

Wave and Tidal Energy Strategic Technology Agenda

February 2014



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strategic initiative for ocean energy



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FOREWORD

No one is in any doubt about the energy potential that exists in Europe's seas and ocean. This resource presents opportunities for economic growth, energy security, job creation and a massive export potential, which are difficult to ignore. Turning these opportunities into economic and social realities requires strategic tackling of the obstacles to commercial deployment that exist today. It is for this reason that the SI Ocean project was created.

SI Ocean is an Intelligent Energy Europe project led by Ocean Energy Europe, the European trade association for ocean renewables. Other project partners include the European Commission's Joint Research Centre (EU), the University of Edinburgh, Carbon Trust and RenewableUK (UK), WavEC (Portugal) and DHI (Denmark).

SI Ocean was conceived by Ocean Energy Europe to strengthen Europe's ocean energy networks, enhance collaboration on research and development, and overcome technology, policy and market barriers, to build a pan-European ocean energy sector. The project is focused on identifying a realistic trajectory for the commercialisation of wave and tidal stream energy¹ across Europe's Atlantic Arc region.

Geographically, the Atlantic Arc spans the western-facing Atlantic coastline and the northern area of the North Sea. This area encompasses the EU Member States of Denmark, France, Ireland, Portugal, Spain and the United Kingdom (UK).

The Joint Research Centre of the European Commission, the University of Edinburgh and The Carbon Trust have prepared this Strategic Technology Agenda (STA) outlining opportunities and steps to overcome challenges identified by the *SI Ocean Gaps and Barriers* report, identifying the path to a commercially viable and integrated ocean energy industry.

In 2013, Ocean Energy Europe launched TiP Ocean – the Technology and Innovation Platform for Ocean Energy. This initiative will take forward the work of the STA and use it to identify the research priorities that will most efficiently take the sector forward toward commercialisation.

¹ Tidal barrages and tidal lagoons are not included in the scope of this report.

Details on the Strategic Technology Agenda

The Strategic Technology Agenda (STA) is based upon previous work undertaken by the SI Ocean consortium on wave and tidal energy technology assessment, thus bringing it to a close by highlighting strategic actions aimed at the commercialisation of wave and tidal technologies.

Starting with an overview of the sector in the form of a *Technology Status report*², the project progressed with an outline of current wave and tidal energy costs. Future cost-reduction pathways were then identified, together with an assessment of anticipated cost-reduction trends. The means of achieving cost-reduction pathways were also presented in the *SI Ocean Cost of Energy report*³.

Following close industry engagement, the challenges and obstacles facing developers, utilities, supply chain companies and the industry as a whole, were explored in the *Gaps and Barriers report*⁴, which suggested the main technology challenges and the development activities that are required in order to achieve significant industry progress.

The STA focuses on the lessons learned to address, and provide an answer to, the issues identified by the *SI Ocean Gaps and Barriers* report. This document is intended as a combination of a road map and an action plan, thus providing both targets for the development of the wave and tidal energy sectors and recommendations on how the technology challenges can be overcome.

It is hoped that the Strategic Technology Agenda will be a useful tool to assist policy makers in identifying the support mechanisms that will allow the wave and tidal energy sectors to become commercial industries, and for Europe to exploit the associated benefits of offsetting carbon emissions, increasing energy security and job creation.

Key recommendations from the STA will help in developing a Market Deployment Strategy (MDS) for the ocean energy sector (Figure 1). The MDS will use the inputs from the STA to identify support and financing mechanisms, as well as policy actions that will benefit the growth of the sector.

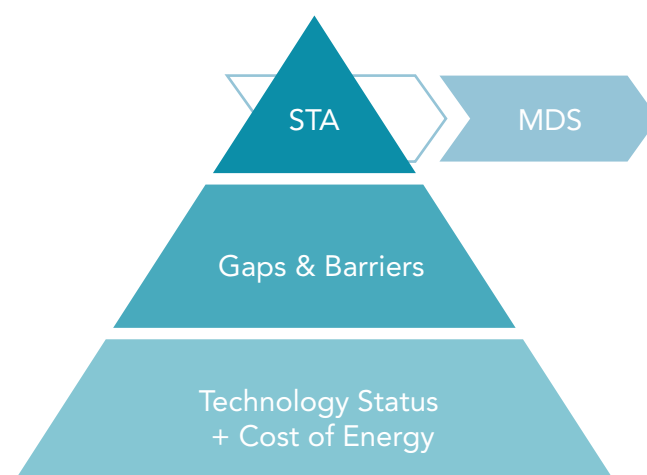


Figure 1 – Structure and role of the Strategic Technology Agenda

² SI Ocean (2012), at www.si-ocean.eu/en/Technology-Assessment/Technology-Status/.

³ SI Ocean (2013), at www.si-ocean.eu/en/Technology-Assessment/Cost-of-Energy-Assessment/.

⁴ MacGillivray, A., Jeffrey, H., Hanmer, C., Magagna, D., Raventos, A., Badcock-Broe, A (2013). *Ocean Energy Technology: Gaps and Barriers*, published by SI Ocean; www.si-ocean.eu.



GLOSSARY

AEP	Annual Energy Production
CAPEX	Capital Expenditure
KPI	Key Performance Indicator
LCOE	Levelised Cost Of Energy
MDS	Market Deployment Strategy
OPEX	Operational Expenditure
MEAD	Marine Energy Array Demonstrator
PTO	Power Take-Off
RDI&D	Research, Development, Innovation and Demonstration
STA	Strategic Technology Agenda
TEC	Tidal Energy Converter
TRL	Technology Readiness Level
WEC	Wave Energy Converter

EXECUTIVE SUMMARY



1 Executive Summary

The Wave and Tidal Energy Strategic Technology Agenda (STA) is the first of its kind for the ocean energy sector and its distinctive technologies. Developed and drafted by the SI Ocean consortium, the STA outlines the parameters to help accelerate current and future technological development of the sector.

This STA provides an independent review of ocean energy sector needs and presents recommendations for overcoming technology barriers that have been identified within the SI Ocean project. Significant engagement with industry, in both stakeholder interviews and a supply chain-focused workshop, has generated a diverse range of inputs into what is a challenging and demanding topic within the ocean energy sector; providing recommendations for overcoming the barriers facing the wave and tidal energy sector, facilitating development and deployment of nascent ocean energy technology to enable its commercialisation; and the establishment of a viable and successful industry.

This document presents recommendations that represent a key opportunity to reinforce Europe's leadership in Research, Development, Innovation and Demonstration (RDI&D), as the ocean energy sector progresses from concept to commercialisation, and will provide direct input into a Market Deployment Strategy for the sector – the final output of the SI Ocean project.

It is the goal of this document to assist policy and decision makers, at EU and Member State levels, by providing a short review of the current technological and economic trends in the wave and tidal energy sector (Section I) and of the current gaps and barriers hindering its development (Section II). Section III

presents the core of the Strategic Technology Agenda, identifying mechanisms and actions required to overcome existing challenges. Section IV presents conclusions and recommendations for the technological development of the wave and tidal energy sector.

Topics discussed in Section III are based on existing barriers and grouped in two main themes (Table 1). Overcoming both of these barrier types is fundamental to achieve performance improvement and cost-reduction targets:

1. **Technology Development:** Addressing the need to develop reliable, robust and efficient technology; engaging with manufacturers and supply chain; and developing tools for the optimisation of farms and their operational yields.
2. **Deployment and Risk Reduction:** Focusing on the need to increase the rate at which devices are installed in operational conditions; on developing procedures for installation, operation and retrieval of converters; and on ensuring that infrastructure is put in place to facilitate all the various facets of ocean energy development.

Developing the suggested actions through joint research and industrial activities would play an important role in achieving the critical mass and effectiveness required to ensure that wave and tidal energy technologies are ready for deployment across Europe. The recommended mechanisms aim to drive the development of the ocean energy sector toward the deployment of pilot arrays and to reduce the levelised cost of energy (LCOE), thus levelling the playing field between wave and tidal technology and other, more mature renewable technologies.

Table 1 – Topics addressed by the strategic themes of the STA

Theme	Topics
Technology Development	• Proving reliable operation • Device design: cost reduction for frontrunners and development of promising technologies • Enabling technologies (for example cabling and electrical connection) • Innovation: novel technologies, new components and sub-components • Knowledge sharing
Deployment and Risk Reduction	• Operations and maintenance risk reduction • Reducing risk for investors • Sharing risk across the supply chain • Infrastructure

The LCOE for early arrays⁵ ranges between 34 and 63c€/kWh for wave technologies and 24–47c€/kWh for tidal, whereas other established technologies range 8–15c€/kWh. A lower LCOE is expected to be achieved through technological improvements and risk reduction.

The reduction of the current costs of wave and tidal technologies is the common denominator for the two main streams. Both technology development and deployment and risk reduction are needed to drive the sector toward competitive LCOE.

At the European level, the newly launched “Horizon 2020” framework programme has set great emphasis on low-carbon energy technologies through the development of promising or innovative technologies, the deployment of demonstration plants, and engagement with manufacturing and supply chains. Furthermore, the strategic role of ocean energy technologies in Europe in the future has been highlighted by the recent EU communication on Blue Energy.⁶ Within this context there is clear scope for the wave and tidal energy sector to develop, improve and bring its technologies to market.

At the current stage of development, however, effort is needed to secure the correct technology solutions and the underpinning policies that will enable growth of the ocean energy sector, facilitating competitive and sustainable development. The sector has seen the announcement of numerous ambitious targets; however, the current deployed capacity is small. The step from pre-commercial device demonstration to array demonstration requires significant investment. Sustained long-term support mechanisms, in addition to existing ones,⁷ will be required in order to allow the first array projects to be deployed. In many cases efforts are focused on reducing the overall costs of ocean energy technologies and toward improved performance. However, other critical issues that look at the lifetime of installations, materials and harmonisation of the energy produced with the existing grid need to be addressed.

The two themes presented in this document address prioritised topics hindering the progression of wave and tidal energy technologies, identifying mechanisms and actions to remove existing barriers, and ensure in the short term the development of the sector and the deployment of pilot farms for both technologies. An overview of recommended actions is presented in Figure 2. Actions and mechanisms presented address key technology necessities that the ocean energy sector needs to address: the actions do not take into account any support mechanisms that may be needed to facilitate such development.

⁵ Early arrays are defined as arrays of 10MW following the first 10MW of installed capacity.

⁶ Blue Energy Action Needed to Deliver on the Potential of Ocean Energy in European Seas and Oceans by 2020 and Beyond, EU/COM(2014)8.

⁷ The NER300 scheme and the Marine Energy Array Demonstrator capital grant scheme (MEAD) are examples of existing support mechanism facilitating the deployment of small wave and tidal energy arrays.

Figure 2 – Recommended actions for the development of the wave and tidal energy sector

	Priority Topics	Recommended Mechanisms
Technology Development	• Technology advancement • Reliability demonstration • Performance data collection • Design for maintenance • Sub-system development and optimisation: • Foundations and moorings • Intelligent predictive maintenance systems • Device structure • Control systems • Power take-off • Power electronics • Array design and modelling tools • Novel system concepts • Knowledge transfer and dissemination	• Establishment and reinforcement of RDI&D programmes for development of novel technology and towards TRL progression, with strong emphasis on sub-systems • Validation of performances and reliability of WECs and TECs reaching capacity factors of >25% and availability of >75% • Standards and guidelines for evaluation and testing of devices • Co-operation at European scale for addressing overarching issues
Deployment and Risk Reduction	• Pre-commercial array sea trial and demonstration • Intelligent predictive maintenance systems • Resource analysis tools • Offshore grid design and optimisation: • Array electrical system • Subsea electrical system • Array interaction analysis • Offshore umbilical/wet mate MV connectors • Techno-economic tools	• Demonstrating WECs and TECs, through facilitated access to test and demo facilities in Europe • Standardised procedures for installation, maintenance and retrieval of devices • Co-operation with supply chain for standardised manufacturing • Collaboration with other energy sectors for grid integration and connection issues

Overall, to aid the continuous development of wave and tidal energy technologies in the short term, it is recommended that the following take place:

- Demonstration of advanced technologies, including demonstration and validation of existing prototypes in full-scale testing (TRL 5–7) and supporting work towards pilot array deployment (TRL >8).
- Technological progression of technologies at TRL 3–5 and development of novel and innovative technologies (TRL1–3), components and materials, and furthering existing concepts when these have good prospects of reducing LCOE.

By working together and with the appropriate public support, the industry can achieve the targets outlined within this report, demonstrating that the sector is capable of large-scale deployment, and addressing the threefold challenge of energy security, CO₂ emission reduction and inward investment within the EU. It is only through addressing these challenges that the sector can gain traction and ac-

celerate toward 2030 and 2050 ocean energy deployment and commercialisation targets.

Core recommendations from the Strategic Technology Agenda (STA) will directly feed into the Market Deployment Strategy (MDS), which will provide a series of holistic technology and policy support recommendations to the European Commission, Member States and regional governments.

1.1 Technology Development Key Recommendations

The aim of the Technology Development theme is to identify mechanisms and actions that could help accelerate existing technology towards commercialisation, whilst allowing for continuous innovation and development to take place to ensure cost reduction in the long-term. The theme focuses on developing reliable, available, survivable and affordable technologies. Overarching activi-

ties as well as technology-specific activities have been identified in order to unlock the potential of both tidal and wave technologies, and ensure they move to a higher TRL. Four main mechanisms have been identified to achieve the goals of the Technology Development theme.

1.1.1 RDI&D Programmes

The core activities for the technological progression of ocean energy technologies are the development of new and the furthering of existing RDI&D programmes. The first activity is designed to develop innovative solutions that could ensure long-term cost reduction for ocean energy technologies, whilst the latter one focuses on proving reliability, availability and survivability of existing technologies. Such an approach will accelerate the development of novel technology moving towards higher TRLs, whilst advancing frontrunners towards market deployment.

It is essential to ensure that attention is given to the development of emerging designs and the investigation of optimisation and innovation of sub-systems components, to unlock cost-reduction pathways through engagement with the supply chain.

1.1.2 Reliability and improvement

One of the essential steps that the wave and tidal energy industry should adopt is the validation of the performance and reliability of their devices in real sea conditions. In the short term, developers should aim at ensuring that technology operates with capacity factors >25% and that devices offer an availability of at least 75–85%, thus significantly reducing risk for potential investors.

1.1.3 Standardisation of performance evaluation

The creation of standards and guidelines for performance evaluation and device testing is essential to ensure technology competitiveness, future mass manufacturing and technology deployment potential, whilst encouraging inward investment from the supply chain.

1.1.4 European industrial co-operation programme for knowledge exchange

Both technologies could benefit by a greater co-operation at European scale, aimed at addressing overarching issues and developing common solutions concerning reliability of devices, component and subcomponents.

1.2 Deployment and Risk Reduction Key Recommendations

The Deployment and Risk Reduction theme focuses on identifying mechanisms that will facilitate the installation and testing of WECs and TECs. This will help reduce the inherent risk that device developers are currently facing in validating their technologies; whilst stimulating the learning of the sector to accelerate the current technological status and implement the standardisation of deploying, operating and manufacturing procedures. Four key mechanisms have been identified to achieve the objectives of the Deployment and Risk Reduction theme.

1.2.1 Network of European test and demonstration facilities

A fundamental step for demonstrating wave and tidal energy technologies, aimed in particular at advancing full-scale devices toward roll-out, is the provision of access to test and demonstration facilities across Europe. The consolidation of a network of facilities in Europe that facilitates such an approach will be essential to reduce risk for device developers, and for the overall growth of the sector.

1.2.2 Collaboration for installation, operations and maintenance

Increased deployment allows for the creation and establishment of cross-sector operational procedures for installation, maintenance and retrieval of devices, thus unlocking reduction in the OPEX cost component in the long run.

1.2.3 EU cross-industry co-operation for serial manufacturing

Further cost reduction can be obtained by unlocking economies of scale. This can be achieved by enhancing co-operation with the supply chain, moving toward standardised manufacturing and mass production of converters and infrastructure.

1.2.4 Cross-sector platform for ocean energy grid integration

Grid issues are likely to stall the development of ocean and offshore renewable energy sources. The sector needs to establish, in collaboration with other energy sectors, guidelines and standards for grid integration and connection, whilst facilitating access to the grid in the short term, to assure deployment targets are met.

SECTION I

State of the Art and Current Costs



2 State of the Art and Current Costs

2.1 Technology Status

The development of wave and tidal technologies has made significant progress in recent years. A number of companies are moving from prototype development to the installation of first demonstration arrays, a significant step forward towards commercial deployment. Concepts at a relatively advanced TRL have undergone a series of iterations, and experienced sustained testing at full scale in operational conditions as stand-alone demonstration projects.

The industry is still in a nascent state, with the most advanced prototypes currently undergoing long-term testing to prove reliability, operability and durability the device.

In order to supply a substantial amount of electricity to the grid, and contribute significantly to the future electricity mix, however, both wave and tidal technologies will have to operate in array or farm installations. The progression from single demonstration device to the deployment of wave and tidal energy farms requires technologies to be proven, reliable and affordable.

Tidal technologies appear poised to reach commercial breakthrough earlier than wave technologies, and this is highlighted by the number of concepts that have reached sustained full-scale demonstration. Tidal energy concepts present a greater convergence in design, with the majority of developers opting for horizontal-axis turbine concepts; thus indicating that the tidal energy sector is at a more mature stage of development.

On the other hand, wave energy devices have not reached similar technology maturity and may benefit from further R&D, innovation and testing before being able to tap the most resourceful sites available in Europe. Only a few concepts have consistently undergone full-scale testing, and the sector presents a vast number of different concepts, with no clear convergence in design.

Further development of wave and tidal energy technology is crucial to securing reliable, available, cost-effective deployment, thus enabling the sector to become a major source of electricity supply by 2050. Currently, the development status of the technology is associated with a high levelised cost of energy (LCOE) compared to both traditional and other renewable energy sources. Progression is required within both device development and the supply chain to enable the European tidal and wave industries to become competitive in the EU and global electricity markets.

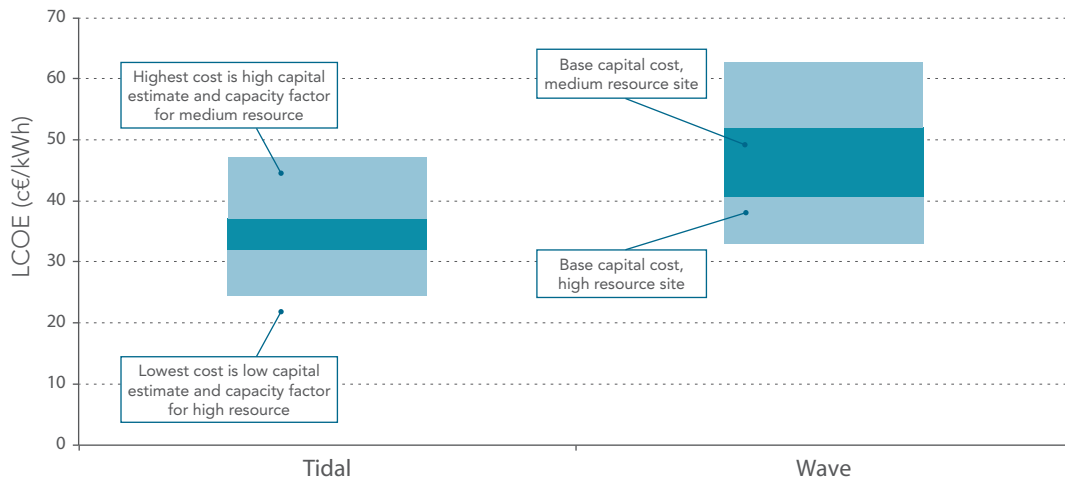
2.2 Cost of Energy

The LCOE provides an estimate of the cost of electricity from a farm of devices over a twenty year period, and it is reflective of capital cost, operating cost, decommissioning cost, and of the expected annual energy production (AEP) (Figure 3). It is thus influenced not only by the performances of the technology but also by the capital and maintenance expenditure necessary to develop, construct and maintain a project.

Figure 3 – Components of the levelised cost of energy (LCOE)

LCOE	AEP	• Site resources • Device performance • Availability and reliability
	CAPEX	• Device • Foundations • Connections • Installation • Decommissioning
	OPEX	• Maintenance • Operation • Insurance • Lease • Transmission charges

Figure 4 – Early array costs (SI Ocean, 2013)

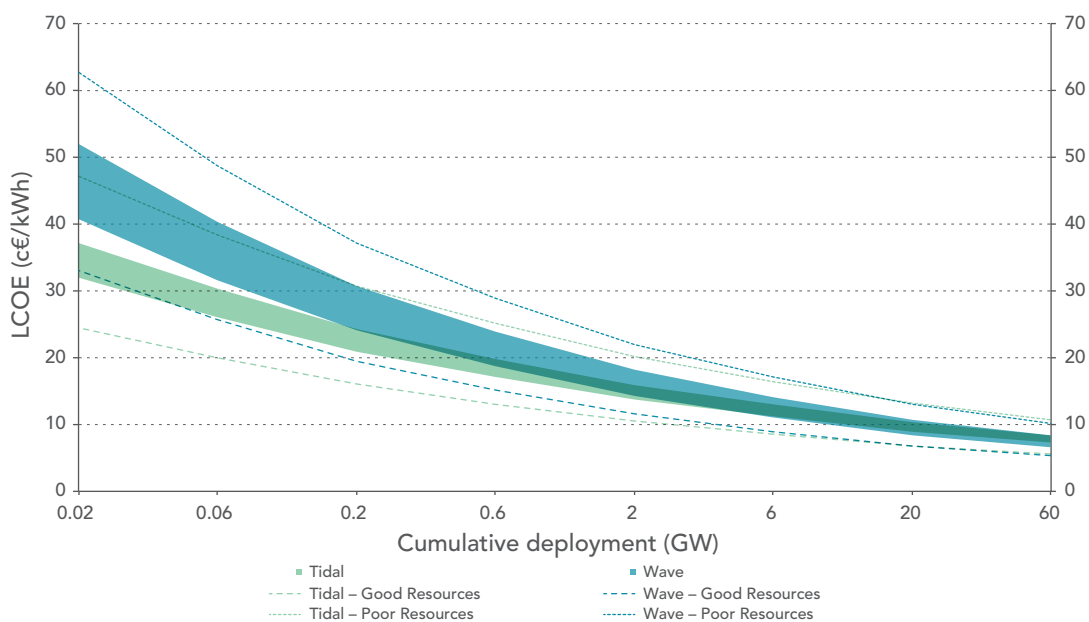


Estimates of the LCOE for early arrays have been determined for both tidal and wave energy technology. Early array costs are based on data from technology developers, thus forecasting the costs of a 10MW array when 10MW capacity has already been installed (SI Ocean, 2013).⁸ As can be seen in Figure 4, the LCOE for early tidal energy arrays varies between 24 and 47c€/kWh, whilst the current cost range for wave energy arrays ranges between 34 and 63c€/kWh.

The need for competitiveness with alternative energy technologies requires concrete actions that will reduce the LCOE to more competitive val-

ues. LCOE predictions (Figure 5) based on a 12% learning rate and cumulative deployment indicate that tidal technologies could achieve commercial competitiveness with other renewable energy sources once approximately 5GW of cumulative capacity has been installed. Wave technologies, on the other hand, would require a cumulative capacity of over 10GW to become cost competitive. Currently, however, both estimates appear quite challenging for the industry. These predictions were developed considering as a starting point a cumulative deployment of 20MW for both technologies, and could be achieved if common design consensus is reached.

Figure 5 – LCOE predictions for 10MW early arrays, after 10MW already installed (SI Ocean, 2013)



⁸ SI Ocean (2013), *Ocean Energy: Cost of Energy and Cost Reduction Opportunities*.

It should be noted that the overall deployment capacity for wave energy far exceeds that of tidal. The European (and global) wave resource is significantly greater than the tidal resource across the same geographic area (29,500TWh/year vs 1,200TWh/year).⁹ While tidal energy is very dependent on geographic conditions and is very site specific, wave energy is much more prevalent along a given west-facing coastline with significant fetch length. As a result, it is anticipated that, in the long term, wave energy LCOE will fall to a similar level to the cost of tidal energy once the technology has reached maturity.

It is important to highlight that cost-reduction can be achieved through a series of mechanisms that fit with the continuous development of tidal and wave energy technologies, in particular:

1. **Performance Improvement:** Improved energy capture from individual devices and arrays, and much better reliability, resulting in increased energy yield and economic return.
2. **Upscaling:** Scale and volume production give room for cost-reduction opportunities. These can be achieved through the upscaling of devices (lower cost/capacity) and increasing number of devices (lower installation cost per device), thus driving reduction through scale of production and scale of engineering support.
3. **Experience:** Increased know-how, gained through learning-by-doing, allows for optimisation of production, installation and O&M of ocean energy arrays. In particular increased reliability (track record of installation) will play a significant role in risk perception and in project cost assessment.
4. **Innovation:** Innovation of device components or in production mechanisms could allow new solutions (such as materials) to emerge, potentially helping to bring down the cost associated with ocean energy arrays.

The reduction of the LCOE will allow both technologies to become commercially viable and to achieve increased rate of deployment.

⁹ www.ocean-energy-systems.org/about_oes/oes_vision_brochure/.

SECTION II Technology Challenges



3 Current Challenges, Gaps and Barriers

The major challenges and obstacles facing the sector have been outlined and discussed within the *SI Ocean Gaps and Barriers report*.¹⁰ The report identified major challenges and obstacles hindering the development of the ocean energy sector, including the difficulties in securing funds to progress technology development. Economic and financial risks are associated with the development of the sector, and the slow rate of deployment is ensuring that many gaps and challenges remain in place. At a high level, these challenges include:

- **Enabling technology:** Developing cost-effective technology that, once ready, will enhance, or add value to, the deployment capabilities of the wave and tidal sector. Enabling technologies will allow deployment of existing wave and tidal energy converters in a more cost-effective manner.
- **Risk management:** Technology developers are exposed to a series of risks when looking to develop and deploy marine energy projects. Utility-scale projects are deemed to be too risky for both investors and developers, thus hindering deployment. Managing risk, through increased collaboration practices and risk sharing, will allow furthering deployment and development of the sector.
- **Technology fragmentation and design consensus:** An issue hindering the development of both sectors is presented by the lack of design consensus amongst technologies and subcomponents. A number of benefits could be unlocked by working toward design consensus, particularly at component and subcomponent level.
- **Grid access, connectivity and infrastructure:** Securing access to the grid is necessary to avoid slowing down the development of the ocean energy sector. Grid access is one the major infrastructure issues that could potentially slow down marine energy installation; thus providing secure, adequate and timely connection to the grid is of primary importance.
- **Economic perspective:** As discussed in the previous section, the current LCOE for marine energy projects is too high, and it needs to come down in order for technologies to compete with alternatives. Targeting a reduction of

LCOE is essential to gain investors' confidence, therefore deployment must actively take place.

- **Establishing equitable environmental mitigation measures:** The ocean energy sector is faced with a wide number of challenges relating to the licences required for testing and deployment of devices. The unknowns related to the environmental impacts of ocean energy parks are causing delays and setbacks to the development of the sector. There is a need for streamlining monitoring activities and developing mitigation actions which could become beneficial to the overall sector.

Through discussion with ocean energy industry representatives within the stakeholder engagement process, a list of innovation activities was created, identifying the technology needs of the ocean energy sector. Whilst all topics are important, some are more urgent than others. The list of activities, most urgent work, and identification of key actors that should take responsibility for the delivery of these activities was presented within the *Gaps and Barriers report*. The key actors for delivering successful commercialisation of the wave and tidal energy sector are represented by:

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

¹⁰ MacGillivray, A., Jeffrey, H., Hanmer, C., Magagna, D., Raventos, A., Badcock-Broe, A. (2013), *Ocean Energy Technology: Gaps and Barriers*, available at www.si-ocean.eu/en/upload/docs/WP3/Gaps%20and%20Barriers%20Report%20FV.pdf.

- **Governments:** The development activities that are perceived to require government funding in order to proceed. Government (at a European, Member State, and regional level) must identify suitable mechanisms to support the development of these activities in order to allow timely resolution; otherwise the challenges will remain. Examples of activities that require government funding support include device- and subcomponent-level reliability demonstration (technology push); array-level reliability demonstration (technology push and market pull); and knowledge transfer and dissemination.

The barriers and challenges facing the sector will require significant cross-industry effort, with re-

sponsibility and risk needing to be shared by all stakeholders. The high-level goals for the sector are clear, but the challenges must be overcome:

- Reduce the cost of the technology, through innovation and learning-by-doing.
- Address technology fragmentation at subcomponent level to increase supply chain appetite for investment.
- Address lack of co-operation by identifying collaboration opportunities.
- Identify the best strategies that will allow safe and efficient deployment of arrays.

The two-theme approach presented in this document allows identifying the appropriate actions to achieve these high-level goals.



SECTION III

Strategic Technology Agenda

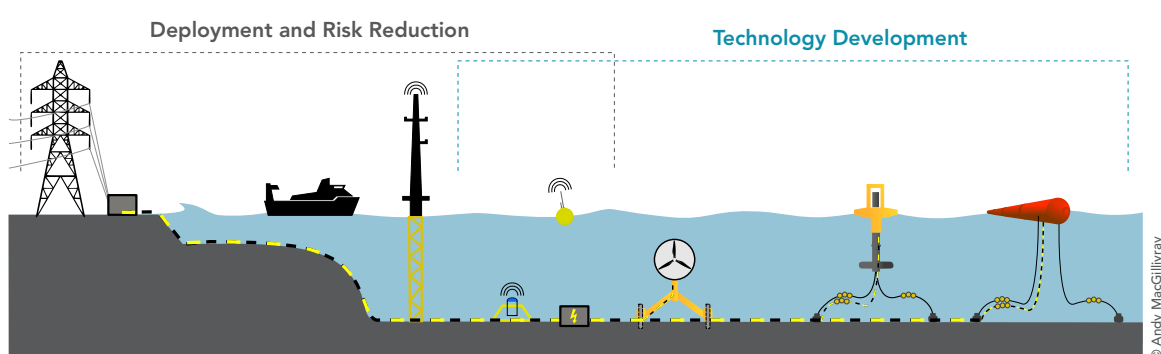


4 Thematic Approach of the Strategic Technology Agenda

The delivery of reliable and cost-effective ocean energy technologies will depend on reducing or eliminating the risk associated to the challenges presented earlier, which constitute the core to two main themes: **Technology Development** and **Deployment and Risk Reduction**, focussing respectively on devices, their reliability and subcomponents, and on ancillary technologies, subsys-

tems and procedures necessary for assuring the operations of wave and tidal energy farms (Figure 6). Each theme contains a number of high-priority topics, addressing technology-specific challenges identified within the *SI Ocean Gaps and Barriers report*. It has to be noted that those gaps relating to environmental and consenting issues will not be addressed in this document.

Figure 6 – Topics addressed in each stream



An overview of the prioritised topics for each theme is presented below.

A. Technology Development – Getting technology ready for deployment:

- Proving reliable operation
- Device design: cost reduction for frontrunners and development of promising technologies
- Enabling technologies
- Innovation: novel technologies and new component and subcomponents
- Knowledge sharing

B. Deployment and Risk Reduction – Proving technology in arrays and getting infrastructure ready

- Operations and maintenance risk reduction
- Reducing risk for investors
- Sharing risk across the supply chain
- Infrastructure

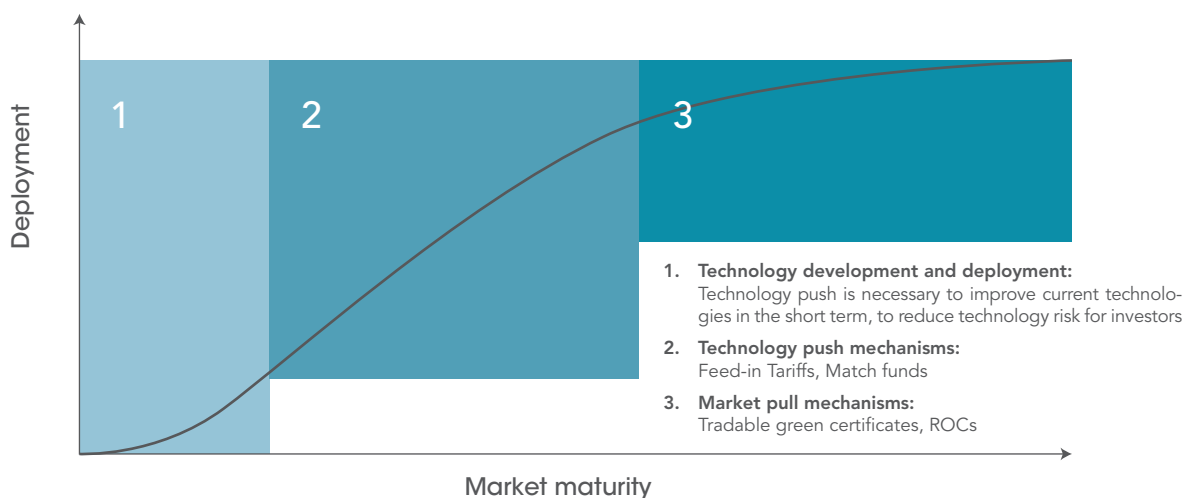
Themes

Topics

Mechanisms

Actions

Figure 7 – Actions and support mechanisms according to deployment



By addressing the above themes and topics, this document presents actions to achieve significant commercial deployment for the wave and tidal energy sector. Additionally, this document seeks to identify the right instruments needed to stimulate growth as a whole, and to investigate more technology-specific mechanisms, based on current and predicted levels of development in the near future.

From an economic point of view, substantial investments are needed for the next phase of array deployment, and this requires investors' confidence. However, at present, investors have insufficient confidence in the technology to take such a large investment step; although increasing support is seen for tidal technologies that have proven reliable operations over the years. Looking at the development path of other renewable sources, such as the wind energy experience of the early '80s, it can be seen that concept demonstration and reliability is essential to secure further financing and to ensure technology convergence toward an optimal design. Support methods such as market push and market pull mechanisms are needed to guide the wave and tidal sector toward commercialisation and higher market penetration. However, such mechanisms need to be carefully implemented at the correct time in order to stimulate the most effective sector development. As indicated in Figure 7, the development status of the sector is still in the early stages (1), thus technology-oriented mechanisms are envisaged to help the sector take off, and facilitate the development of a technology until it is ready for array deployment. Once this step is achieved, technology push and market

pull mechanisms will be required, in order to incentivise the first deployments (or early adopters) of more mature ocean energy technology (2) and once the ocean energy market is mature (3).

The two selected themes identified at the outset of this section will allow focus on the technological needs of the sector – to prove reliable device operation – whilst looking toward the future market needs of the sector – reducing risk for investors, securing project investment and providing credible pathways for future cost reduction.

The reduction of the LCOE is the common denominator of the two main themes of this technology agenda. It is clear that reduction of the current costs of tidal and wave energy technologies can only take place through the combination of technology development and deployment, thus the recommended actions and mechanisms aim to ensure that cost-reduction is achieved.

Other sectors have already highlighted the importance that technology development, deployment and transfer to industry play in influencing manufacturing and installation costs and overall competitiveness. In the long term, the LCOE is envisaged to become the key performance indicator (KPI) for continuous penetration of wave and tidal technologies into the energy market. In order to achieve this step, it is necessary to prove technology development through increased deployment rates. In short, LCOE cannot be lowered without significant deployments in the first instance.

4.1 Scenarios and Drivers for the Strategic Technology Agenda

The long-term goal for the sector is to achieve and sustain market penetration through the reduction of the LCOE. However, in light of reduced 2020 deployment targets that have recently been announced,¹¹ the sector must deliver results in the short term to encourage long-term commitment from governments, stakeholders and investors.

Two main timeframes are taken in consideration for the development of the STA, using the following definitions:

1. Short-medium timeframe (present–2025):

aimed at identifying the actions to overcome existing technology challenges to insure in the short term the deployment of pilot arrays (3–10MW); stimulating technological progress in the medium term towards the deployment of small commercial arrays (20–50MW) — “What technologies will, in the short term, allow small array deployment to take place?” In this timeframe, technological progress and maturity of frontrunners will allow for “market creation” in resource-rich countries.

It should be noted that some ocean energy projects larger than 50MW will be initiated during this time period but their deployment will be in phases of 10–20MW. Technological challenges will need to be addressed before 50MW+ farms are developed as single-phase projects.

2. Long-term timeframe (2025–2050): aimed at favouring technology maturity to ensure the deployment of large-scale farms (in excess of 50MW) — “What technologies will, in the long term, allow large array deployment to take place?” Both technologies will become mature; offshore installations will be developed at an industrial scale, with increased cost reduction and higher market penetration. LCOE is on a par with other renewable energy technologies.

The STA will focus specifically on actions and recommendations that will help to address and meet the needs of the prioritised topics in the short-to-medium term (pilot arrays). The wave and tidal energy sector has a responsibility to demonstrate proof of technology reliability and provide evidence for plausible cost-reduction pathways to ensure future market rollout of technology. To achieve significant headway in addressing the key priorities, there is a requirement for support from both research (to advance underpinning R&D and technology development) and market initiatives (to provide incentives to facilitate and assist higher-risk early deployment of more mature technologies).

The introduction of the Horizon 2020 framework in 2014 provides further stimulus for the sector to align its development objectives and timeframes to those of the EU, fostering rapid innovation and progress to secure innovation, development, and demonstration funds, and future private investments. Technology innovation, development and demonstration are themes that have been set within the Horizon 2020 framework and are to be addressed in the period 2014–2020. For the ocean energy sector to match the 2020 timeline, a series of different mechanisms is required to meet urgent development and deployment needs. The level of success in which the wave and tidal energy sector will meet the objectives by 2020 will be in direct proportion to the political will for the advancement of the sector. A significant role exists for technology developers of both wave and tidal energy devices to focus on meeting the technology development targets highlighted, giving greater confidence in demonstration of the first pilot farms by 2020.

It is only through the implementation of mechanisms that directly support advancement in the near term, addressing the most urgent topics, that long-term goals can be met, thus allowing the deployment of large commercial wave and tidal farms.

The proposed parallel approach suggested in this STA aims to drive the sector toward increased credibility and visibility, whilst simultaneously triggering continuous development and optimisation

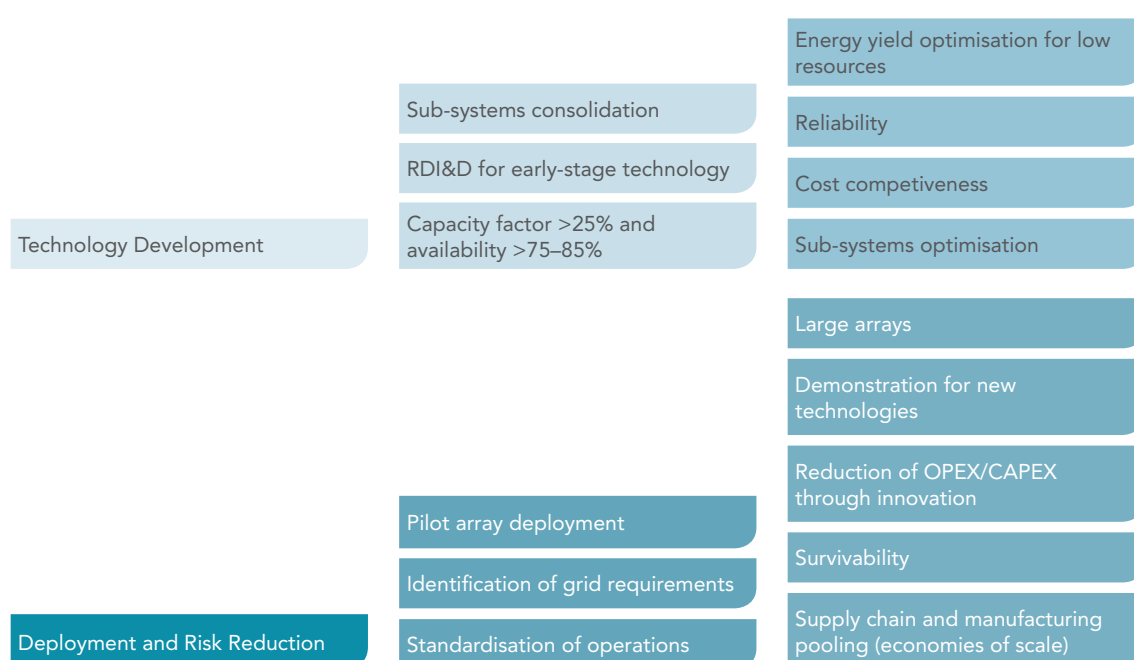
¹¹ *SI Ocean, Gaps and Barriers Report – Section 5.12*

of conversion technologies, and of installation practices, leading to significant MW-scale large array projects being developed in the longer term. To achieve long-term goals, a series of intermediate steps needs to be completed (Figure 8).

With ambitious targets recently laid upon the new low-carbon energy sector,¹² the ocean energy sector needs to prioritise actions for technologies requiring further development and for those ready for array demonstration. As highlighted in the

SI Ocean Gaps and Barriers report, tidal technologies appear to be set for small array demonstration up to 5–10MW,¹³ whilst wave technology still needs to show reliability and operability at single-device scale, or arrays up to 3MW. The STA covers both technologies; however, technology-specific priorities and actions will be outlined. Cross-cutting recommendations for both wave and tidal industries with regards to areas for co-ordinated actions will be presented.

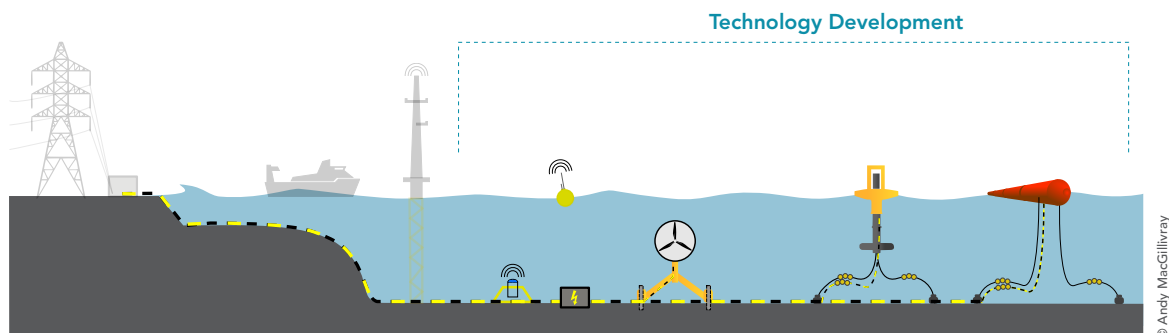
Figure 8 – Steps towards the full deployment of the wave and tidal energy sectors



¹² A Policy Framework for Climate and Energy in the Period from 2020 to 2030, EU/COM(2014)15 final.

¹³ In 2012, NER300 funds were awarded for tidal array projects of 8 and 10MW cumulative capacity, and for 5MW wave energy arrays. The current NER300 calls aim at 10MW tidal arrays and 5MW wave arrays. http://ec.europa.eu/clima/news/docs/c_2012_9432_en.pdf.

5 Strategic Theme: Technology Development



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Reliable and efficient conversion technologies are the core of every functioning renewable energy sector, and likewise the wave and tidal energy sector will have to deliver technologies that perform reliably and can survive within harsh environments. Proven technology is the first necessity for the wave and tidal industry, reducing risk and allowing both manufacturers and investors to engage with the wider ocean energy sector in order to secure the development of future farms.

However, a number of challenges and barriers are hindering the development of both technologies:

- **Reliability, operability and Survivability of devices and subcomponents.** Pre-commercial demonstration devices and newer concepts still have to demonstrate consistent operational hours and address concerns related to low capacity factors and low availability of devices. Innovation in maintenance of devices is needed, both through learning from failures and advances in other sectors,¹⁴ and through increased reliability of subcomponents.
- **Implementation of design tools.** Tidal and wave devices are designed to operate in farms, rather than in single installations. Tools aimed at the optimisation of farms are needed to ensure the optimal development and functioning of farms; thus, addressing design of physical and electrical layout to optimise energy yield, and identification of common structures and infrastructures. Validation through the use of experimental data and deployment experience

will be beneficial for the correct development of design tools.¹⁵

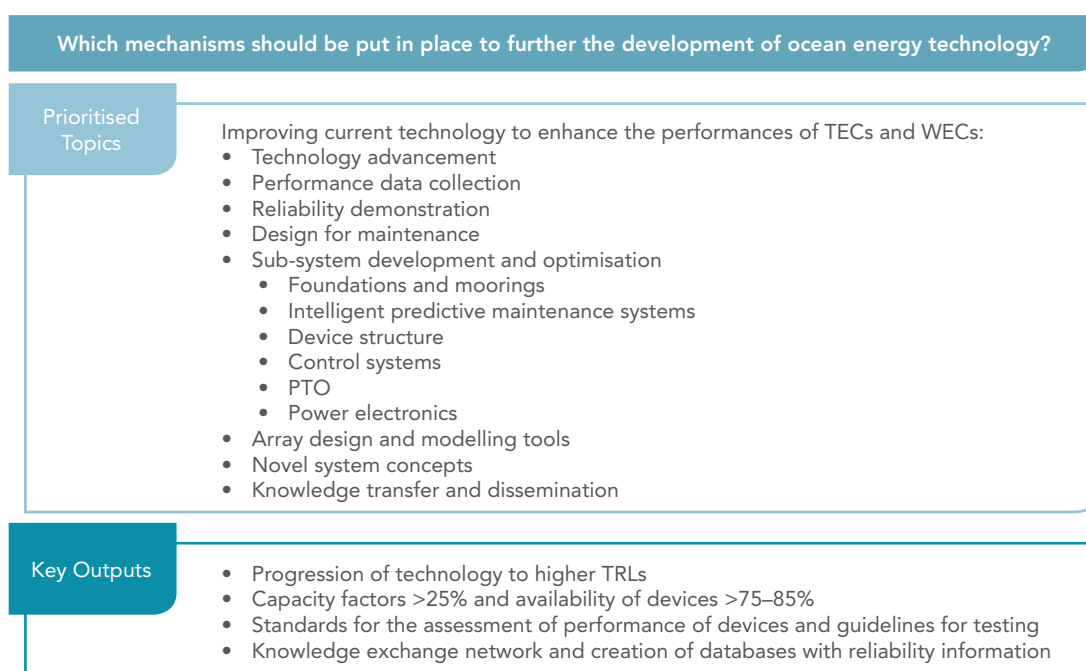
- **Manufacture and supply chain.** Gaps and barriers in this area mainly relate to a lack of design consensus and standards, which, as a consequence, increases the risk of not engaging sufficiently with potential manufacturers and subcomponent suppliers to create and stimulate the formation of a supply chain. Design consensus is needed to optimise current technologies, both at device level and at subcomponent level. The use of off-the-shelf components is desirable.
- **Knowledge exchange.** Experience from other sectors shows that expertise and knowledge exchange help bring technology to maturity quickly. The ocean energy sector needs to put in place mechanisms that allow the sharing of best practices aimed at converging designs, addressing failures and increase understanding amongst players.

Improved efforts in research and demonstration are needed to ensure that increased levels of technology maturity are reached, and that continuous development of the next generation of converters will be possible. The path toward full commercialisation involves proving technology reliability, therefore giving enhanced confidence in the performance of a given technology. The possibility of developing greater levels of design commonality through use of off-the-shelf components has often been highlighted; collaboration and industrial co-ordination

¹⁴ Knowledge transfer from offshore wind, and from the offshore oil and gas sector experience.

¹⁵ The DTOcean project (Optimal Design Tools for Ocean Energy Arrays), launched in 2013, is a three-year EC FP7-funded project designed to help tackle these complex issues, whilst Energy Technology Institute has funded the PerAWaT Project for optimising layout of wave and tidal energy farms.

Figure 9 – Output expected from the Technology Development stream



is needed to identify optimal design and application of subcomponents. Structural and component design should ensure that maintenance of high-risk components is taken into account, thus limiting failure and downtime. Technology progression and development should be achieved by improvement in Power Take-Off systems (PTOs), prime mover efficiency improvements, optimal substructures, foundation, and mooring designs, and optimising sub-system components.

The urgency of the sector in the short term is to address prioritised topics,¹⁶ to ensure that stable market penetration can be achieved in the long term. An overview of prioritised topics that require addressing is presented in Figure 9, along with a list of expected outcomes that can be achieved within the Technology Development stream.

5.1 Objectives

There is an opportunity for wave and tidal stream energy technologies to provide a meaningful contribution to European electricity supply. In order to realise this opportunity, achievable objectives for the Technology Development theme have been defined as follows:

- To prove and advance technology towards the development of small scale arrays. Support towards the development of small arrays has been announced from NER300, UK MEAD¹⁷ and the French Government. In this context, tidal energy arrays up to 10MW and wave energy arrays up to 5MW are envisaged. An intermediary step for both technologies could be to develop fully operating arrays with kW-scale devices. The successful development of wave and tidal energy farms is dependent on achieving small scale arrays first.
- To improve the reliability of WECs, TECs and their components through the use of proven offshore components and systems. Tidal and wave energy converters need to deliver efficient and effective operability, in addition to a high-level of reliability, in order to ensure the survivability of devices throughout the twenty-year life expectancy of the technology. Devices should target availability levels of 75–85%, and capacity factors of at least 25–30%, in the short term to unlock greater levels of confidence in the technology's ability to achieve design parameters. Future development work would involve improvements to availability once confidence in initial targets has been gained.

¹⁶ Prioritisation of activities was undertaken through engagement with the sector and is presented in the SI Ocean Gaps and Barriers Report.

¹⁷ Two tidal projects were awarded £20m funding through MEAD in the UK.

- To increase component, subcomponent and sub-system reliability and performance levels, helping technologies to meet and exceed availability targets.
- To continue the development of emerging designs and components. Innovation and development of new concepts should not be halted by the need to prove existing technology. Continuous innovation and new prototypes are needed to identify and ensure efficient and effective long-term cost reduction, and to develop new materials and to stimulate positive competition amongst developers.
- To implement effective long-term cost reduction pathways and high levels of reliability and survivability. There is a need to validate structural and conversion performances through the use of operation data for new and established concepts.
- To enhance control and monitoring systems for single devices and develop array tools through verification of single-device operations.
- Continued technology push programmes to finance the development of relevant innovative systems and sub-systems through to commercial readiness.

It is recognised that the targeted cost-reduction and performance improvement objectives can be achieved through various cycles of technological iteration and progression. For example, up scaling and device optimisation can only be achieved once a reliable technology has been identified. Similarly, cost-reduction pathways can only be identified when convergence of design and components opens up significant cost-reduction opportunities.

5.2 Identified mechanisms

In order to support the above objectives, the following mechanisms have been identified and are recommended to address urgent activities within the Technology Development theme:

- RDI&D programmes focused on WEC and TEC designs and materials.
- Reliability and performance testing of different concepts in mild resource environments.
- Standardisation of performance and reliability of machines.
- Establishment of a European industrial co-operation programme for knowledge exchange.

5.2.1 RDI&D Programmes

One of the key factors affecting the deployment of wave and tidal technology is the lack of long-term reliability demonstration from devices in ocean wave and current stream environments. TECs and WECs need to undergo final long-term reliability testing before being commercially deployed in harsh environments. In this context, it is necessary that programmes aimed at continued research, development, innovation and demonstration of devices are implemented to support the wave and tidal energy sector's growth.

Research, development and innovation programmes should be designed with a focus on two key development areas:

1. Novel system and sub-system concepts at a low TRL (1/2) to identify promising technologies that could offer step changes in cost or performance.
2. Intermediate technologies (TRL3–5) to support development towards greater technology maturity.

Research programmes should aim to prove the potential value of technologies in our future energy system, thus leading the way towards the development of more flexible and adaptable energy systems. At the same time, research activities should aim at identifying novel designs and components that will ensure the efficient long-term cost-reduction. It is recommended that the development paths address existing challenges with regards to supply chain engagement and components and subcomponent design. It is envisaged that the following activities would aid the development of early-stage technologies and should be given focus when establishing RDI programmes:

- Single prototype testing of innovative concepts and components:
 - Test methodologies to assess performance, survivability and reliability, aimed at a 20 year lifetime.
- Design for maintenance:
 - Innovative designs to increase the lifetime of device.
 - Innovating components and materials to ensure cost-reduction.

Demonstration programmes should focus on device design for devices at higher TRLs (TRL >5/6), aimed at testing and advancing technology toward the deployment of pilot arrays (five devices or 5MW), for either near-shore or offshore applications. Cross-industry collaboration and co-operation is envisaged. Synergies are necessary to develop vital common components and utilisation of existing technologies, in particular:

- Advancement of technology towards:
 - **Commercialisation of TECs.** Tidal energy technologies appear to be closer to commercialisation in the short term than wave energy technologies. Further reliability improvement and demonstration of pilot arrays will provide the necessary experience for the technologies to achieve commercialisation. Extensive component and sub-component testing will help to optimise TEC design and deployment.
 - **TRL progression for WECs.** Wave technologies have, to date, demonstrated a lower level of operational hours and capacity factors than tidal technologies. The design diversity within available wave energy technologies provides an opportunity for an in-depth evaluation of individual devices operating as stand-alone units, and to support those with the strongest technical and business cases. The technology path to commercialisation has to be completed through clear steps and evaluation by means of certified procedures.

In both cases, strong emphasis should be given toward optimisation, development and innovation of wave and tidal energy sub-systems. Sub-systems have a significant impact on overall system performance and reliability. The following actions are envisaged to help tackle many of the issues related to sub-systems optimisation:

- Common research on moorings and foundations structure, including loads and shear stresses, aimed at reduction in CAPEX costs. There is margin for technology developers and the supply chain to identify a set of common solutions that could be applied to different technologies.
- Establishment of a collaborative technical platform for the development of advanced

hydrodynamic modelling systems and of intelligent predictive maintenance systems. Such development should build on the experience gained by the PerAWaT Project¹⁸ and by the FP7-funded DTOcean project.¹⁹

- Development of sensing, algorithms and actuation in control strategies and systems, building on the lessons drawn from the FP7-funded Cores project.²⁰
- Optimisation and novel development of Power Take-Off (PTO) systems and power electronics for both technologies.

It is hoped that by enhancing collaboration on this topic, both the wave and tidal energy sectors could identify optimal solutions, thus achieving accelerated convergence towards design consensus, without affecting technology-specific IPR issues.

5.2.2 Reliability and performance

Many of the tidal and wave energy concepts have yet to be tested at sea in mild- or high-resource environments for long periods. One of the key factors affecting the deployment of wave and tidal technology is the lack of long-term reliability demonstration from devices in ocean wave and current stream environments. Technology developers should be encouraged in proving long-term autonomous and reliable operations of their devices offshore. This proof of reliability will give confidence to investors due to the reduction in project risk. It is envisaged that there will be an opportunity for different concepts to be demonstrated in mild-resource environments, thus allowing for:

- Technology proving, both in terms of reliability and performance.
- Collection of performance data, to inform of the value of existing technology and of the growth in terms of knowledge and understanding of current and future technology yields.
- Optimisation of life cycle costs, by demonstration of operational hours and reduction in maintenance needs..

In particular, technology developers should aim to ensure that devices reach availability of at least 75–85% and capacity factors of at least 25–30% to unlock significant cost-reductions.

¹⁸ www.dnvgl.com/news-events/news/wavefarmer-tidalfarmer-software.aspx.

¹⁹ www.oceanenergy-europe.eu/index.php/communication/press-corner/121-dt-ocean-dtocean-optimal-design-tools-for-ocean-energy-arrays-project-launched.

²⁰ www.fp7-cores.eu/.

5.2.3 Standardisation of performance evaluation

Both the tidal and wave industries need to work together toward the development of standards, guidelines and standardised procedures for testing and manufacturing devices and components. In particular, the sector needs to demonstrate co-operation in order to:

- Define methods and standards for testing WECs, TECs and their components, in collaboration with the IEC (International Electrotechnical Commission), EERA and Ocean Energy ERANET, and based on standards developed at EMEC and through EquiMar. Standardisation practices are already taking place, for example:
 - for TECs, IEC/TC114 is developing "Standard 62600-200 – TEC Performance Assessment", and
 - for WECs, IEC/TC114 is developing "Standard 62600-100 – WEC Performance Assessment".²¹
- Develop "Performance Guidelines" and technical specifications to support and integrate TRLs and provide access to specific funding programmes.
- Improve system lab testing facilities, at national and European scales.

5.2.4 European industrial co-operation programme for knowledge exchange

Knowledge exchange and transfer is essential for the progression of both the wave and tidal energy industries. The offshore environment has proven to be a difficult and unforgiving location, and the increased role it could play in meeting future energy demand requires cross-cutting collaboration. The establishment of a European industrial co-operation programme drawing upon know-how from other industrial sectors (e.g. offshore wind, O&G and maritime industry) is envisaged. Focus should be given to the production of systems and sub-systems for system reliability, the transfer of experience from other offshore sectors, and the building of a record of reliability data and subcomponent failures information from deployments across Europe:

- Knowledge exchange programme for the optimisation of sub-system design and

manufacturing improvements for substructures construction.

- Technology transfer from the other sectors such as the offshore wind energy, O&G and maritime sectors.
- Ocean energy database collecting failure data for a number of wave and tidal energy installations across Europe, similar to the *WindStats* and *ReliaWind*²² projects for the early wind energy sector.

5.3 Recommendations

The technological development of both the wave and tidal energy industries is dependent on a strategic approach to address existing and well-identified challenges. In this context, it is recommended that, in line with the Horizon 2020 vision of identifying developing and demonstrating strategic energy technologies for the future EU energy mix, wave and tidal energy developers should devote their efforts and focus to the following activities, for their technologies to reach commercialisation:

- Establishment of new RDI&D programmes aimed at improving reliability, availability and survivability of existing technologies.
- Establishment of mechanisms that support the development of innovative solutions that could ensure the long-term cost-reduction in ocean energy technologies. In particular, it is envisaged that such an approach will accelerate the development of novel technology toward higher TRLs, whilst advancing frontrunners toward initial pilot arrays before progression towards commercial market deployment.
- Validation of performance and reliability of devices in real sea conditions, thus providing investors with confidence in the technology. In this context, developers should target technology operation with capacity factors of >25% and availability >75%.
- Development of emerging designs and investigation optimisation and innovation of sub-system components, to identify cost-reduction pathways through engagement with the supply chain.
- Creation of standards and guidelines for evaluation and testing of devices.

²¹ www.tc114.us/2012/11/head-of/.

²² www.gl-garradhassan.com/assets/downloads/Wind_Turbine_Reliability_Analysis.pdf.

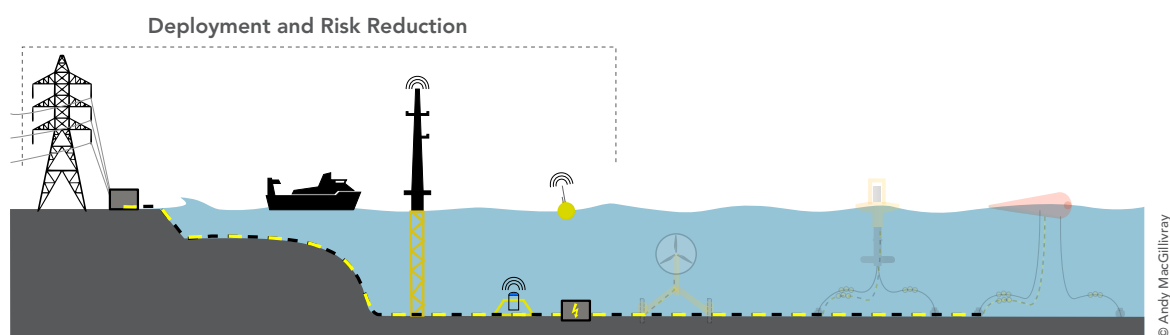
- Co-operation at European scale for addressing overarching issues, and development of common solutions to unlock the full potential of ocean energy in Europe.

In the short term, the results of such activities are expected to move technology toward market roll-out, through the development of pilot arrays. This process should enable validation of ocean energy technologies and their strategic value for the future European energy mix, thus reducing the risk for policy makers, regulatory authorities, industry, the supply chain and investors to invest in ocean energy.

Many of the above recommendations present overarching activities that are required for the development of both the tidal energy and wave energy sectors. For example the modelling of hydrodynamic parameters for the optimisation of performance could provide benefits to both sectors if undertaken through a joint programme. However, technology-specific research agendas are required for the development of both wave and tidal energy sectors.



6 Strategic Theme: Deployment and Risk Reduction



The deployment of ocean energy technology at sea is essential to increase the relevance and impact that tidal and wave energy sources can play in future energy markets. The credibility of both industries is dependent on their ability to get reliable and efficient devices in the water. Taking into account the current state of both technologies, deployment is an essential complement to the technology development theme for proving reliability and survivability of technologies. Deployment is therefore essential to reduce the risk associated with the sector and in attracting funds for further technology progression and stimulating array project development. The limited capacity installed for wave and tidal technologies is delaying the development and future market roll-out of technologies, in particular:

- **Low rates of deployment** are hindering the possibility for the sector to unlock some of the real cost-saving benefits such as economies of scale related to the manufacturing of multiple devices against single demonstration devices.
- **High risk** is associated with progression from single pre-commercial device deployment to the installation of array projects. The majority of the technology developed so far is still largely unproven. The requirement in terms of infrastructure and reliability of devices is high for many device developers to test or to deploy first demonstration arrays. The benefits associated with developing MW-scale machines in terms of harnessing are contrasted with the costs associated for their development testing.
- **Installation, O&M and retrieval operations** are high-cost centres for both wave and tidal energy technologies, whilst standardisation is

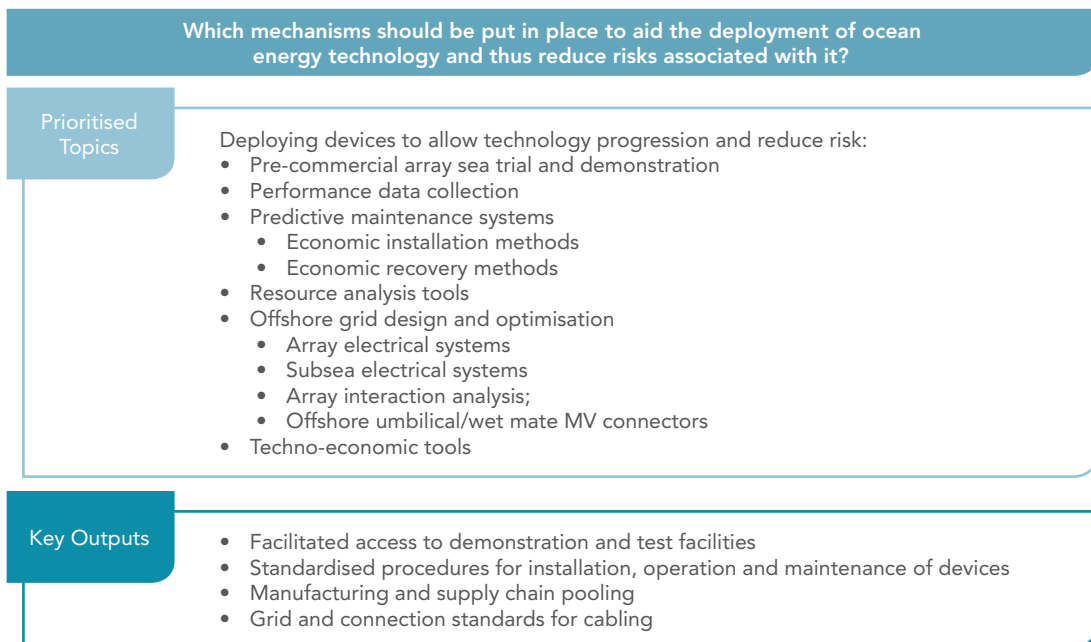
needed to identify best-practice installation and operational procedures. Convergence will allow both industries to develop common techniques and share auxiliary services such as vessels and ports.

- **Infrastructure** is key for the development of offshore energy technologies, as it comprises facilities for testing and integration of wave and tidal technologies with current electrical infrastructure. In particular, grid availability in coastal areas will play a key role in the future development of the ocean energy sector, as will the availability of supporting infrastructure at sea (substation and subsea hubs) and near-shore (manufacturing and maintenance ports).

Cross-sector and cross-industry engagement is needed to help identify pathways for the development of cost-effective installation techniques and deployment methods. Similarly, O&M optimisation is needed, both in terms of driving convergence in optimal design and methodology and in terms of fostering knowledge transfer and future innovation. Given the scale of the challenges related to the deployment theme of the STA, co-operation amongst key actors in the wave and tidal energy industries is essential to ensure a rapid increase of the rate of deployment. An overview of prioritised topics that require addressing in the short term,²³ along with expected outcomes, is presented in Figure 10. Long-term deployment targets will depend on the sector ability to gain sufficient confidence in the deployment of pilot and small-scale arrays in the short-medium term.

²³ Prioritisation of activities was undertaken through engagement with the sector and is presented in the SI Ocean Gaps and Barriers Report.

Figure 10 – Output expected from the Deployment and Risk Reduction stream



6.1 Objectives

One way of empowering the progression of wave and tidal energy technologies is to enable actions aimed toward increased deployment. Objectives for the Deployment and Risk Reduction theme have been set out as follows:

- To encourage through facilitated access and development of demonstration facilities the deployment of WECs and TECs to operate autonomously and in array configuration (up to five devices).
- To demonstrate operability, reliability and survivability of pilot farms in real sea conditions, thus providing vital information and feedback on installation, operations and decommissioning costs and methodologies.
- To develop new replicable and standardised procedures for installation, and innovative methods for access and maintenance of devices.
- To unlock optimised manufacturing processes through cross industrial co-operation with other sectors (e.g. onshore and offshore wind, civil aerospace, etc).

- To investigate grid integration feasibility and to develop infrastructure (hubs, substations) for integration with the grid and balancing with power systems of ocean energy electricity.
- To ensure conditions for deployment of technology in lower-resource, harsh environments.
- To identify and ensure efficiency and effective long-term cost-reduction pathways and high levels of reliability and survivability.

Compared to the Technology Development theme, many of the objectives set for the deployment theme offer the opportunity for cross-technology co-operation and collaboration amongst industries, in particular in terms of grid infrastructure and standardisation of operational procedures at sea. Through an increased rate of deployment, both industries will be able to accrue a higher level of certainty with regard to their technologies; but primarily it will help define learning rates and identify areas for cost reduction through standardised operations. The short-term aim is to facilitate deployment of pilot farms and increase the rate of deployment of device demonstrations at higher TRLs.

6.2 Identified Mechanisms

In order to support the above objectives, the following mechanisms have been identified and are recommended:

- Consolidation and reinforcement of a network of European test and demonstration facilities, building on the experience of FP7 MaRINET.²⁴
- Launch of a work programme for installation, O&M and retrieval operations.
- An EU cross-industrial co-operation framework for manufacturing of standardised components.
- Creation of a cross-sector platform to assess ocean energy integration with grid and power systems.

6.2.1 Network of European test and demonstration facilities

One of the many factors affecting the development of wave and tidal technologies is the unproven status of many concepts. There is the need to increase the number of demonstration programmes for tidal arrays (like those funded through NER300) and wave energy converters. The aim of this action is to establish a network of full-scale testing facilities to test and demonstrate ocean energy converters, where possible operating in arrays.²⁵ Particular attention should be given to facilitate access and co-ordination amongst full-scale test facilities:

- Providing access to standardized full-scale test and demonstration facilities across the EU, thus offering device developers the possibility to test and demonstrate their technologies across EU waters. This should build on the experience gathered from the FP7 MaRINET project, providing access to 42 European facilities (from laboratory to full scale).
- New and improved system-specific testing facilities such as for blades, rotors, moorings, PTOs; for reliability and sustainability, and optimisation of key components.
- Adoption of standardised certification system for test facilities, based on technology performance standards, as suggested in section 5.2.3
- Development of additional field testing facilities for array deployment at intermediate conditions.

The establishment of such a network should be considered only as one of the initial steps in stimulating and increasing the rate of wave and tidal energy array deployment. European and national programmes should be put in place to facilitate the deployment of pilot arrays and to encourage the development of early (inherently high cost and high risk) arrays, which are necessary to establish ocean energy as a commercial-generation technology.

6.2.2 Collaboration for installation, operations and maintenance

A high-risk component of ocean energy array costs is related to the installation and O&M of devices located offshore. If targeted, this area can provide significant cost reduction in OPEX through the standardisation and sharing of best practices at sea. A best-practice work programme is envisaged for installation and retrieval of WECs and TECs, in particular:

- Specific initiatives for installation techniques and retrieval of offshore devices.
- Development of preventive O&M, retrieval and monitoring procedures.
- Development of pan-industry schemes, e.g. assessing the impact of different foundation types on access and maintenance costs-
- A programme for access and maintenance of converters, particularly in remote, weather-hostile sites.
- Focus on Health and Safety procedures.

6.2.3 EU cross-industry co-operation for serial manufacturing

One of the expected results for the Technology Development theme, and from extensive testing of concepts, is the convergence toward standardised design of devices, and in particular of substructures and subcomponents. In order to prepare for the large-scale deployment in both industries, a co-operative demonstration programme for mass production of ocean energy systems and their substructures is envisaged, in particular:

²⁴ MaRINET is the Marine Renewables Infrastructure Network, comprising research centres and organisations that are working together to accelerate the development of marine renewable energy technologies. MaRINET is a four-years funded project terminating in 2015. www.fp7-marinet.eu/.

²⁵ The WaveHub, off the coast of Cornwall in the UK, was developed for testing and demonstration of different wave energy converters in array configuration. www.wavehub.co.uk/.



- Cross-industry initiatives (co-ordinated with the offshore wind industry) for the manufacturing, design and supply of substructures.
- Development of large-scale manufacturing, assembling and logistics processes for ocean energy systems (turbines, PTOs). This process is reinforced by the introduction of Manufacturing Readiness Levels (MRLs) in the Horizon 2020 framework programme, thus aiming to reach the necessary capability for the mass manufacturing of devices.
- Creation of ocean energy clusters—manufacturing facilities, ports and harbours co-located for the supply chain of the offshore wind, wave and tidal sectors.
- Encouragement of supply chain development:
 - Grid – securing grid access and development of its infrastructure to speed up ocean energy development.
 - Vessels – cross-industry collaboration for the development of specialised vessels adapted to the needs of the sector.

6.2.4 Cross-sector platform for ocean energy grid integration

The growth of both the tidal and wave energy sectors will require the implementation of grid infrastructure. Given the variability of the energy supply that can be expected from ocean energy sources, it is necessary to provide the basis for the transformation of current European power systems to adapt to variable energy inputs. Solutions for the integration of ocean energy into the grid are required to ensure grid stability. In particular, cross-sector and cross-industry collaboration are needed to:

- Define grid connection technologies and requirements for offshore farms, in collaboration with other offshore energy sectors. This topic offers the possibility for cross-sector integration and co-operation, in particular with the offshore wind energy sector. A range of projects has been funded to find suitable answers to issues related with grid access in remote areas, grid integration and stabilisation (e.g. EWIS,²⁶ SmartGrid,²⁷ WindGrid).²⁸ It is hoped that through enhanced co-operation, reliable and sustainable solutions can also benefit the ocean energy sector.
- Develop cables (standardisation of cables and connectors), substations and offshore networks.

²⁶ www.wind-integration.eu/.

²⁷ www.smartgrids.eu/.

²⁸ http://cordis.europa.eu/projects/rcn/86435_en.html.

6.3 Recommendations

The aim of the Deployment and Risk Reduction theme was to identify actions that would facilitate the installation of devices in low-risk frameworks, in order to drive learning-by-doing and unlock potential cost-reduction mechanisms. Whilst the mechanisms suggested for the Technology Development theme are mainly technology-specific, those related to the Deployment and Risk Reduction theme present a more ample margin for cross-sector co-operation and engagement. Similarly, core activities aim at putting in place strategies, infrastructure and solutions that should yield long-term benefits by enhancing collaboration with the various ocean energy stakeholders. Co-ordinated activities should prioritise the following actions:

- Demonstrating wave and tidal energy technologies, in particular advancing them toward full-scale demonstration in real sea conditions, essential to ensure that the technologies will be ready for roll-out. A fundamental step in this context is given by the provision of access to test and demonstration facilities across Europe, to reduce risk for device developers, which should increase the industry know-how and allow for the growth of the sector.
- Developing of standardised cross-sector operational procedures for installation, maintenance and retrieval of devices.
- Unlocking, through co-operation with supply chain and standardized manufacturing, economies of scale.
- Establishing, in collaboration with other energy sectors, guidelines and standards for grid integration and connection, whilst facilitating access in the short term.

Facilitating deployment will provide much-needed information and security over technical levels of reliability and survivability of devices; but primarily, it will provide certainty of the costs related to installation, operation and decommissioning of farms, and of related learning rates for the sector. In the short term, the deployment-related activities should concentrate toward deployment of demonstration arrays, thus encouraging and stimulating the learning of the sector to accelerate the current technological status. The deployment of pilot plants should be facilitated to encourage the commercial development of wave and tidal energy. In the medium–long term, efforts should focus on optimising automated manufacturing processes for large-array installation, increasing installed capacity; whilst solutions with regard to grid supply and integration should be identified and acted upon.

SECTION IV

Conclusions and Recommendations



7 Conclusions and Recommendations

The scope of this document was to provide policy makers and actors interested in the development of the ocean energy sector with details of what is needed to help European wave and tidal energy industries accelerate their technologies toward commercialisation, to supply clean and secure electricity in future energy markets.

This document has provided a series of actions and mechanisms that should help the wave and tidal energy sectors move toward large-scale manufacturing and deployment by overcoming many of the technological challenges hindering their development. In the short term, these are aimed at ensuring that technologies are ready for roll-out in the market, driving toward full-scale commercialisation and competitiveness with other energy sources in the long term.

A twin-track approach of Technology Development and Deployment and Risk Reduction was proposed to address a number of high-priority topics that currently hinder the development of the ocean energy sector, as shown in Figure 11. It is recommended that mechanisms are put in place to address and meet the needs of the identified and prioritised topics, in the short-to-medium term, thus driving the sector toward the deployment of pilot arrays. Most of these activities are overarching topics, and their implementation will benefit the ocean energy sector as a whole; however, technology-specific interventions are also required for the progression of the wave and tidal industries, which are currently at different levels of maturity.

Figure 11 – Overarching actions needed by the wave and tidal energy sectors

	Priority Topics	Recommended Mechanisms
Technology Development	• Technology advancement • Reliability demonstration • Performance data collection • Design for maintenance • Sub-system development and optimisation: • Foundations and moorings • Intelligent predictive maintenance systems • Device structures • Control systems • Power take-off • Power electronics • Array design and modelling tools • Novel system concepts • Knowledge transfer and dissemination	• Establishment and reinforcement of RDI&D programmes for development of novel technology and towards TRL progression, with strong emphasis on sub-systems • Validation of performance and reliability of WECs and TECs reaching capacity factors of >25% and availability >75%. • Standards and guidelines for evaluation and testing of devices • Co-operation at European scale for addressing overarching issues
Deployment and Risk Reduction	• Pre-commercial array sea trial and demonstration • Intelligent predictive maintenance systems • Resource analysis tools • Offshore grid design & optimisation: • Array electrical system • Subsea electrical system • Array interaction analysis • Offshore umbilical/wet mate MV connectors • Techno-economic tools	• Demonstrating WECs and TECs, through facilitated access to test and demo facilities in Europe • Standardised procedures for installation, maintenance and retrieval of devices • Co-operation with supply chain for standardised manufacturing • Collaboration with other energy sectors for grid integration and connection issues

Overall, to ensure the progression of both technologies in the short term, it is recommended that technological priorities are in line with the vision of the EU Horizon 2020 funding programme:

- Demonstration of advanced technologies, including demonstration and validation of existing prototypes toward full-scale testing (TRL 5–7), leading toward pilot arrays deployment (TRL >8).
- Technological progression of technologies at TRL 3–5, development of novel and innovative technologies (TRL1–3), components and materials, and furthering existing concepts.

Recommended actions presented in this document have been developed in alignment with the Horizon 2020 goals to ensure greater cohesion and impact at the EU level.

The current state of the art in wave and tidal technologies indicates that tidal energy converters are a step closer to commercialisation compared to wave energy concepts. It is recommended that the wave and tidal energy sectors are differentiated to ensure their establishment within the energy market; it is therefore envisaged that technology-specific research agendas, framework policies and market deployment strategies are developed and put in place. These will aid both sectors in unlocking the funds necessary for R&D of early-stage technology, and make demonstration funds available for advanced technologies and large-scale arrays.

In both cases, technological activities should achieve significant improvements in current and future technologies, by increasing capacity factors (>25–30%), increasing availability of devices (>75–85%), and reducing CAPEX and OPEX by op-

timisation and standardisation of manufacturing, installation and operational procedures.

In terms of aiding deployment and reducing risk, both industries will benefit from cross-sector co-operation aimed at providing solutions to common topics, such as operational procedures, grid integration, and provision of access to facilities.

Achieving the ambitious goals set out for the ocean energy sector requires a level of commitment and co-ordinated RDI&D beyond the current status quo of programmes and funding schemes. The long-term market penetration for both technologies is dependent on success in identifying specific funds and policies, and in achieving the right balance of co-operation and competition amongst different actors. Reliable, available and economic technologies are critical to the development of a flourishing ocean energy industry.

In particular, for the ocean energy sector to match the 2020 timeline, implementation of the above mechanisms is required to meet the urgent wave and tidal development and deployment needs. The level of success to which the wave and tidal energy sectors will meet the objectives by 2020 will be in direct proportion to the political will for the advancement of each sector.

The key recommendations from the Strategic Technology Agenda will directly feed into the Market Deployment Strategy. The MDS is the final deliverable of the SI Ocean project, and will provide a series of holistic technology and policy support recommendations to the European Commission, Member States and regional governments.



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