Research Priorities for PRIMaRE

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1 About PRIMaRE

For the marine renewable energy sector to meet its commercialisation targets and became successful in its development, a required enhanced collaboration between actors in the sector and especially among research institutions is needed. In particular this document presents the research priorities and development needs of the sector to meet commercialisation targets that the Partnership for Research in Marine Renewable Energy (PRIMaRE) has identified.

PRIMaRE is a consortium of marine renewable energy experts across higher education, research and industry which have joined together to establish a 'network of excellence' centred in the south of the UK. The Universities of Plymouth, Exeter, Southampton, Bristol and Bath, along with the Marine Biological Association of the UK and Plymouth Marine Laboratory, have agreed to work together on research projects across the spectrum of marine renewables. Completing the line-up of the Partnership for Research in Marine Renewable Energy (PRIMaRE) is the South West Marine Energy Park (SW MEP) and the Wave Hub facility off the north coast of Cornwall, who will act as conduits between the research community and industry.

In order to speed up the development of the marine renewable energy sector and its supply chain, especially in the south of England, PRIMaRE and the SW MEP have identified the following research priorities and development needs, which are set out in this document. Taking advantage of DECC's UK Marine Energy Programme Board (MEPB) annual meeting, which took place in Plymouth on the 5th of March, PRIMaRE in collaboration with the SW MEP organised a priorities scoping workshop the preceding day. The present document is the result from the inputs and discussions taken at such workshop where representatives from the different PRIMaRE partners, the industry, SW MEP and Wave Hub where present.

The research priorities presented in this document have been grouped into three main categories - (i) technical research priorities, (ii) interdisciplinary research priorities and (iii) environmental priorities -, attending where the priorities affect directly to the development of the technology, where they look at possible effects of the MRE devices on the environment or where they tackle at the same time a combined effect on the technology development, the environment and other factors (i.e., impacts on local communities). Nevertheless, each one of the research priorities presented in this document needs to be tackled following a multidisciplinary approach where, technical, environmental and social aspects needs to be addressed.

2 Technical Research Priorities

The technical research priorities have been classified according to eight different technical research themes identified by PRIMaRE.

2.1 Materials and Manufacture

The development of new materials and manufacture processes is a key element to reducing costs and ensuring survivability of Marine Renewable Energy (MRE) devices. Within this wide field, the following research priorities have been highlighted as key for PRIMaRE.

i. **Biofouling:** Any technology submerged or in contact with the sea is likely to be affected by biofouling. The interaction of the devices or its components with marine growth is crucial as it affects the device performance and design conditions. The development of new materials to avoid or minimise biofouling is a key research priority.
ii. **Corrosion:** Use of steel or metallic alloys is common practice in the MRE industry, correct understanding of the corrosion processes and how to avoid them with new coatings or techniques and how to adapt the O&M corrosion cycles and inspections to maximise the life time and operability of MRE devices is crucial to reduce their total cost.
iii. **Disposable materials:** The use of disposable materials in the design of MRE devices or components is crucial to ensure a low cost and low impact decommission and carbon life-cycle of the devices.
iv. **New materials:** The application of novel materials and construction techniques that will reduce costs, improve reliability and extend the lifetime of devices is crucial to reduce the cost of energy and move the sector forward - e.g., novel materials such as reinforced concrete and composites, novel construction techniques, etc.

2.2 Fluid Dynamics & Hydrodynamics

As technology devices that harness energy from fluids in motion and are affected by the extreme forces produced by these motions, a proper understanding of the fluid dynamics and hydrodynamics of MRE devices is crucial to their development.

i. **Turbulence:** A deep understanding of turbulence, and its effect at single and multiple devices is crucial to understand how devices will interact and perform in arrays.
ii. **Combined loading:** In the real sea environment MRE devices commonly face the effects of combined waves, tidal currents and wind. The combined action of these forces on MRE devices makes characterisation of their response at laboratory scale and with numerical models of special relevance to obtain a better understanding of how they perform under such circumstances.
iii. **Extreme loads:** One of the particularities of MRE is that the devices need to face extreme loads and survive storms. Thus, the development of novel evaluation techniques to appropriately model these extreme loads at laboratory scale and by numerical models is required.

iv. **System dynamics:** At real sea conditions, MRE devices are subjected to irregular waves and variable tidal currents. The particularity of these variable resources is that the differences between maximum and mean values are particularly high, especially for wave energy.

v. **Non-linear effects:** The standard engineering techniques to model the behaviour and response of MRE devices consider linear models in order to simplify the problems and obtain faster solutions. However, the reality is often far from the linear model and non-linear effects must be considered to achieve a proper understanding of the performance of the devices in real conditions. Thus, the development of non-linear models and tools to assess these effects is of special relevance.

vi. **Improved numerical models:** Advanced numerical models able to simulate accurately the response of full scale devices require long computational times and resources. The development of validated tools and resources that optimise simulation times is crucial for the development of MRE.

2.3 Survivability and Reliability

The survivability and reliability of MRE devices in the marine environment need to be proven for the industry to become commercial.

i. **Extreme events:** Ensuring the survivability of devices under the high loads occurring during extreme events is crucial to reduce the risk of failure and increase their range of operability. To do this, new research is needed to understand the behaviour of MRE devices under such extreme events.

ii. **Mooring and anchoring:** The particularity of MRE devices means that traditional oil and gas or seakeeping mooring concepts are usually not valid, due to either their high cost or to the different loading conditions. Thus, the development and proof of novel cost efficient mooring solutions is key to the MRE sector.

iii. **Reliability vs cost of energy & lifetime:** A competitive cost of energy which allows MRE to become competitive in comparison with other renewable energies is fundamental for the development of the sector. This means that a compromise between reliability and cost of energy along the lifetime of the device should be found. New research is needed in order to understand better the resilience of MRE devices and optimise their costs.

iv. **Component lifetime:** The weakest of its components defines the entire reliability of a MRE device. This together with the harshness of the marine environment and the frequent exposure to extreme loads makes design of all components crucial. On one hand, some of these components are overdesigned coming from the oil and gas industry; and on the other hand, some components are weak, representing a potential risk for the devices' integrity. Research is needed to asses each individual component and adapt it to the MRE industry needs, redesigning the expensive components and strengthening the weak ones.

v. **Impacts:** MRE devices are subject to potential impacts - e.g., an impact of a marine mammal over the rotor of a tidal turbine, and a collision between wave energy converters due to a mooring failure - and these impacts could damage severely the integrity of the device. Research is needed in order to understand the potential of these possible impacts and to propose novel techniques or solutions to avoid or minimize their effects.

2.4 Environmental Resources

Understanding thoroughly MRE resources is imperative to harnessing them in an efficient manner.

i. **Physical processes:** Even though wave, tidal currents and offshore winds are well understood at medium and large scales, there are still plenty of physical processes related to them that require further study, especially when energy extraction is involved. Further research on physical process is required. This means phenomena such as: turbulence, atmospheric thermal gradient, oceanic fronts, salinity, spatial (and spectral) variability of waves, sediment transport, etc.
ii. **Macro vs regional scale:** Wave, tidal and wind macro scale models are well known and have been validated during the last years, however, to transfer the input from these large scale models into more reduced scale regional models still requires further research.
iii. **Remote sensing:** Monitoring MRE resources at the sea is expensive and sometimes risky or impossible due to the weather conditions. The development of novel remote sensing techniques which allow monitoring of MRE resources further from the site or to cover larger areas is crucial to reduce uncertainties about the resource and its costs. Further research is needed on monitoring techniques or instruments such as floating LIDAR's, HF radars, satellite monitoring.
iv. **High resolution resource models:** Forecasting MRE resources with high resolution is not only important to be able to predict the energy production, but also to inform control strategies that require being able to predict and respond precisely to the incoming resource.

2.5 Devices & arrays

The level of technological development among MREs is very variable depending on the type of energy being harnessed, thus on one hand floating offshore wind and tidal turbines have successfully achieved full scale demonstrations and are moving towards arrays, in the other hand wave energy converters are less developed in their progression towards array deployments.

i. **Remote monitoring:** Accessibility of MRE devices at sea is not always possible due to the weather conditions which makes that develop remote monitoring and control techniques and operation procedures an important requirement to increase operation times and reduce Operation & Maintenance (O&M) costs.
ii. **Moorings:** Mooring systems for MRE devices are a crucial subsystem that influence both the global performance of the device and its survivability. However, when it comes to arrays of MRE devices, these became even more important, as the mooring dynamics and interactions will condition the layout of the array. This means that future research to understand the mooring dynamics and to develop new techniques and operations for moored systems is required.
iii. **Array interactions:** Few MRE devices have been tested in arrays so far, which means that significant unknowns remain around how the energy extraction of some devices will affect the performance of the other devices in the array. This is a crucial research topic as it will influence significantly the layout of future arrays.

iv. **Component sharing:** One of the particularities of arrays is that they may lead to sharing of some infrastructure, such as the mooring lines and the PTO, with the consequent cost reduction. Future research is needed in order to assess whether sharing of this subsystems is suitable to be implemented or not.

2.6 Power conversion and control

Ultimately MRE devices are meant to produce electricity at an affordable cost. This means that power conversion and control subsystems are fundamental parts of a MRE device.

i. **PTO:** A Power Take-Off (PTO) is one of the fundamental components of every MRE device, as it is through this where ultimately the power is harnessed. Increasing PTOs performance, making them more reliable and extending their lifetime are required steps to reduce MRE costs.
ii. **Control strategies:** Due to the irregular character of the MRE resources, and in particular of wave energy, control strategies are required in order to maximise the power output. Future research is needed in order to prove control strategies that have been suggested during the last years and to develop novel techniques.
iii. **Cost of energy and extremes:** The cost of MRE today is still too expensive to make it affordable in comparison with other renewables. This together with the fact that the difference between maximum and mean power productions is very high in comparison with other renewables, means that additional research is needed to tackle these issues.
iv. **Electrical control systems:** Novel power electronics control systems able to transform the variable energy production obtained from the MRE resources into conditions required for the electric grid are required for successful development of the devices.

2.7 Infrastructure and Grid Connection

For offshore energy projects, the infrastructure and grid connection costs represent one of the largest components of the total project costs. This means that future research is needed in order to reduce cost and reduce the cost of energy.

i. **Subsea connectors:** The development of novel concepts of subsea electric connectors which will allow reduced times for installation, decommissioning and standard plug and unplug operations during O&M are required.
ii. **Operation & Maintenance site specific issues (Wave Hub):** The development of specific protocols and tools for O&M procedures at MRE test centres is of special interest in order to extrapolate them to other future projects. Furthermore, these test centres can be used also to develop and test novel O&M techniques.
iii. **Co-located devices:** The combination of more than one MRE technology at the same site is a novel approach that takes advantage of the multiple synergies arising from deployment of more than one technology at the same location. Understanding the implications of this practice is crucial in order to further develop these kinds of projects.
iv. **Grid integration:** Integrating the energy harnessed at MRE parks into the existent energy grid is not a simple task due to the existence of multiple challenges, such as: the lack of grid

infrastructure inland near the parks, the variable character of the energy production, the lack of coupling between the production and the demand of energy.

2.8 Marine Operations and Maritime Safety

Operations and Safety at Sea are not simple tasks due to the variable conditions and harsh working environment, which means that operations to access an offshore device or to deploy a wind turbine may be high risk challenges. Further research in order to simplify and reduce the risk in these tasks is crucial to further develop the sector.

i. **Disposable devices:** The consideration of the decommissioning phase of a MRE device at its development phase is very relevant in order to save time and resources. Further research is needed in order to include these aspects during the development phase or the design of novel materials or devices.
ii. **Access to devices and facilities:** To access an offshore device is not a simple task, especially when the sea conditions differ. This means that at some sites access times to devices are reduced to even below the 60% of the year, resulting in an increase of the O&M costs and in performance reduction. Design of novel access techniques or unmanned O&M protocols is one of the main challenges for the MRE sector to accomplish in order to reduce their operation costs.
iii. **Co-located devices:** The deployment of more than one MRE technology at the same site has the associated risk of possible interference between technologies - e.g., reducing the energy production, collision or impact between devices, etc. In order to make this promising solution a reality, these challenges must be further addressed in the next years.
iv. **Weather windows:** An accurate forecast of the weather windows to access offshore sites to perform O&M and deployment activities is highly important to reduce costs and deployment times. Future research is needed in order to produce new short and long term models to forecast weather windows.

3 Interdisciplinary Research Priorities

Research is required that bridges different disciplines (engineering, socio-economic and governance, environment) to support sustainable development of MRE.

3.1 Socio-economic implications

As marine renewable energy develops beyond the demonstration scale, improved knowledge of the potential socio-economic implications of larger arrays is required. In particular, a better understanding is needed of what the social, economic and environmental costs and benefits are and how they are distributed spatially and temporally d between local, regional and national levels. The findings of this empirical research can then be applied to support Marine Planning, licencing, and Governance and stakeholder engagement (Section 3.3, below).

i. **Public and stakeholder attitudes**: The foundation for understanding socio-economic issues is to determine how stakeholders and the wider public perceive the development and impacts of MRE, and which socio-demographic factors shape their attitudes. At present, the public has very limited awareness of MRE, and so it is also important to understand how different messages and media types are perceived as sources of credible information.

ii. **Ecosystem services and natural capital valuation**: There is a growing policy trend to seek to understand environmental impacts in terms of their societal implications, which is achieved through the framework of ecosystem services. Ecosystem service approaches also facilitate monetary valuation of natural capital impacts, and hence support enhanced cost-benefit analysis of MRE developments and natural capital accounting. For these reasons, ecosystem service approaches need to be embedded in full life-cycle analysis of MRE.

iii. **Regional and national economic impacts:** Commercial-scale MRE developments have the potential to bring economic benefits though, for example, job creation and supply chain development, although other sectors (e.g., fisheries, recreation) may be negatively affected. At present, the scale of these effects and their implications for regional and national economies is poorly understood.

iv. **Understanding trade-offs:** Also key to planning and policy decisions is understanding how the benefits of MRE development - e.g. clean, renewable energy, job creation - are traded-off against natural capital and ecosystem service impacts at the level of individual energy consumers, local communities and regional and national economies.

3.2 Implications of Multi-use of Marine Resources and Cumulative Impacts

The development and consequently deployment of marine renewable energy devices at sea brings a new agent and a completely new industry to the maritime environment, and hence also new combined technological, environmental and social challenges that could present potential benefits and risks.

i. **Multi use of marine resources:** Multiple marine resources are usually available at the same site or geographical location and synergies between the different users of these resources exist. Sustainable development of the exploitation of these marine resources requires their multi-use. For successful implementation of multi-use of resource and space further research and development are required into the viable options for synergistic (as well as antagonistic) combinations of wave, tidal and offshore wind energy with other uses, such as aquaculture, or maritime leisure. This is being successfully planned at sites elsewhere (e.g. Peterhead)

ii. **Cumulative impacts:** As development of MRE increases impacts on the environment, society and economy are likely to be cumulative. For example, the impacts of large scale extraction of marine energy on hydrography, the increasing scales of noise impacts on marine organisms, impacts on ecosystem services and their socio-economic benefits. Undesirable thresholds could be reached. Interdisciplinary understanding as well as improved modelling projections are required to anticipate and manage for undesirable outcomes from scaling up of MRE extraction. Understanding of multi-use and cumulative impacts is required to support marine planning and MRE licencing decisions.

3.3 Marine Planning and Governance

Traditionally the marine and maritime sectors have been characterised by the absence of a coordinated planning and governance, as opposed to what happens onshore where coordinated regulations and planning have been in place for many years - e.g., land use planning, mining exploitation concessions and natural protected areas. However, in the last few years some EU initiatives, such the Maritime Policy, Maritime Spatial Planning, and Integrated Coastal Protection Management as well as the Marine Strategy Framework and Water Framework Directives (via consideration of impacts of MRE on the targets of good environmental/ecological status) are driving the need for more coordinated planning of the marine and coastal space. Integration of different resources uses is crucial to ensuring a sustainable development.

i. **Stakeholder engagement:** The engagement of the stakeholders and especially of the local communities is crucial for the successful development of a MRE project. Plenty of examples show that not taking into consideration these actors at early stages of the project development has been damaging for the projects. Developing novel tools to facilitate this engagement and to increase the communication between the developers and the stakeholders is of special relevance for the success of future MRE projects.
ii. **Life-cycle planning:** An appropriate assessment and planning of the complete life-cycle of a MRE device is of important to increase the sustainability of the technology. The development of new generation concepts and new tools to tackle this at full scale is necessary.
iii. **Spatial planning:** An appropriate planning of the spatial distribution of maritime resources and uses is vital for a sustainable development of the seas and its coexistence with traditional and new users. A significant effort has been made by European and national administrations to start this large endeavour; however, future research is needed to propose novel approaches and uses of the sea's resources.

4 Environmental Priorities

The environmental research priorities identified have been classified according to five environmental research areas.

4.1 Impacts of Infrastructure on Physical Processes

Understanding the effects on the physical processes that the deployment of MRE infrastructure such as mooring anchors or solid foundations have is of special relevance to understand how these technologies affect the environment.

i. **Morphodynamic and coastal morphology:** understanding how the energy extraction from harnessing waves or tidal currents affects to sediment transport processes occurring in tidal stream flows or coastal erosion phenomena at the coastline are of a special relevance to overview the large scale effects of MRE deployments.
ii. **Scouring:** The interaction between solid foundations of MRE devices with currents and waves produces erosion of the seabed in the surroundings of the structure. This phenomenon known as scouring is of special interest due to its possible effects altering the

previous sediment transport processes. Further research is needed in order to understand how relevant this possible impact is.

iii. **Electrical and Magnetic Fields:** There is a lack of international standards or common industry practice about what is the required burying depth for the cables to consider the effects of the electromagnetic fields over the ecosystem as acceptable, so further research should be conducted in order to develop a unified approach to tackle this issue.

4.2 Impact on Fishes and Benthic Communities

The deployment of MRE devices has a clear effect over all components of the local and wider environment, though detecting these against high natural variability and the consequences of exploitative activities (such as fishing) is inherently difficult. This is usually compounded by the lack of pre-development, location-specific monitoring.

i. **Displacements, barriers to motions and migrations:** The presence of new structures altering the environment could potentially act as barriers or generate displacements or altering migrations in the coupling of fishes and other communities. In order to understand these possible effects further research should be conducted in anticipation of and during future deployments of MRE devices.

ii. **Effects on the trophic chain:** The energy extraction caused by harnessing marine resources could potentially affect the trophic chain. Understanding whether or not MRE devices could affect the production of nutrients, displace species, etc. should be considered during the next years.

iii. **Introduction of non-native invasive species:** Deploying MRE devices creates new habitat with a potential risk of introducing non-native invasive species that can significantly alter the ecosystem. New research should be conducted to understand this risk and develop contingency measures to avoid it.

4.3 Impact on Local Communities

Complementarily with the research needs for fishes and other marine biota communities, there are other biological components whether generally present or transitory that affect local communities such as fishes, birds and marine mammals.

i. **Acoustic monitoring:** Development of novel active and passive acoustic monitoring techniques and instruments is an important area of research needed to acquire a better understanding of how MRE devices affect local communities. AS MRE device deployment continues, the study of such interactions using novel techniques will be of special relevance – e.g., new hydrophones or lateral sonars able to record the interaction of local communities with MRE devices

ii. **Marine mammals modelling:** modelling the behaviour of marine mammals, as individuals in the upper levels of food chains and of societal importance, is needed to understand possible effects of MRE devices. Future research is needed in order to produce novel and accurate behaviour models for marine mammals.

4.4 Reef Effect

One of the possible impacts of deploying MRE devices is the facilitated or accidental creation of artificial reefs, however, this side effect needs to be fully understood and monitored in order to find possible negative/positive effects. In order to do this, new research including early planning and life-cycle monitoring of new deployments of MRE devices is needed.

4.5 Entanglement & Entrapment

Large individuals such as marine mammals may be at risk of collision or being entangled of entrapped with the MRE devices or some of their subsystems – e.g., an impact of a marine mammal with a tidal turbine or the entanglement with the mooring lines. In order to understand the possible risks for the mammals, or the MRE devices themselves, further research is needed. The definition of marine mammals' characteristics in order to produce accurate models which will allow a realistic simulation of a possible impact or the creation of novel techniques or protocols to avoid possible entanglements are two of the future research priorities identified at this point.

5 Conclusions

In summary, MREs are amongst the renewables with the greatest potential; however, to succeed in the quest to develop the MRE energy sector, some significant challenges need to be tackled during the following years. This document takes the input from a workshop organised by PRIMaRE in collaboration with the South West Marine Energy Park on the 4th of March of 2015, to draft the technological and environmental research priorities for the PRIMaRE partners in the upcoming years.