Supergen

Offshore Renewable Energy

CORE RESEARCH

Engineering and Physical Sciences Research Council

BACKGROUND AND CONTEXT

The need to explore and develop new renewable energy sources is well understood. Globally we must reduce our dependence of fossil fuels due to their pollution and insecurity of supply. As agreed internationally at the Paris UN Meeting in 2015, and reinforced in Bonn 2017, it is imperative to keep global temperature rise below 2 degrees centigrade, by drastically reducing CO2 emissions. The energy landscape for 2050 and beyond will need to be transformed from that today, and will likely comprise a combination of: demand management; nuclear; fossil fuel, with Carbon Capture and Storage (CCS); biomass (with CCS); solar; with significant contribution from ORE.

The scale of ORE potential is vast; the UK is currently at the forefront of the sector and, with its large coastline, ORE is a natural solution to the UK requirements. It has the advantage of being locally available, providing energy security, and could be an important export market.

SUPERGEN ORE HUB OBJECTIVES

There are many common stakeholders across offshore wind (OW), wave and tidal. Co-ordination of research through a single hub will enable enhanced engagement, easier access to the knowledge base and better coherence for stakeholders with shared interests. The Hub will work with the ORE community to disseminate information to industry and link challenge owners, SMEs and academia.

High-level objectives for the Supergen ORE Hub are to:

1. Provide 'Visible Research Leadership'
2. Execute, publish and inspire distinctive and ambitious world class research through the core programme;
3. Facilitate a programme of co-ordinated UK led research through the flexible fund;
4. Be a respected voice for policy makers and a trusted partner for industry;
5. Have strong international collaboration;
6. Take a whole systems approach to ORE;
7. Become a 'beacon for equality, diversity and inclusion' (EDI);
8. Support the development of early career researchers (ECR).

These objectives build on the Hub's ORE Area Strategy, which describes the role of the Supergen ORE hub and research challenges, building on the work of the Supergen Leaders engagement project to define a distinctive programme of research which is both adventurous and deliverable.

The research conducted by the Supergen ORE Hub, along with the wider programme of UK and international research that is nurtured and promoted by the Hub, will be applicable to a range of potential future ORE systems. To provide focus, the hub will establish three Aspirational ORE Systems (AOSs) as beacons for step changes in ORE.

These AOSs provide a clear, coordinated motivation and a benchmark against which research progression can be measured, as confidence in the viability of each AOS is improved.

The AOSs are:

- **AOS1: A large scale floating future**
  A multi-GW floating ORE farm, unlocking ORE beyond the water depths currently targeted, and creating a step change in farm scale via innovative new engineering systems.
- **AOS2: Scaled-up and safe exploitation of tidal streams**
  A step change in scale for tidal stream systems, moving the industry from prototype proving to systems designed for operation in commercial arrays with high confidence in prediction of performance and ecological acceptability.
- **AOS3: Farm-scale wave energy**
  A wave energy ORE sector in which the scaling benefits from single to multiple devices are realised, creating the step change in the viability of this technology that is required to secure ongoing investment.

METHODOLOGY FOR THE CORE RESEARCH

The fundamental challenge for all ORE systems is to reduce costs and risks. This can be achieved by addressing interconnections between stages and scales of analysis required for ORE system design. Improved understanding of the response of ORE systems to environmental inputs is central to improved predictions of performance. Equally, better understanding of environmental response to ORE system presence is critical to understanding environmental impacts and to ensure accurate predictions of resource.

Feedback between system operation and resource behaviour are clearly important for tidal stream arrays, for wave arrays in the form of radiated waves and of increasing importance for offshore wind with the development of deeper arrays and closely spaced farms. The core research package focuses on addressing these detailed interconnections, drawing on a whole systems approach. The overview of the work is summarised in Figure 1. This identifies 5 Work Packages (WP) focused in different ways on the three AOSs.

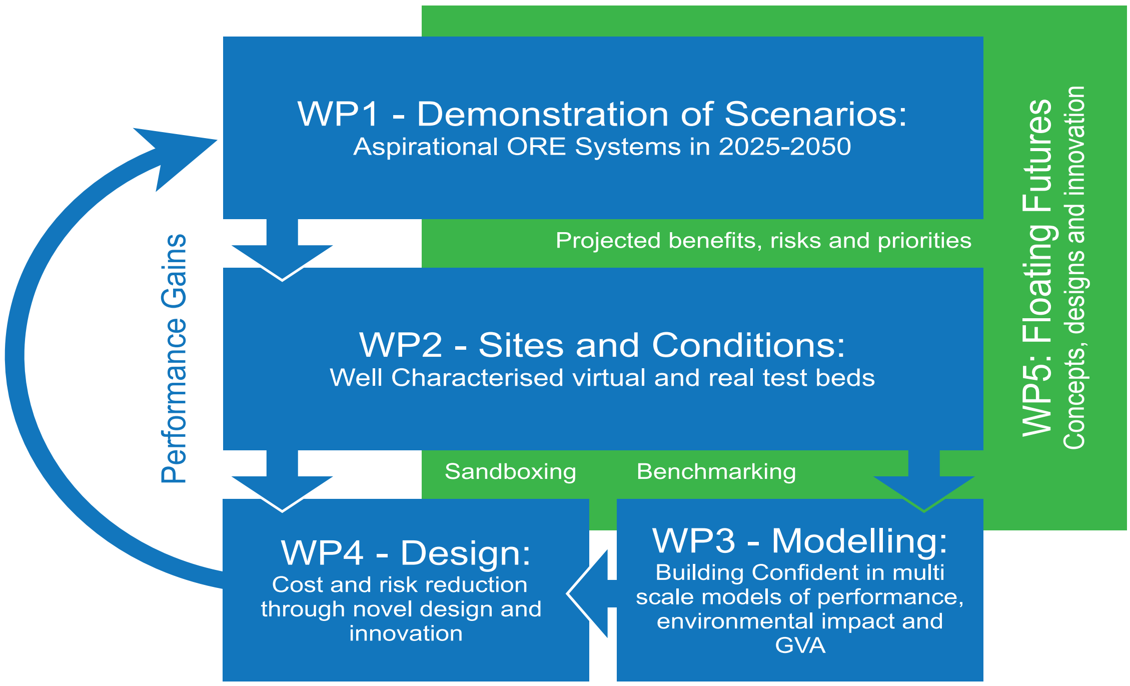

Figure 1: Overview of Supergen ORE Hub core research

CORE RESEARCH WORK PACKAGES

WP1 establishes the projected UK and international deployment scenarios for wave, tidal and OW from 2025 to 2050. Oceanographic setting and site conditions will give definition to WP2 and the key uncertainties and enabling technologies will guide WPs 3 and 4 on modelling and design. WP5 explores future ORE structures and configurations, such as very large floating structures, drawing on the results from the previous WPs.

The predicted performance gains, environmental and GVA impacts will allow the projected deployment scenarios to be refined over the duration of the Hub and give increased confidence to industry and society. Outputs will include evaluation tools for future ORE systems that incorporate – and quantify the benefit from – the overall research and innovation programme within the hub and beyond.

The objectives of the core research are:

- WP1: Define the characteristics of aspirational ORE deployment scenarios required to meet changing demand for the period from 2025 to 2050 with associated benefits, risks and research priorities.
- WP2: Establish a set of site and condition characteristics for use, by the hub and the wider research community, as benchmarks to evaluate options for the array scale deployment of ORE technologies.
- WP3: Develop and validate models to support the confident prediction of ORE system performance, operation and environmental and societal impact.
- WP4: Develop and validate methods and tools needed for the design and evaluation of future ORE technologies enabling cost, risk and environmental impact reduction.
- WP5: Assess the potential of very large ORE structures, including floating, and address key technical challenges to the design, deployment and operation of such structures.

The following pages provide a detailed description of the core research work packages, with individual tasks (denoted as TX.X).

WORK PACKAGE 1
DEMONSTRATION OF SCENARIOS

Each of the defined AOSs will be explored to enable evaluation of: technology innovation needs; effect on UK economy; benefit to fragile regions and ecological impacts of the scenarios.

T1.1 Deployment scenarios:

This outlines high-level characteristics of deployment scenarios using energy system models (e.g. ESME, TIMES) to estimate realistic deployment scenarios based on projections of energy consumption and utilisation of alternative energy technologies (e.g. onshore wind, nuclear, gas).

Additional energy system models will be developed to increase sophistication of the ORE mix estimates. These energy system models will determine optimum energy mixes that, accounting for different levels of system storage, balance OW, wave and tidal technology deployments to produce most energy whilst minimising cost and negative consequences of fluctuating inputs to grid. The model will mix the quantities of each technology and their locations in the optimisation.

T1.2 Technology innovation:

This identifies the technology innovation required to achieve the scenarios set out in T1.1. Activities will inform technology pathways and complement the design and modelling research carried out in WP3, WP4 and more widely in the UK and beyond.

T1.2 will investigate the practicalities of expanding the range of deployment locations to achieve higher capacity targets. It will examine an present the implications of moving from operating in shallow and intermediate water depths to deepwater sites, through investigating how devices, arrays, subsystems and substructures, electrical conditioning and transmission methods need to change and innovate.

T1.2 activities will inform the energy system models employed in T1.1, iteratively improving the accuracy of the deployment scenario estimates.

T1.3 Assessment metrics:

This evaluates the economic prize based on the AOSs, quantified primarily in terms of Gross Value Added (GVA) to the UK economy and number of job years created, in addition to alternative metrics identified.

OW technology draws heavily on expertise built up in onshore wind industries, located outside the UK, and this means that the GVA benefit to the UK is relatively low, although there is significant UK benefit to offshore Operation and Maintenance (O&M) activities carried out by UK based contractors and their supply chain. However, the UK could develop wave and tidal industries to take advantage of the UK and global wave and tidal resource. The economic and job creation implications of such developments will be investigated, as well as how the ORE industries will engage with, reinvigorate and ultimately benefit economically marginalised coastal communities.

T1.4 Ecological assessment:

This investigates the ecological impacts of the AOS scenarios from T1.1 and T1.2. The Ecological Trade-Offs tool kit will be used to assess the range of options provided in T1.3 within a natural capital approach.

T1.4 will identify and use approaches for evaluating how devices, array design and O&M activities affect the environment at near-field, mid-field and far-field levels. At a device level, the LifeCycle Cost Assessment (LCA) methodology will be used to determine the Global Warming Potential (GWP), Energy Return on Investment (EROI) and Energy Payback Time (EPBT) of devices and deployed arrays.

WORK PACKAGE 2
SITES AND CONDITIONS

The research community lacks validated benchmark scenarios of ORE sites and conditions for testing and comparing models of ORE system performance (e.g. for quantifying relative design merits, confidence or certainty levels). ORE device proponents, in industry and academia, have no intermediate step between idealised tank testing of single devices and full-scale field conditions. This inhibits the full testing of devices, arrays and innovative sub-systems in realistic environmental conditions to explore engineering performance or assess ecological impact.

This WP will address these shortcomings by developing 4-6 virtual sites and associated conditions, covering appropriate environments for the AOSs, as well as sites that represent commercial ORE frontiers. Each Virtual Site will be driven by the scenarios from WP1 and will be created from multi-scale datasets that describe, as fully as possible, the environmental conditions relevant to the design, performance and operation of an ORE System. The new research developed by the hub can be assessed against benchmark sites and conditions to quantify progress towards the AOSs.

The data-scales will range from low fidelity regional-scale basin data to high fidelity velocity fields of the detail relevant to blade-scale loading analysis. Guided by WP1, the virtual sites will span all ORE sectors, including open ocean, channels and estuaries (suited to tidal stream), barrage or lagoon systems. The database will draw on real data from actual sites for validation if available, and synthesise missing data via simulations or targeted experiments. Any data synthesis will take into account the specific research questions related to the sector and AOS, so as to be robust.

Published output from recent projects will be adopted including from ReDAPT, FLOWwBEC, PerAWaT, Dylotta, EBAO and X-MED. WP2 has four discipline-led but overlapping Tasks, to define the virtual sites and conditions, then assemble available data, synthesise new data and finally disseminate the virtual sites and conditions:

T2.1. Metocean conditions:
Wind, wave and current, with directionality, through seasonal variations; through-depth velocity profiles and headings including turbulence characteristics.

T2.2. Seabed conditions:
Bathymetric at regional and centimetric scale, to link with flow characteristics, and geological and geotechnical parameters relevant to foundations and cables.

T2.3. Turbine and WEC models:
Drawing on available public domain data for device characteristics necessary for modelling of system behaviour, including operating modes.

T2.4. Ecological conditions:
Habitats, individual behaviour and spatial population dynamic

Completion of the stages of definition, assembly and synthesis will form the milestones of the WP.

The definition phase will involve input from other WPs and cross-discipline expertise, including from industry, as well as a global scanning and screening process. Assembly of the virtual sites and conditions will involve collation, combination and validation of the datasets, which will be followed by a synthesis stage to fill data gaps. The final deliverable is release of the virtual sites and conditions via the Hub Data Platform, although data will be released continually to the other work packages throughout the Hub. Dissemination will focus on reaching all potential users of these virtual sites and conditions, beyond the ORE hub network, nationally and globally.

WP2 will also seek to improve the practice of defining site conditions, using new technologies and approaches to reduce uncertainty in mean and extreme design values and local heterogeneity – in metocean, geotechnical and environmental aspects. Emergent techniques for remote sensing, sampling and observation could offer improved fidelity and reduced cost and human risk.

WORK PACKAGE 3
MODELLING

Development of new and advanced modelling tools is critical to engineering design, innovation and reduced cost. This WP advances the understanding of combined environmental conditions local to individual devices, in isolation and within arrays, and assesses the changes of environmental conditions due to ORE array operation. This feedback to the resource is of increasing importance in all areas of ORE.

This work builds on research from Supergen (Marine), EPSRC, NERC, Horizon 2020 and ETI projects on single device behaviour in unsteady conditions and the effects of array operation at regional scale. Further advances are required to assess the influence of design choices such as device type and operating strategy on system design, time-variation of power supply, ecological processes and limits to resource exploitation.

T3.1 Synthesis and extension of local unsteady metocean conditions:

This task will characterise and synthesise unsteady onset conditions – waves and turbulent flow – for devices operating within an array accounting for the operating conditions of proximate devices.

Synthesised unsteady flow-fields representative of conditions at exemplar sites (T2.1) will be employed, in combination with appropriate turbine models, to gain insight into the physics of wake-wake interaction and wider array effects across alternative operating points. Selected high-fidelity simulations will be employed to complement multi-physics datasets available from experiments or full-scale (Supergen, ETI) with synergies between tidal and OW explored to accelerate progress. This will inform analysis with Reynolds Averaged Navier-Stokes (RANS) CFD and semi-empirical approaches to define onset conditions for in-array design (T4.1-T4.3).

The same combination of synthesised inflow and turbine models will be employed to analyse collision probability and disruption of marine animals based on models of animal movement in turbulent flow.

T3.2 Feedbacks from an operational array to regional scale flow:

Modelling will be completed of the momentum extraction and modification of unsteady metocean conditions by the future AOS arrays, across operating and shut-down conditions.

These aspects of array behaviour depend on device configuration (e.g. number, proximity and layout) and type, as well as metocean conditions and array operating strategy.

Building on T3.1, array momentum extraction and wakes will be parameterised as a function of turbine operating point and metocean conditions, and assessed through CFD, with experimental or high-fidelity studies targeted at specific cases. This will enable assessment of array design and operating strategies for alternative design objectives such as maximisation of power supply, standardisation of fatigue or peak loading, minimisation of output variability or to meet constraints to environmental/ ecological change.

The parameterised results will be employed within regional scale models with seasonal modification of physical conditions adopted by different marine populations for activities such as feeding or reproduction. For exemplar sites (WP2) the ecological acceptability of device types, array configurations and operating strategies will be assessed for tidal stream arrays (AOS2). The techniques and understanding developed will also be used within atmospheric flow models for analysis of future ORE design conditions, such as multi-turbine systems in close proximity, informing WP5 and AOS1.

WORK PACKAGE 4
DESIGN

This WP will develop and validate tools required for innovative design approaches, enabling cost and/or risk reduction, and potential step-changes in technology. The focus will be on AOS1 as a common platform for OW, wave or tidal, but the work is applicable to the other AOSs.

A key challenge is to combine performance of the energy conversion system with survivability of the support structure, under variable environmental loads with high levels of uncertainty. Present design methods, inherited from the offshore oil and gas sector, typically involve a single very large unit designed to minimise motions.

Floating ORE systems require mooring and anchor systems for each of multiple units and are designed to enhance motion responses in some metocean conditions, but suppress them for others for survivability and reliability.

Design responses and loads result from combinations of environmental conditions and hydrodynamics of the structure, each of which are stochastic processes. Hence a probabilistic design approach will be explored.

T4.1 Design load cases from combined environmental forcing:

This will identify critical load cases for modelling in T4.2. Combined environmental forcing and response conditions leading to extreme and fatigue loads and their probability will be investigated. Scale model tests on representative structures under combined wave, current and wind conditions will be undertaken. Measured loads and responses will identify critical cases. Tests will be representative of structures across the range of device scale (e.g. point absorber to large floating wind platform). The dataset will validate the probabilistic approaches to predicting extreme combinations.

T4.2 Extended parameter study on extreme load cases:

A fully coupled CFD model for exploring multi-forcing design cases will be developed and validated using experimental data.

The model will be used to extend the dataset to a wider parameter space for floating ORE structure design.

The research will unlock an integrated modelling approach to survivability, coupling the effect of mooring and anchoring systems with the floater response.

This work is relevant to all floating ORE systems, and will be validated by wave basin and geotechnical centrifuge testing, at two EPSRC flagship facilities: COAST Laboratory in UoP and the National Infrastructure Laboratory in UoS.

T4.3 Probabilistic design in ORE systems:

Prediction of critical load cases in T4.1 will demonstrate the potential of probabilistic design to reduce cost for both individual ORE devices and AOS arrays by design to acceptable failure risks. Existing probabilistic models of environmental conditions and of design conditions for in-array operation from T3.1 will be coupled with load estimations and critical physical component reliability.

T4.3 delivers a coupled reliability-centred design for selected AOSs (single device and array design) under the conditions studied in T3.2.

T4.4 Structural Health Monitoring of Future ORE Systems:

Operations and maintenance costs can be reduced through better prediction of blade fatigue and erosion. Potential solutions exist in Structural Health Monitoring (SHM) using embedded sensors and autonomous visual inspection. By leveraging research from the EPSRC Prosperity Partnership (UoH) the benefits of developing embedded sensor systems for wave and tidal systems will be explored, using design criteria from T4.2 and conditions from T3.1.

WORK PACKAGE 5
FLOATING FUTURES

Most wind and tidal stream R&D activities involve design and optimisation of fixed foundation installations. Wave power devices adopt fixed and floating, but these have been at relatively small device scale. The southern North Sea, with over 90% of the world's installed OW capacity, is unusually shallow (generally <45m water depth) allowing the incremental risk managed development of OW. Realising the global potential for ORE requires cost-effective, environmentally sensitive and safe floating support and foundation systems.

Floating offers numerous advantages over fixed structures;

- Integrated device and platform system installation is possible, removing dangerous/ costly offshore operations
- Potential return of platform to shore for major refit, maintenance and repair removes dangerous/costly offshore operations
- Exploitation of (much) deeper water sites
- Structural-hydrodynamic responses can be modified by altering ballast and draft, meaning optimum solutions for transport, operating and survival modes can be developed
- Floating arrays can be reconfigured to optimise for seasonal/other resource variations
- Floating platforms can more easily accommodate multi-modal energy generation devices and could potentially be at the km scale.

Floating represents a radical step change for ORE with the potential for very large installations (e.g. 50MW platforms), deployable across a large range of water depths (50m→∞) and further from shore, reducing offshore human intervention in a cost efficient and environmentally less intrusive manner (within the water column).

T5.1 Limitations in scale and depth for floating offshore renewable energy platforms:

Initially research into Very Large Floating Structures (VLFS) will be assessed for application to ORE. Structural and hydroelastic models will be developed and applied to test the physical limits of scale on individual platforms supporting wind, wave or tidal energy devices, considering ultimate and fatigue limit states.

Attention will be given to the supported renewable energy devices and the machine forces imparted to the floating structure and vice versa. In addition, mooring systems and models will be adapted for use with floating offshore platforms. A key deliverable is to determine the minimum water depth for feasibility of floating structures and to assess the limiting parameters, including environmental impact, in the context of ORE. The limits in scale of floating platforms also depend on the effectiveness of the control system. T5.1 will include investigation of a systematic advanced control design by considering both the structural and electrical systems to mitigate or minimise power interference effects.

Development of a suite of parametric tools and methodologies for the structured assessment of the benefits they bring to overall costs will underpin future technology strategy on wave and tidal energy scale-ups. In addition, the limit of floating platforms will be evaluated in the context of: hydrostatic transmission wind turbines (HSTWT); environmental impact; emerging materials (e.g. optimised biomimetic structures and nanocomposite materials for extra-large wind turbine blade manufacture).

T5.2: Expandable and reconfigurable floating arrays systems:

This considers floating ORE array systems in terms of scale of individual platforms and the number of platforms combined with spatial distribution characteristics. Interaction effects between moored platforms from a hydrodynamic perspective along with grid and environmental impacts will be studied.

Impact models from WP3 will be applied and the Ecological Trade-Offs tool-kit based on the developments in T1.4 will assess the public acceptability of AOSs. In addition, the coupling between the low frequency vibrations of turbines and the electric grid could augment vibrations of the floating platforms. These array electro-mechanical interaction effects will be considered and a framework developed for their proper assessment. The potential for reconfigurable floating systems that can be either returned to shore/near shore for maintenance and/or repositioned within the array to optimise performance will also be explored, as will vessel and port requirements.

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