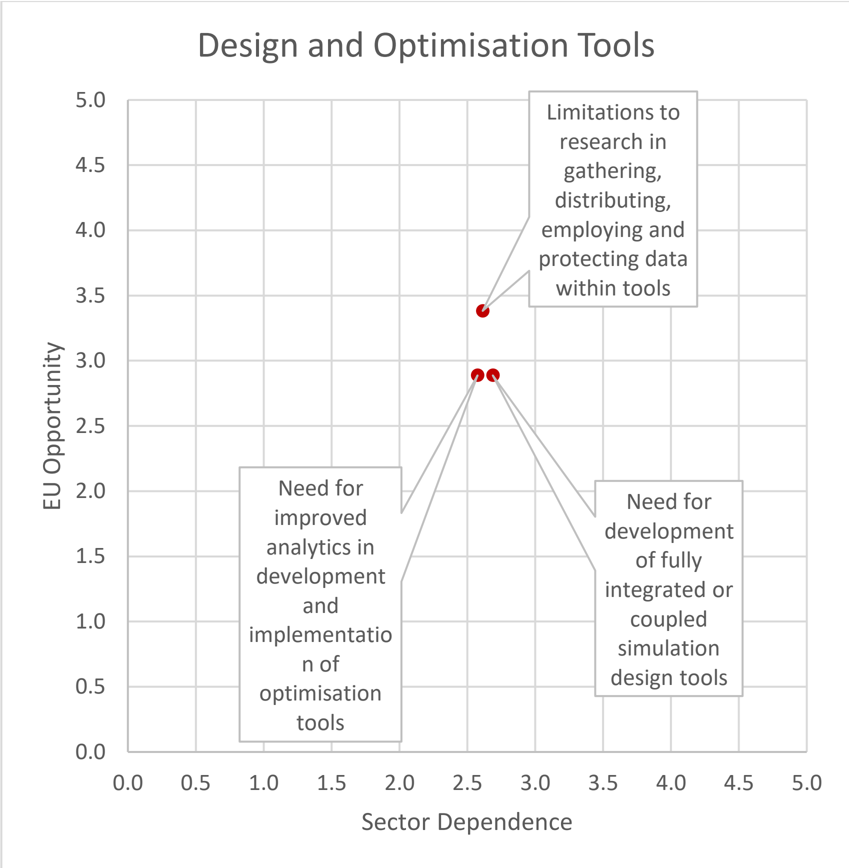

Figure 12 Design and Optimisation Tools challenges