Supergen Offshore Renewable Energy

University of Bath I-SEE Webinar
Tues 3 Oct 2023

Harnessing The Oceans' Energy

Professor Deborah Greaves OBE FREng
Director of the Supergen ORE Hub
Professor of Ocean Engineering,
University of Plymouth

UKRI Engineering and Physical Sciences Research Council

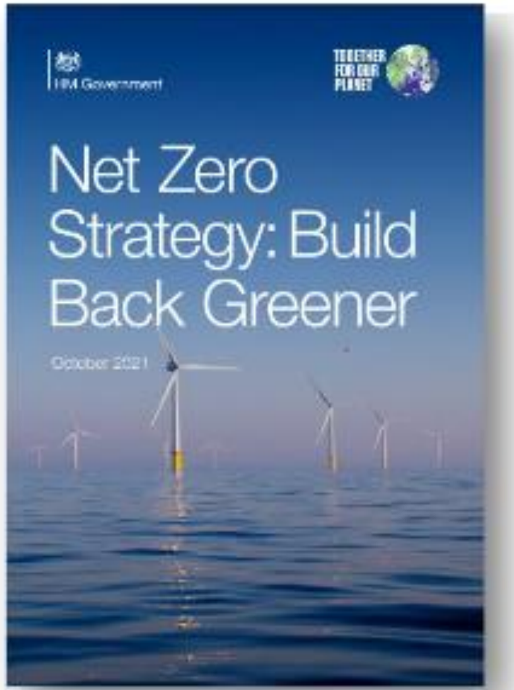
Climate Change Mitigation: UK Strategy and Targets

2025
- Capability to run the electricity system with no fossil fuels

2030
- 50GW of offshore wind (including 5GW floating)
- 10GW low carbon hydrogen capacity (50% green)

2035
- Net zero power system

2050
- Net zero economy – like to require ~100GW of offshore wind



Context

UK Government's Energy Security Strategy (April 2022) sets out plans to significantly increase the deployed capacity of offshore renewables within the next decade, including:

- increasing the deployment of fixed offshore wind to 50GW by 2030
- deliver up to **5GW of floating wind by 2030**, with rapid expansion anticipated thereafter
- nced £20m de Minimis of ring-fencing for tidal stream development
- A move to annual Contracts for Difference (CfD) auctions to stimulate investment

Credit: Hywind

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Crown Estate Scotland Scotwind Leasing – 25GW

Contracts for Difference Allocation Round 4 results

- TwinHub Floating Offshore Wind Project 32MW
- Offshore Wind 7GW
- Tidal Stream 41MW

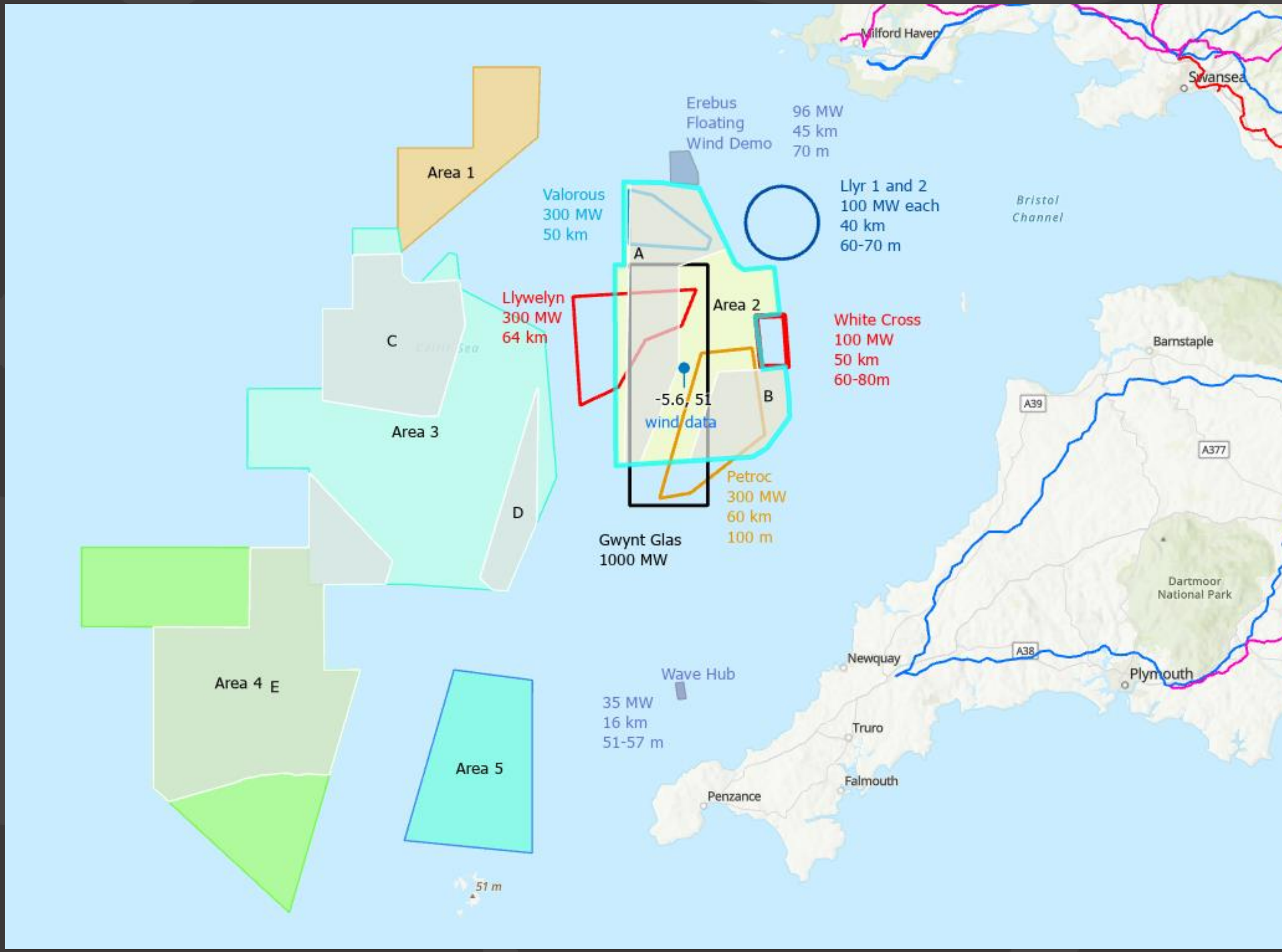
Contracts for Difference Allocation Round 4 results

- Tidal Stream 40.5MW
- Offshore Wind 0GW
  - Inflationary pressures impacting project economics
  - Turbine costs increased by 20-40% in 2 years
  - Some CfD AR4 projects cancelled
  - Auction capped at £44/MWh – lower than AR4

Scotwind and AR4 Offshore Wind sites

Celtic Sea FLOW opportunity

- Pre-commercial, smaller projects are also supported.
- The 96MW Erebus floating wind project, in the Welsh waters of the Celtic Sea
- The Llŷr 1 and Llŷr 2 projects, comprising two separate 100MW sites, located to the south of Pembroke on the Welsh coast (subject to HRA)
- The 100MW White Cross project, located off the coast of Devon and Cornwall (subject to HRA)
- The 32MW TwinHub Floating Offshore Wind Project, secured in latest CfD auction – 1st FLOW project in Celtic Sea



Credit: The Crown Estate

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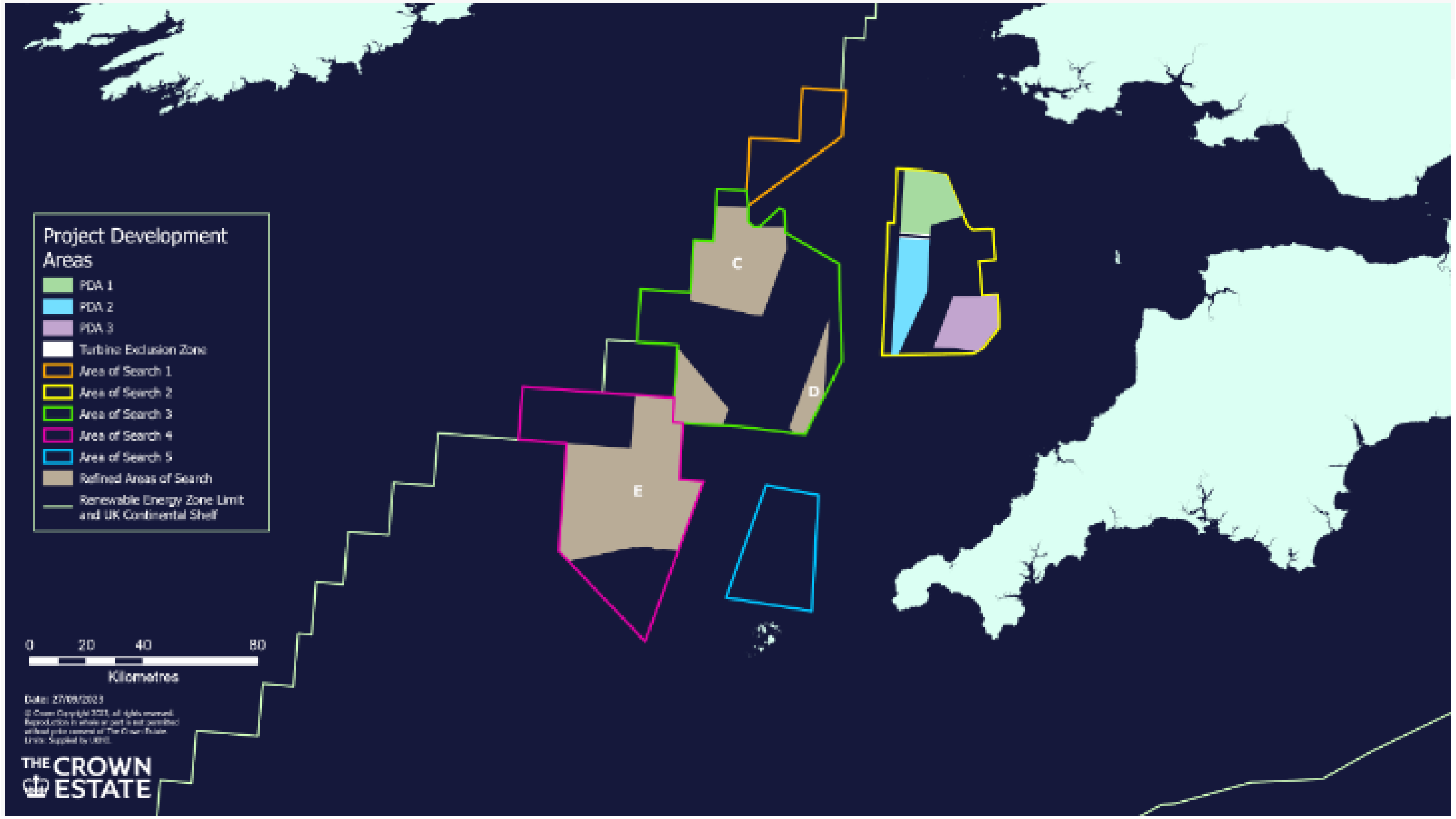
The Crown Estate Offshore Wind Leasing Round 5

- Celtic Sea Project Development Areas
- Minded To Scenario update, October 2023
- 4.5GW by 2035
- Potential for additional 20GW by 2045



Celtic Sea FLOW opportunity

- Celtic Sea development is a significant part of the UK requirement for at least 75GW of offshore wind energy by 2050.
- The Celtic Sea Cluster (CSC) estimates that 100GW of FLOW deployment can deliver £43.6bn in UK gross value add (GVA) by 2050, whilst boosting industry and socio-economic opportunity in Wales and the South West (SW).
- The ORE Catapult estimated that the benefit to the SW economy of building 1GW of floating offshore wind in the Celtic Sea would equate to £315m GVA, 1,788 local jobs, offsetting 21,199 tonnes of CO_2.
- Opportunities for collaboration

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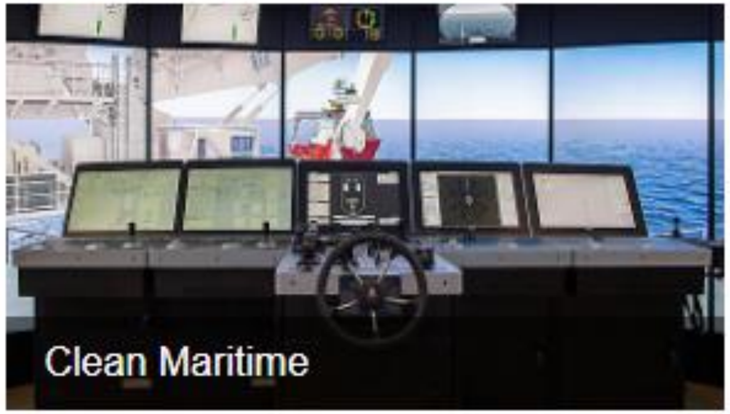
CENTRE FOR DECARBONISATION AND OFFSHORE RENEWABLE ENERGY

Overarching research themes



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https://www.plymouth.ac.uk/research/centre-for-decarbonisation-and-offshore-renewable-energy

Facilities

COAST LABORATORY WITH PLYMOUTH UNIVERSITY
COASTAL OCEAN & SEDIMENT TRANSPORT

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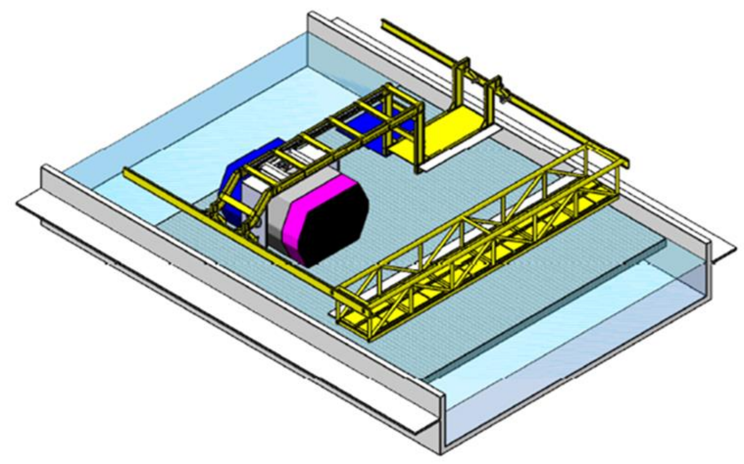
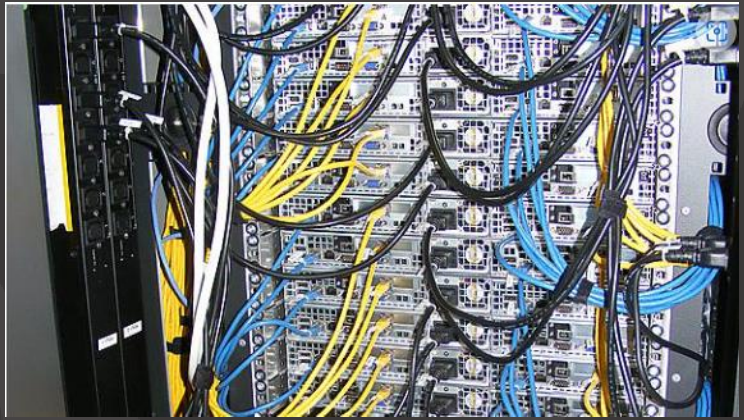
Facilities

- UK Floating Offshore Wind Turbine Test (UKFOWTT) Facility
  - £ 1.1 million award from EPSRC Strategic Equipment Process
- Dynamic Positioning Simulator
  - ERDF funded Cornwall Flow Accelerator
- High Performance Computing Resource, £1.3 million investment





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We are building a new home for engineering
New Engineering & Design Facility

“This new facility will create a space where students, researchers and industry come together to develop new ideas that enable society to meet some of its most pressing global challenges.

Professor Judith Petts CBE, Vice-Chancellor of the University

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Feilden Clegg Bradley Studios

Supergen ORE Impact Hub 2023

Led by Professor Deborah Greaves, University of Plymouth

£7.5 million from EPSRC.

Professor Deborah Greaves OBE
Director of the Supergen ORE Hub
(University of Plymouth)

Professor Tim Stallard
Co-Director of the Supergen ORE Hub
(University of Manchester)

Professor David White
Co-Director of the Supergen ORE Hub
(University of Southampton)

Henry Jeffrey
Co-Director of the Supergen ORE Hub
(University of Edinburgh)

Professor Richard Willden
Co-Director of the Supergen ORE Hub
(University of Oxford)

Professor James Gilbert
Co-Director of the Supergen ORE Hub
(University of Hull)

Professor Philipp Thies
Co-Director of the Supergen ORE Hub
(University of Exeter)

Professor Beth Scott
Co-Director of the Supergen ORE Hub
(University of Aberdeen)

Professor Byron Byrne
Co-Director of the Supergen ORE Hub
(University of Oxford)

Professor Xiaowei Zhao
Co-Director of the Supergen ORE Hub
(University of Warwick)

Professor Feargal Brennan
Co-Director of the Supergen ORE Hub
(University of Strathclyde)

University of Plymouth · University of Southampton · University of Exeter · University of Aberdeen · University of Edinburgh · University of Hull · University of Strathclyde · The University of Warwick · Manchester 1824 The University of Manchester · University of Oxford

The Supergen Offshore Renewable Energy Hub provides **research leadership to <u>connect</u>** academia, industry, policy and public stakeholders, **<u>inspire</u> innovation** and maximise societal value in offshore wind, wave and tidal energy.

Supergen

Offshore Renewable Energy

Engineering and Physical Sciences Research Council




- Research that **supports and accelerates** the development of ORE technologies for society
- **Whole systems approach**: allowing transfer of fundamental knowledge, shared learning and use of resources for inter-disciplinary research
- **Clustering**: Marine (wave and tidal) and offshore wind sharing of expertise, strategies and best practice
- **Networking:** building UK and international collaboration
- **Flexible Funding**
  - Seedcorn funding for projects aligned with the hub.
- **Impact**
  - Early Career Researcher Support
  - Equality, Diversity and Inclusivity Support
  - Industry Partnership
  - Policy Engagement

SupergenOREHub@plymouth.ac.uk

@SupergenORE

www.supergen-ore.net

linkedin.com/company/supergenore

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Advisory Board members

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Carbon Trust
UK Marine Energy Council
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Marine Energy Wales Ynni Morol Cymru
Celtic Sea Power
Catapult Energy Systems
Vericity

Supergen Offshore Renewable Energy

Engineering and Physical Sciences Research Council

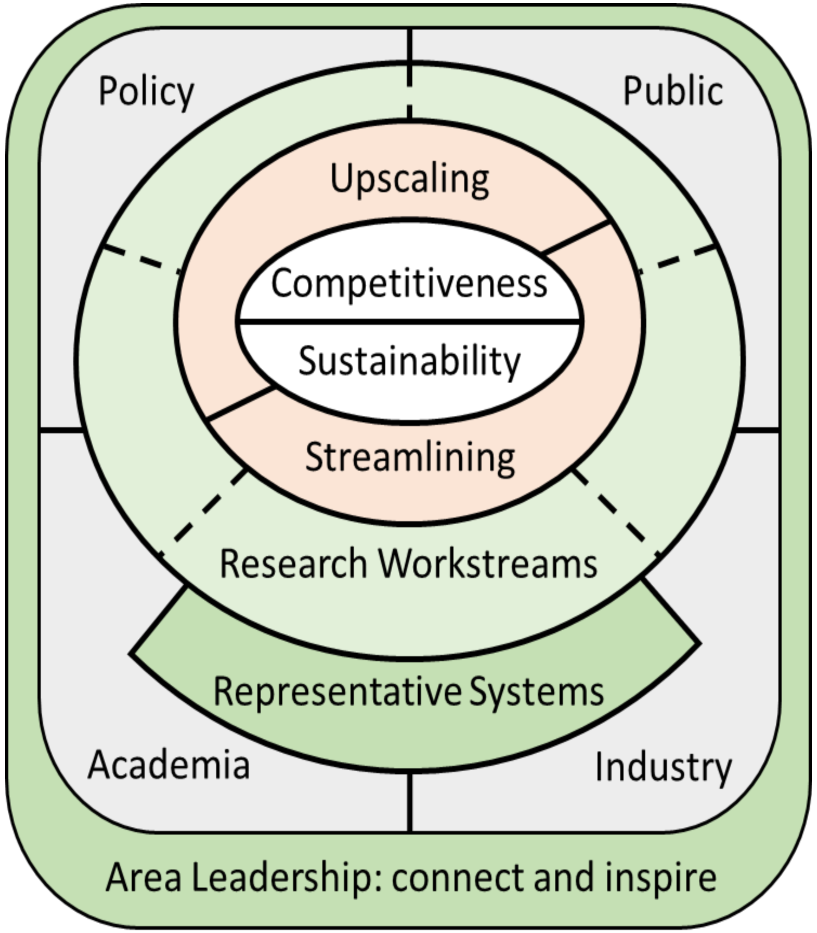
Core, Flexible Fund and ECR Research

Find out more:
https://supergen-ore.net/ecr-community/ecr-research-funding

Supergen ORE Hub 2023: Vision

Rapid Offshore Renewable Energy (ORE) expansion is essential to the UK for (i) Net Zero and climate change mitigation, (ii) energy security, (iii) green growth and jobs.

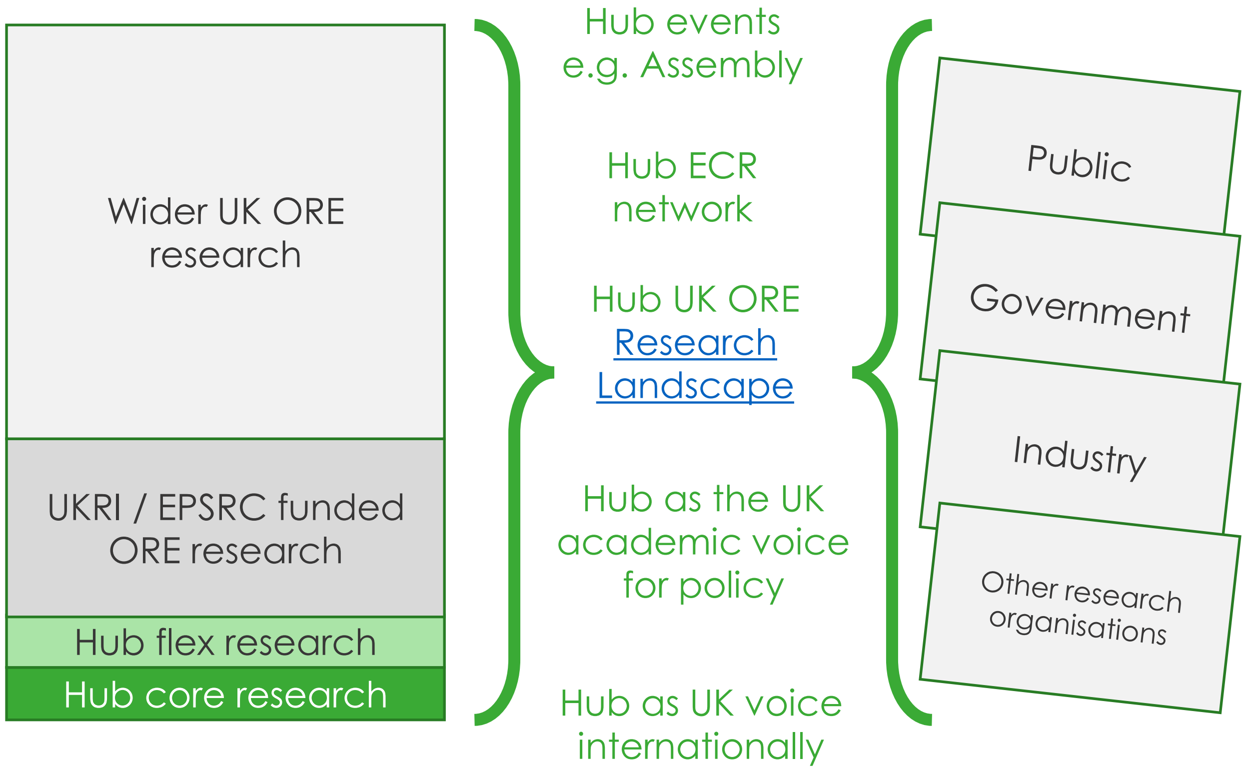
- *Streamlining* ORE projects, by accelerating planning, consenting and build out timescales
- *Upscaling* the scale and efficiency of ORE devices and systems, and the ORE workforce
- *Competitiveness*: maximising ORE local content and ORE economic viability in the energy mix, to maximise UK benefits of the drive to Net Zero
- *Sustainability*: ensuring positive environmental and societal benefits from ORE



Supergen ORE Hub 2023

Deliver vision and lead the contribution of ORE to Net Zero via Core Research and Area Leadership

- Core Research and Supergen Representative Systems for community collaboration and research translation for key ORE challenges.
- Area Leadership to **connect and inspire** as a trusted voice for the sector, through events, training, policy advice, flexible funding, outreach, curation of the research landscape, and as a beacon for EDI.



Research Landscape

Interactive web-based landscape tool to enable industry, government and researchers to share opportunities and challenges across challenge themes, and allows researchers to promote ORE projects to the wider community.

www.supergen-ore.net/research-landscape

Supergen Home - Supergen ORE

supergen-ore.net

Supergen Offshore Renewable Energy

Join our newsletter | Research Landscape

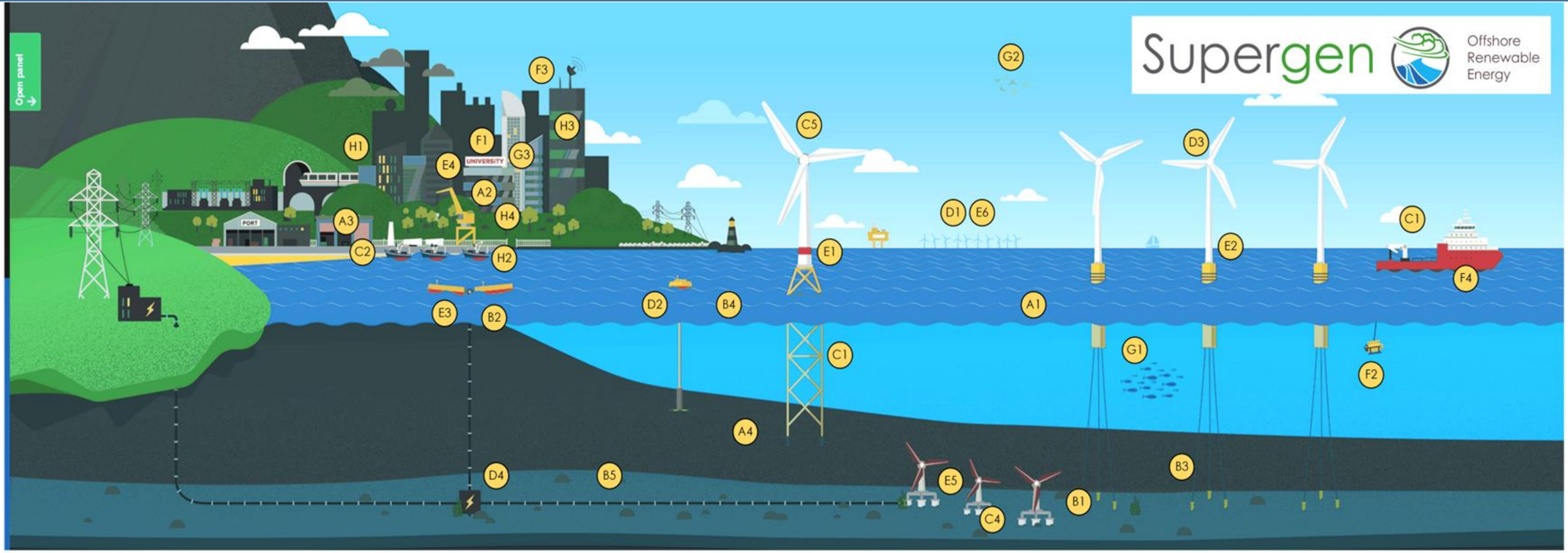
Home | About | Impact | Funding | Research Landscape | ORE Facilities | ECR Community | News & Events

Welcome to the Supergen ORE Hub

We provide research leadership to connect academia, industry, policy and public stakeholders, inspire innovation and maximise societal value in offshore wind, wave and tidal energy.

Find out more

Research Landscape



Theme A: Resource and environment characterisation
A1. Better measurement techniques for forecasting and resource characterisation
A2. Improved modelling tools for resource and loading assessment
A3. Resource and environmental characterisation in physical modelling facilities
A4. Long-term sediment transport measurement and modelling

Theme B: Fluid-structure-seabed interaction
B1. Realistic fluid-structure-seabed design tools that work together, not in isolation
B2. Novel design concepts – rethinking the mechanism of energy extraction
B3. Mooring anchors and foundations
B4. Multi-purpose hybrid systems for ORE and ocean resources
B5. Design of reliable cabling systems

Theme C: Materials and manufacturing
C1 Structural integrity in the marine environment (corrosion, fatigue, coatings etc)
C2. Serial (volume) manufacturing of complex structural systems
C3. Design for safe and cost-effective installation methods
C4. New materials and coatings
C5 Recycling / reuse of composites

Theme D: Sensing, control and electromechanics
D1. Control of ORE farms
D2. Smart sensor use
D3. Drive train design
D4. Power electronic conversion

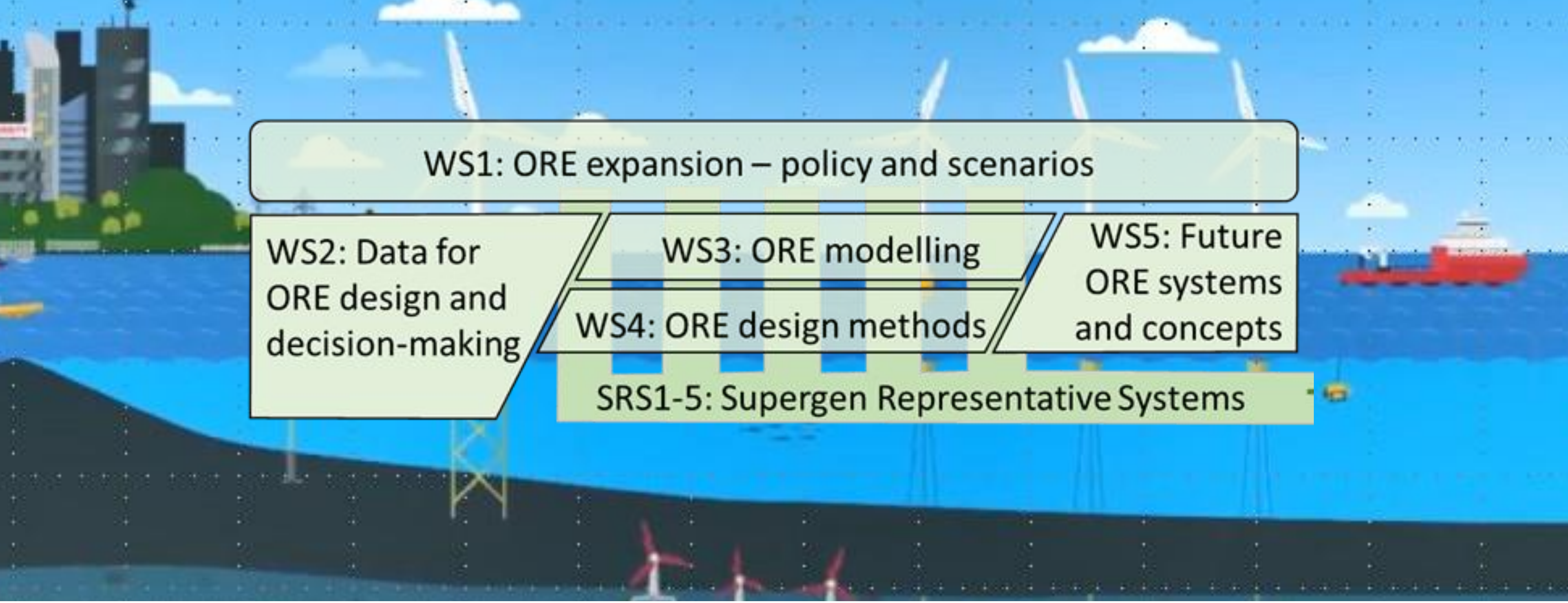
Theme E: Survivability, reliability and design
E1. Higher and more consistent reliability through risk-based design
E2. Extending limits to operation or performance by mitigating extreme actions
E3. Innovative sub-systems to provide higher and more consistent reliability and better performance
E4. Sustainable whole-life design methods
E5. Design tools for arrays.
E6. Whole systems approaches to operation of large-scale ORE

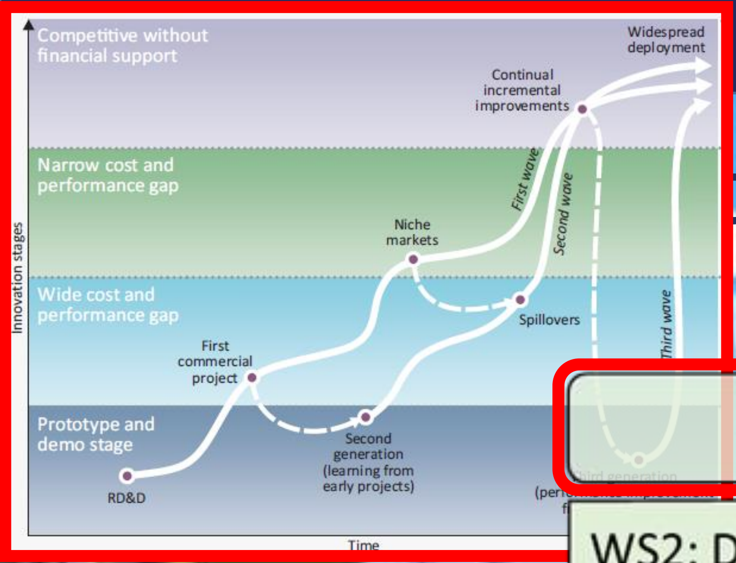
Theme F: Operations, management, maintenance and safety
F1. Analysis of remote sensing and condition monitoring data
F2. Use of autonomous systems for inspection
F3. Data and digital cyber security
F4. Increased use of automation to reduce risk in installation and operation (O&M)

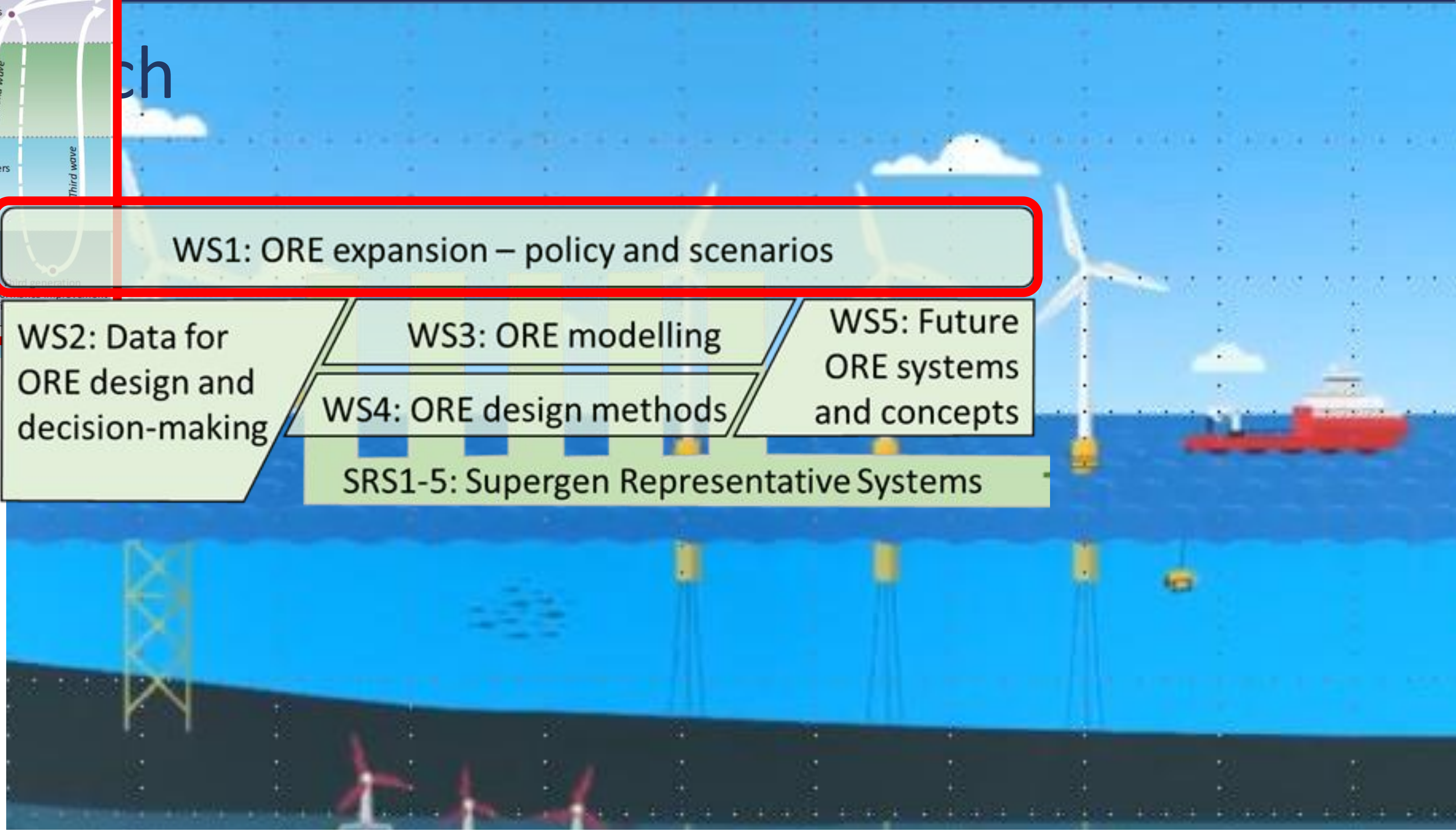
Theme G: Environmental and ecosystem aspects
G1. Fit-for-purpose approaches to environmental monitoring
G2. Development of population level environmental impact models
G3. Ecosystem modelling.

Theme H: Marine planning and governance
H1. Communications: Ocean literacy and public perception of ORE
H2. Interaction with other marine users
H3. Development of market mechanisms for ORE
H4. Reducing uncertainty of both technology and social costs of ORE

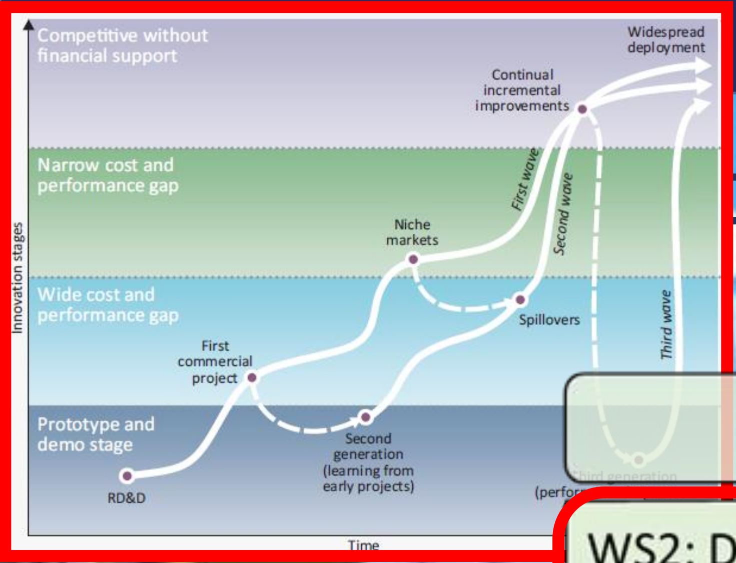
Core Research







- *Supply chain and skills policy requirements for Net Zero*
- *Roadmap for upscaling ORE within the circular economy*
- *Recommendations for streamlining of consenting policy*
- *GVA with net gain*



WS1: ORE expansion – policy and scenarios

WS2: Data for ORE design and decision-making

WS3: ORE modelling

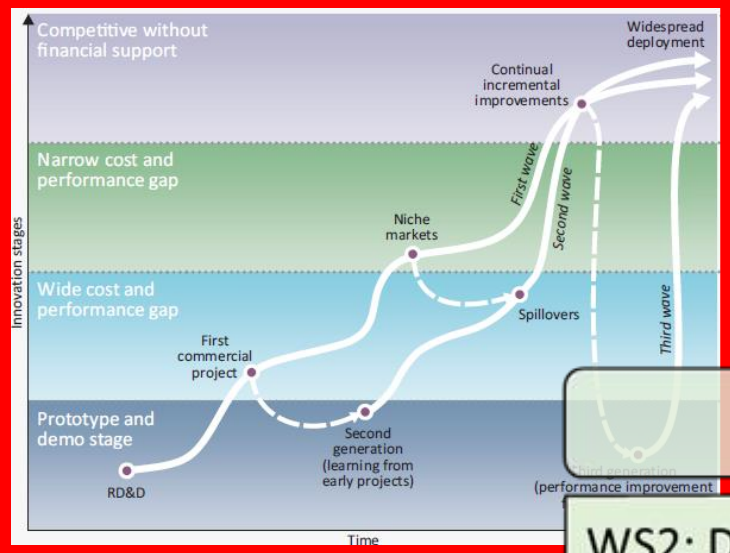
WS4: ORE design methods

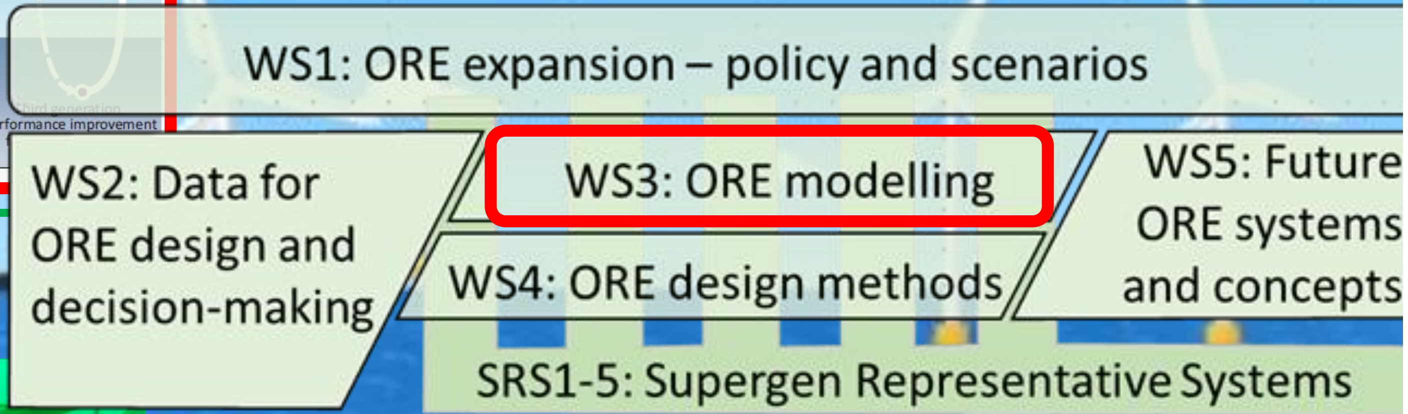
WS5: Future ORE systems and concepts

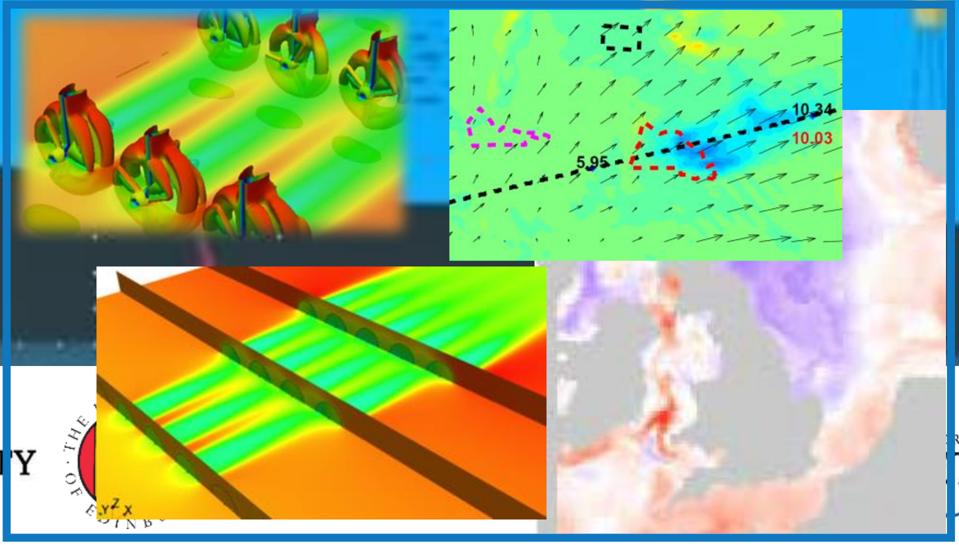
SRS1-5: Supergen Representative Systems

- *Data-driven opportunities to streamline ORE project planning, design and development*
- *Datasets of ORE frontiers to inform research, planning and innovation development*

Engineering and Physical Sciences Research Council

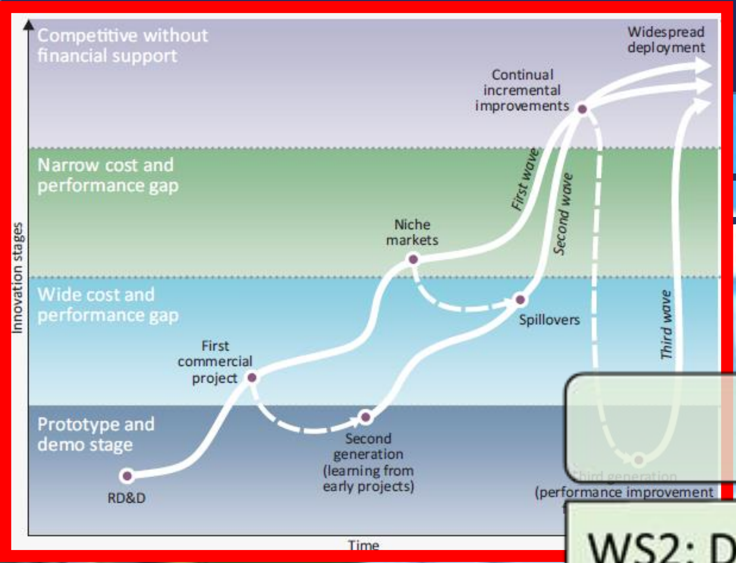






- *Unsteady load prediction for tidal turbine design: accelerating cost-reduction*
- *Array energy yield predictions and siting – enabling array planning for scale-up*
- *Physical processes affecting ecosystems – accelerating consenting for Net Zero targets*

- *Optimising geotechnical models for ORE Design*
- *Design wave approaches for ORE*
- *Risk-Based Design for cabling systems*



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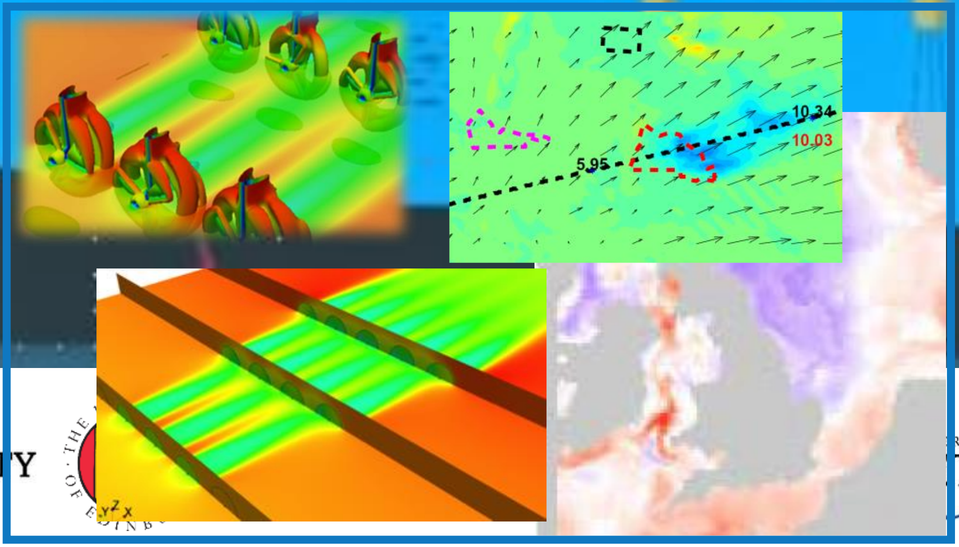

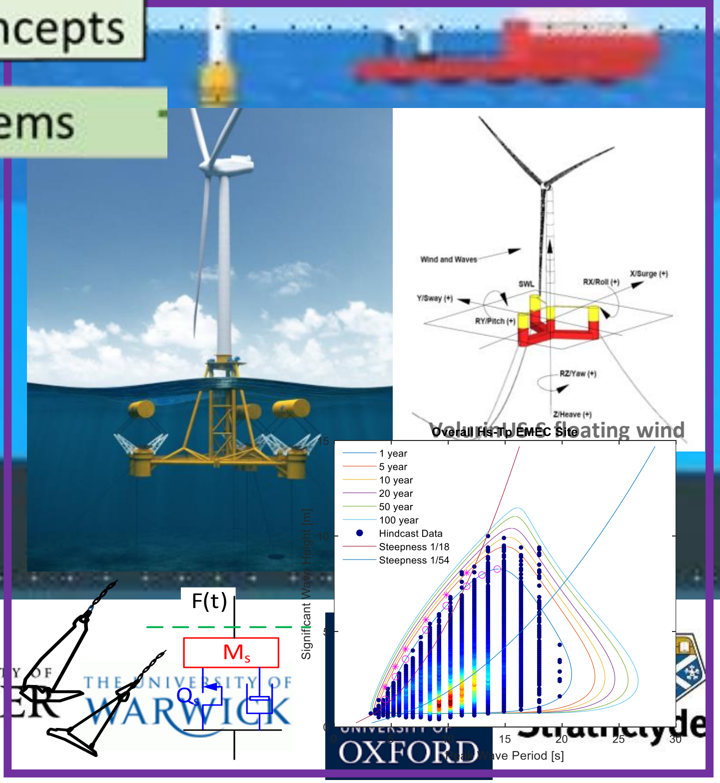

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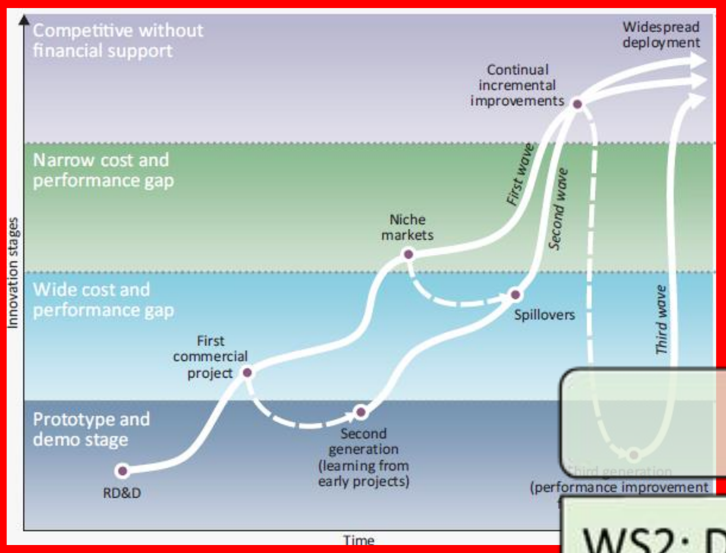
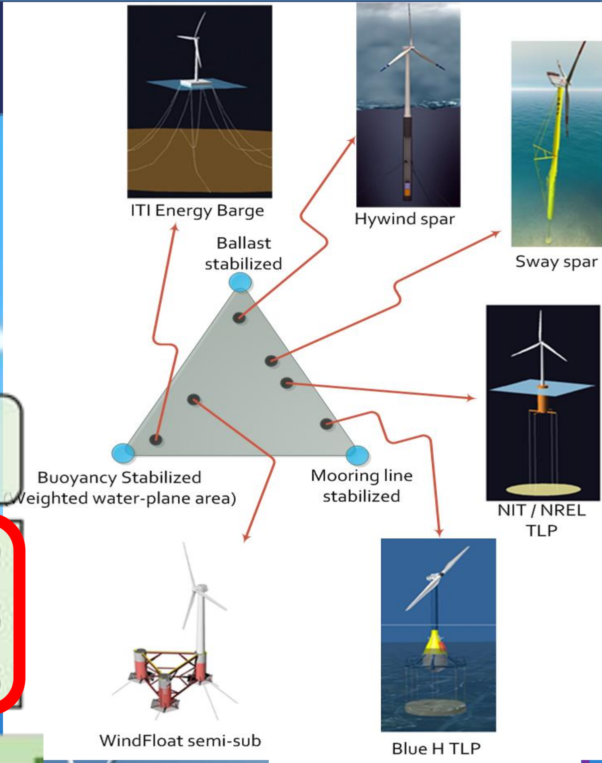


- *Power density*
- *Longevity and Resilience Design Philosophies*
- *Resilient onshore and support infrastructure*
- *Power Integration*



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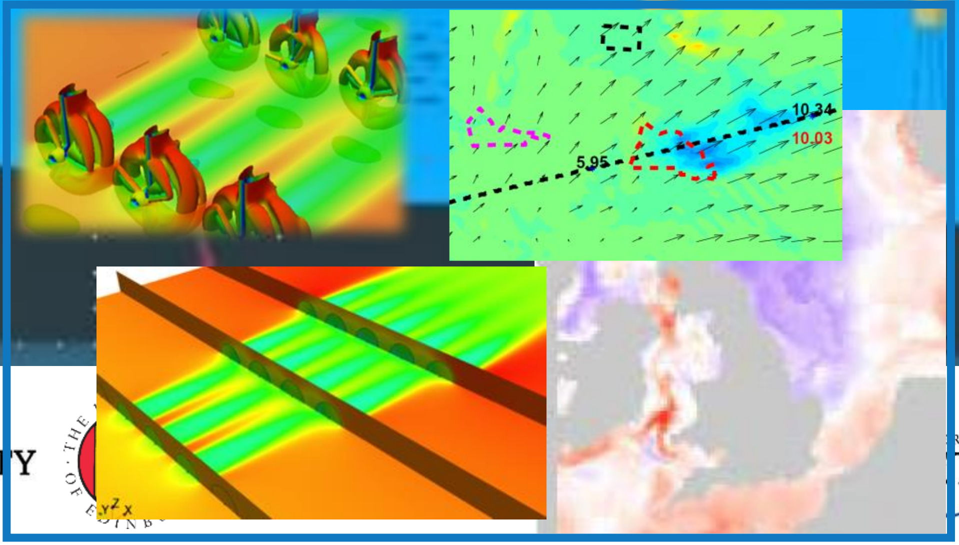

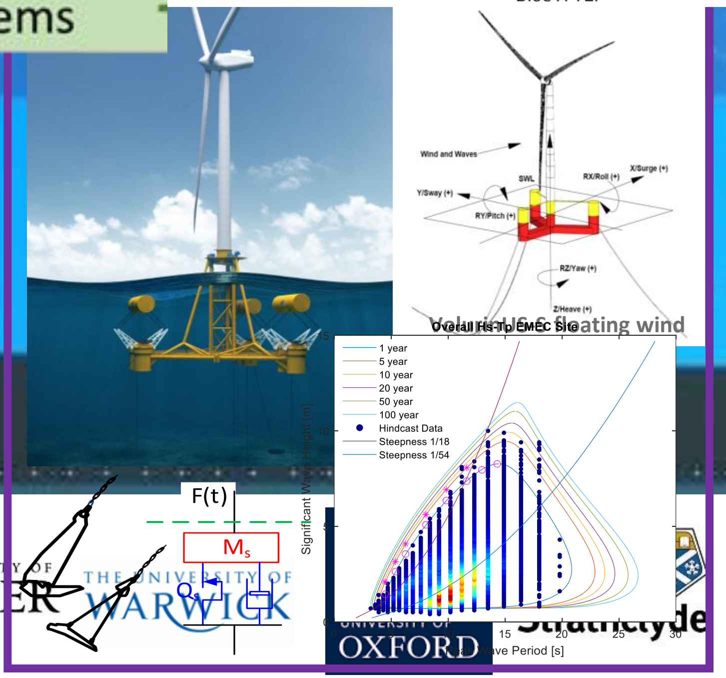

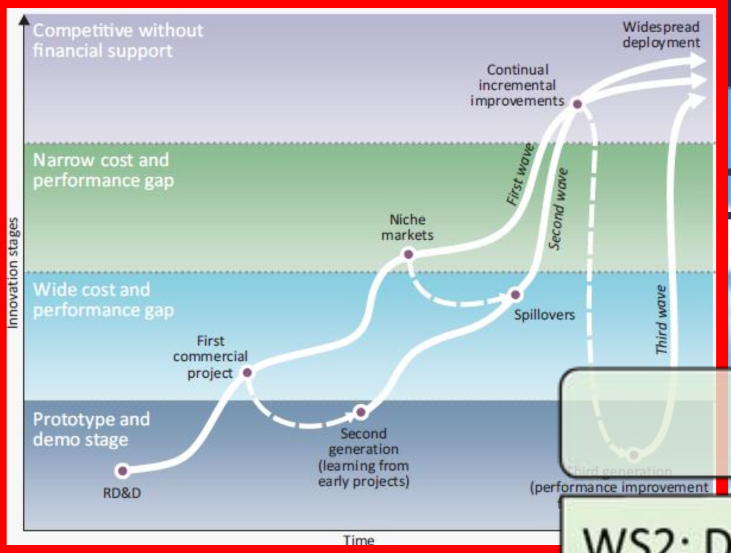

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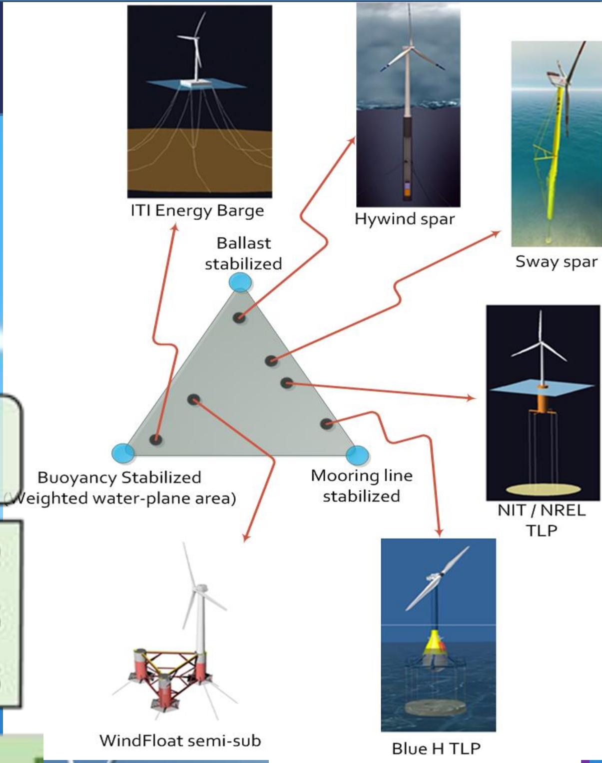
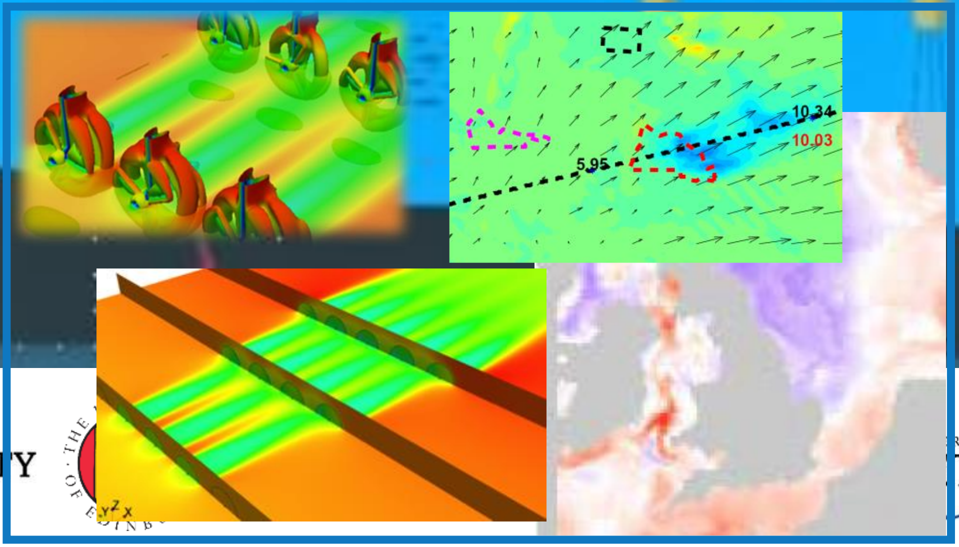
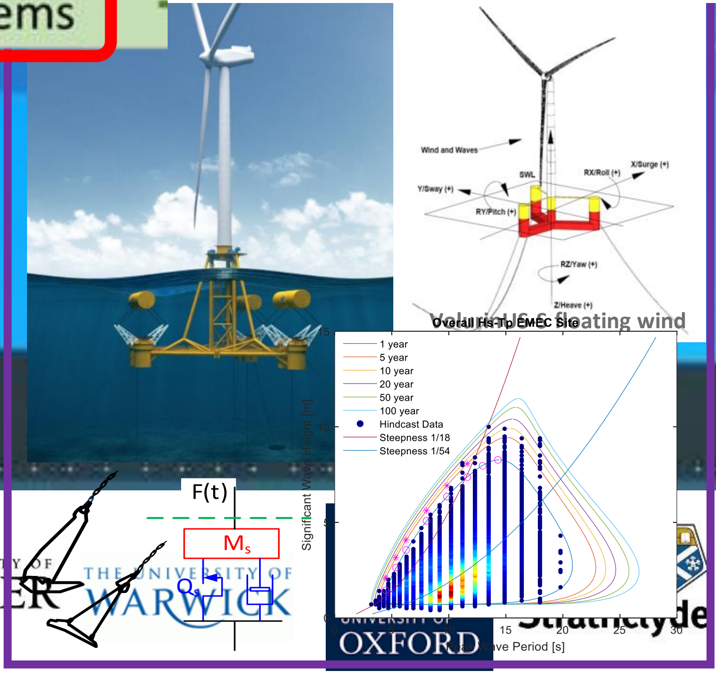


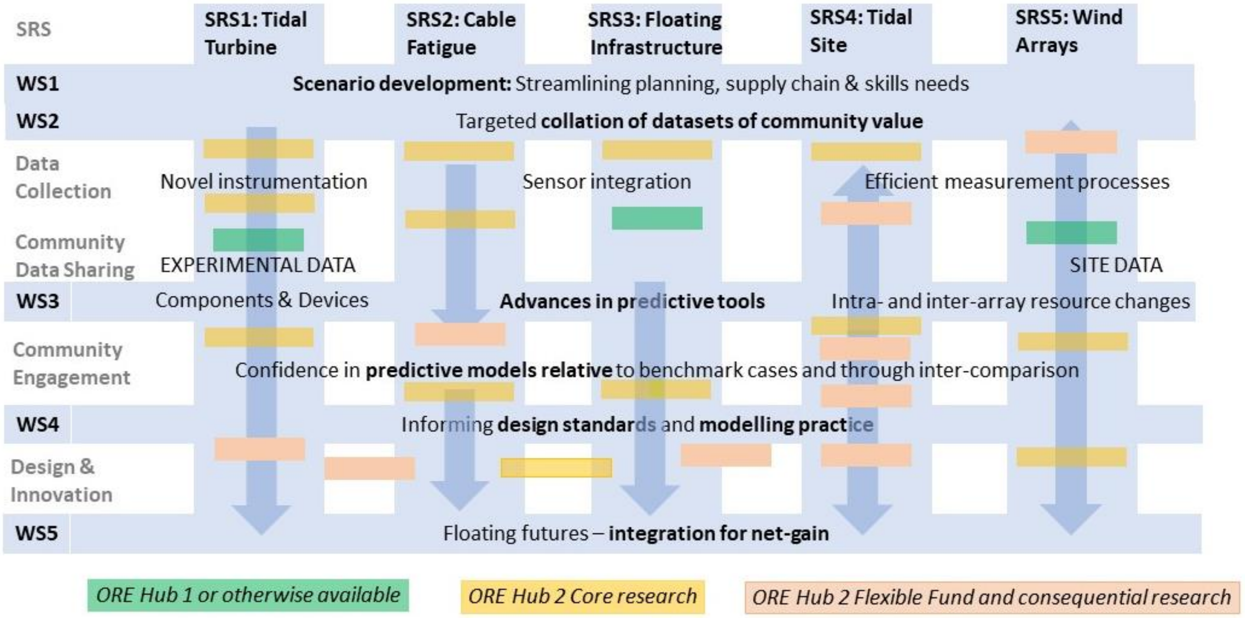




Supergen Representative Systems

Open metadata sets shared with the community, built through Core and Flexible Funded research

- Academic and industry community engagement
- Comparative reference cases for testing and comparing modelling tools and approaches
- Assessing applicability of emerging technology to existing standards and codes and making recommendations for updates and data gaps
- Assessing data processing techniques and packaging to provide informative and de-sensitised datasets



Impact Focus

- New *Impact Officer role*
- *New parallel funding* option for industry-funded research
- New option for *buy-out of PDRA time*
- New *Placement Scheme*, providing exchange/ placements for researchers
- *Impact Workshops, Themed Research Webinars and Focus Group Workshops*
- Expansion of the ECR network to include fee-paying *Early Career Industry* participants
- *UK ORE Innovation Ecosystem Forum – quarterly meetings*
- *International Collaboration*

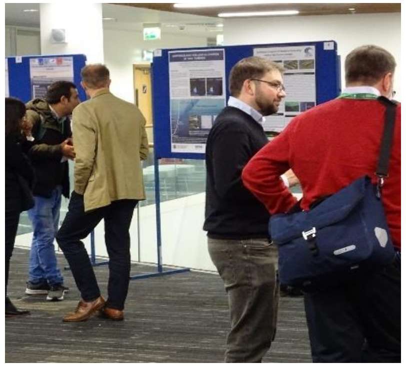
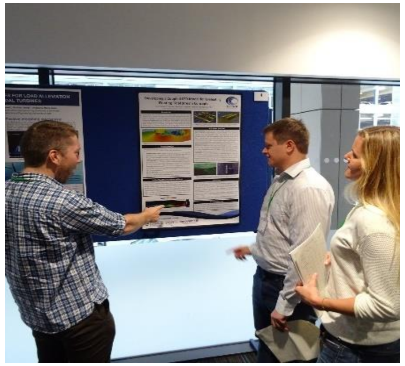
£4m (>53%) industry £1.7m (>23%) HEI leverage on EPSRC investment

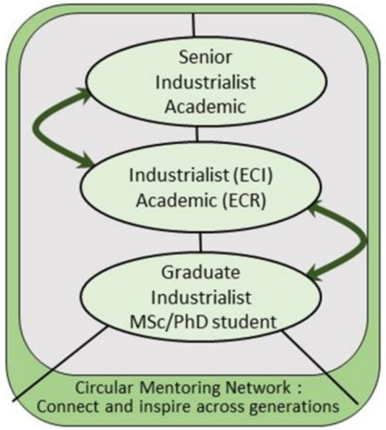
Flexible Funding

- Annual calls launched in July with a deadline in September
- The funding available will be extended through co-funding in specific areas with external bodies
  - Floating Offshore Wind Centre of Excellence
  - Wave Energy Scotland
- Flexible Fund proposals will be invited in three stages
  - Stage 1: Expressions of Interest: anonymised and assessed by members of SMB and AB
  - Stage 2: Full proposals: double-anonymised peer review by SMB, AB and wider Network
  - Stage 3: Review panel drawn from SMB, AB, EPSRC observer and co-funding partners.

Early Career Researchers

- A specialist, flexible research and travel fund for international exchanges for ECRs totalling £150k FEC and limited to £5k per application.
- The ECR network will support the wider dissemination of ORE activities and skills training, as well as showcase the high-quality research being completed by ECRs.
- Development of the ECR network, expanded to include activities with ECIs, allowing ECRs to link up with industry colleagues.
- A range of specialist skills training available, advanced masterclasses and career advancement skills training, including cross-hub activities and training with Supergen Bioenergy and Energy Networks.
- Seeking Supergen ORE Hub Lead ECR
- SuperGen-erations Mentoring Scheme



Our Impact Highlights (2018 – 2023)

Working with Industry
- 51 industry partners in Flexible Funded projects
- 38 strong world leading advisory board

Working with Policy
- Producing 8 policy briefings
- Contributing to COP26 and the G7 Summit
- Influenced the ORE sectors across UK

Equality, Diversity, and Inclusion
- Children's book - over 500 copies distributed
- 30% Annual Assembly speakers identified as women
- EDI surveys across the Supergen programme

Early Career Researchers
- 200+ members in the community
- £150,000 invested into 37 projects developing research and skills

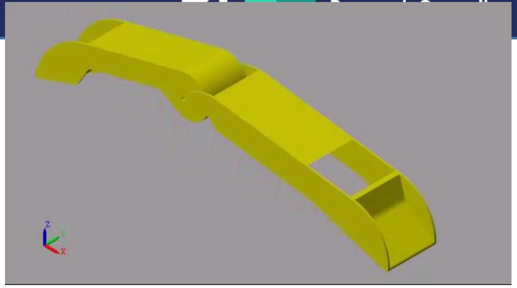
Flexible Funding
- £3m invested into 30 projects
- £2.9m total industry match
- 240+ research publications
- Improved gender split in funding applications (30% female)

Research Leadership
- Engaging 95 UK Universities
- Sharing UK ORE research landscape
- International collaboration

University of Plymouth | University of Aberdeen | University of Hull | The University of Edinburgh | University of Southampton | The University of Manchester | University of Exeter | The University of Warwick | University of Oxford | University of Strathclyde

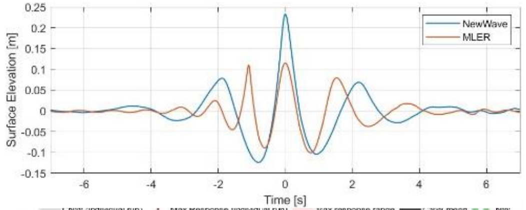
Supergen ORE Hub Phase 1 Design research at the University of Plymouth

Aim: Develop & validate design methods for floating ORE devices



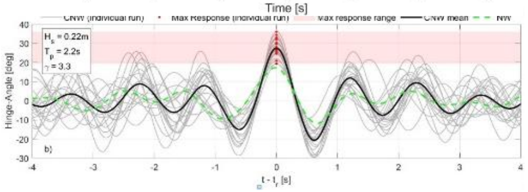
Existing Methods/Present Design Standards

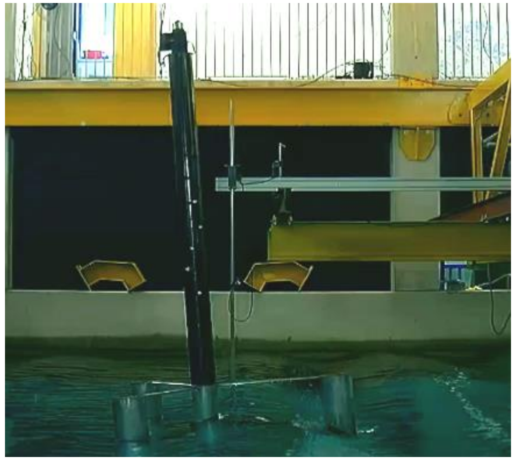
- Probabilistic approaches using large number of irregular sea states
- Robust but requires large quantities of simulated data



Short Design Waves (SDWs):

- More efficient method for characteristic load prediction in-line with design standards has been developed
- Single/embedded wave group to produce extreme responses
- Tested on a range of floating devices (WECs, FOWT)
- Promising results relative to present recommendations
- SDW procedures need refining for particular applications





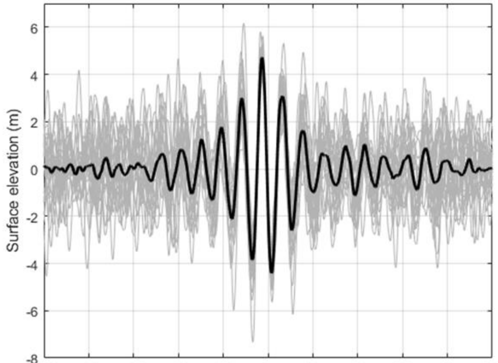
Impact:

- Wide range of device (TLPs, Spars, barges), response and mooring types
- Recommendations for floating ORE best practice/design standards
- Optimise SDW procedures (e.g. background wave selection)

Supergen ORE Hub Phase 2 Core Research at the University of Plymouth

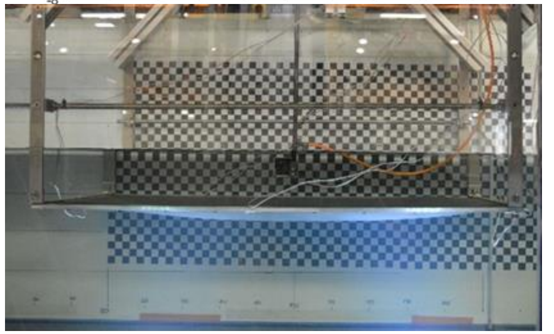
Probabilistic design approaches for ORE floating structures:

- Extend to include additional environmental conditions such as turbulent win currents and complex wind-wave-current misalignment scenarios
- Extend scale model experiments and numerical modelling to other FOWT platform types, multi-turbine platforms, floating tidal concepts and hybrid systems
- Comparison with blown wind simulations using the COAST Laboratory's new wind generation system
- FOWT fully coupled numerical model and representative design conditions the Celtic Sea, feeding into SRS3 and 5



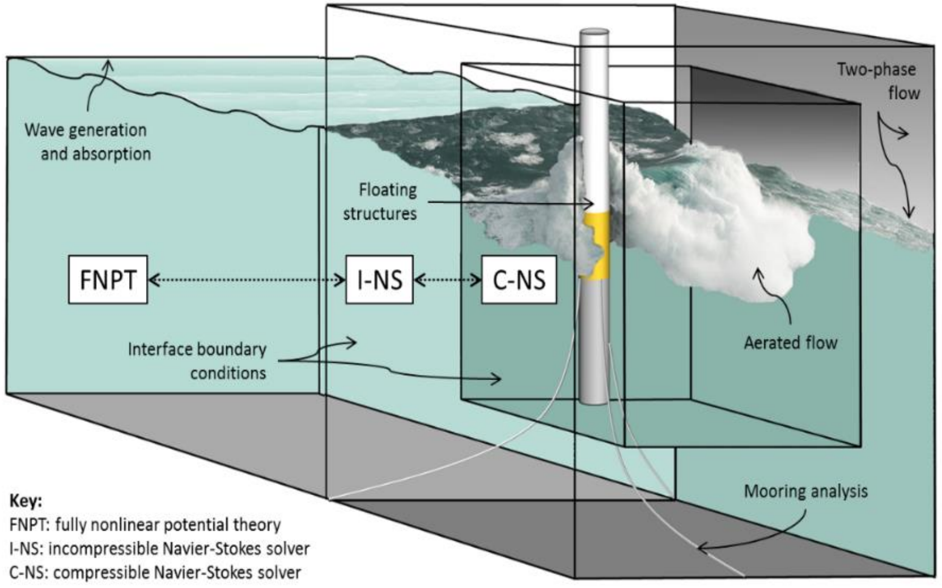
Future ORE concepts:

- floating systems supporting multiple turbines/devices or hybrid platforms
- Flexible elastomer-based wave energy converters and direct embedded energy generation.
- Novel concepts and numerical tools feeding into SRS5



The Collaborative Computational Project on Wave Structure Interaction (CCP-WSI)

- EPSRC EP/T026782/1 2020- 2025
- Develop and maintain a robust and efficient computational WSI modelling tool
- Build the community of researchers and developers around WSI
- Provide a focus for software development and code rationalisation
- *www.ccp-wsi.ac.uk*



CCP-WSI Blind Test Workshops

CCP-WSI
a Collaborative Computational Project in Wave Structure Interaction

Format:

* Participants/volunteers are invited to demonstrate their codes through a series of blind WSI test cases, i.e. without the physical results being made available prior to submission
  * Solutions using any type of WSI model accepted
  * No enforced implementation strategy, e.g. free domain and mesh design

Aims:

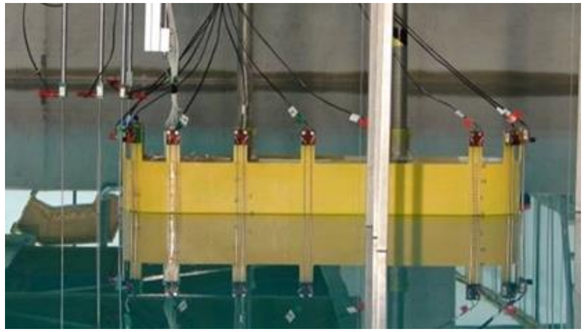
* To bring together numerical modellers within the WSI community
* To assess numerical codes currently in use
* To provide a better understanding of the required level of model fidelity in WSI simulations
* To help inform the development of future numerical modelling standards

CCP-WSI Blind Test Workshops

CCP-WSI
a Collaborative Computational Project in Wave Structure Interaction

CCP-WSI Blind Test Series 1

Focused wave interactions with a fixed FPSO-like structure



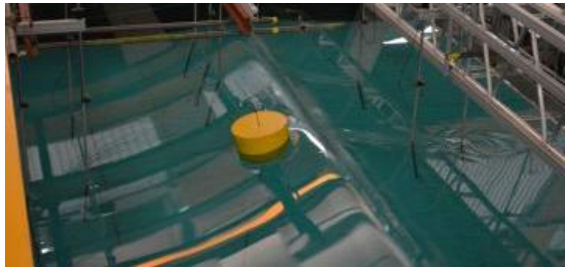
ISOPE 2018 (10-15 June 2018), Sapporo, Japan

- 34 participants from 16 institutions/companies

https://www.ccp-wsi.ac.uk/data_repository/test_cases/test_case_003

CCP-WSI Blind Test Series 2 & 3

Focused wave interactions with floating structures



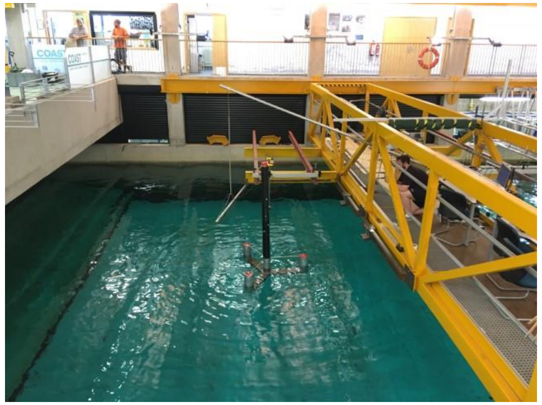
EWTEC 2019 and ISOPE 2019

- 30 participants from 13 institutions/companies
-main paper won ICE Baker Medal

https://www.ccp-wsi.ac.uk/data_repository/test_cases/test_case_004, 005

1st FOWT Comparative Study

Hydrodynamic response of a floating offshore wind turbine



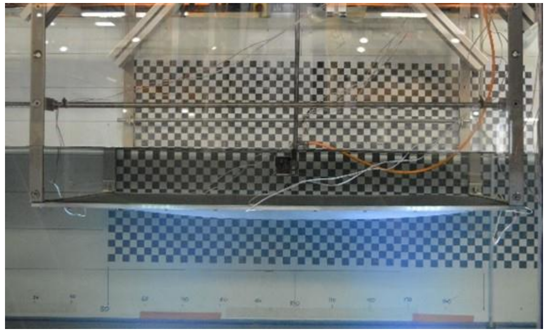
ISOPE 2023, Ottawa, Canada
19-23 June 2023

- 22 groups of interested participants
- many different approaches
- 17 ISOPE papers
- 14 nations represented

https://www.ccp-wsi.ac.uk/data_repository/test_cases/test_case_015

CCP-WSI Blind Test Series 4

Focused wave interactions with a submerged flexible membrane



ISOPE 2023, Ottawa, Canada
19-23 June 2023
ISOPE24, Rhodes (Rodos), Greece, June 16–21, 2024

- 8 groups of interested participants
- 8 different approaches
- 9 nations represented

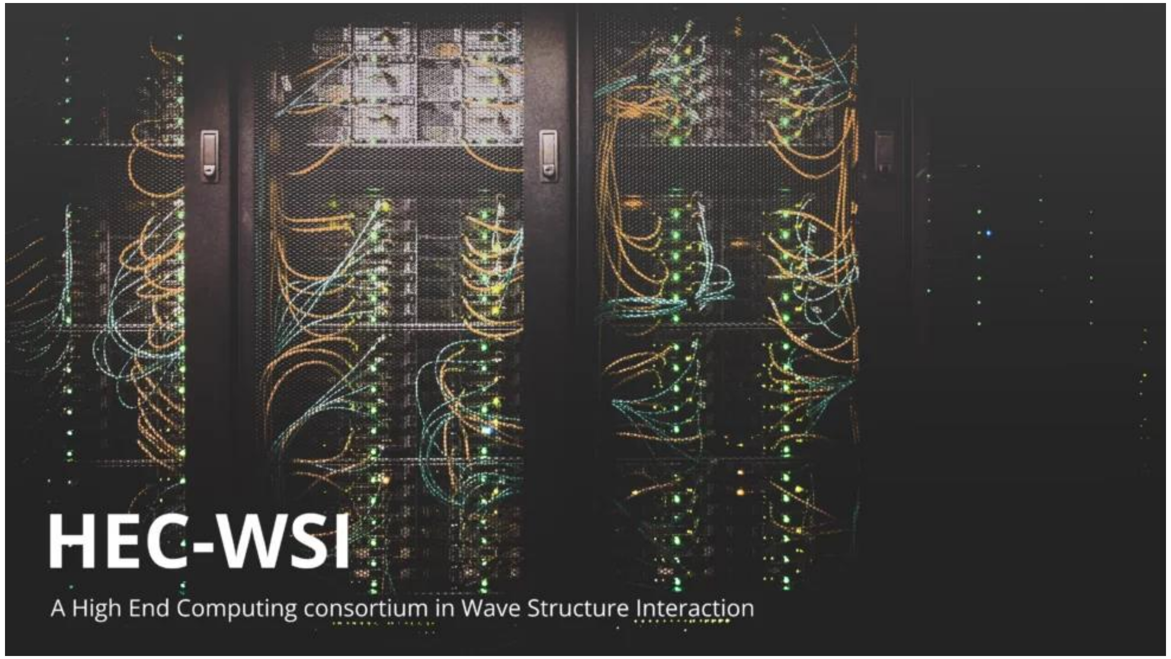
https://www.ccp-wsi.ac.uk/data_repository/test_cases/test_case_014

University of Plymouth · University of Exeter · Manchester Metropolitan University · University of Bath · City University of London · The University of Manchester · University of Glasgow · Newcastle University · UKRI Science and Technology Facilities Council · UKRI Engineering and Physical Sciences Research Council

HEC-WSI

a High End Computing Consortium for Wave Structure Interaction
EP/X035751/1

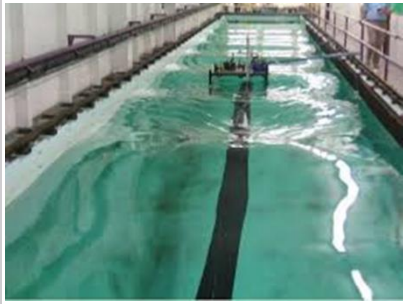
- A Scientific Consortium formed around wave structure interaction (WSI)
- WSI community recognised for having substantial and continuous computational needs.
- HEC-WSI aims to facilitate world-class WSI research using national High-End Computing (HEC) resources
- Awarded considerable resource on the UK National Supercomputing Service (ARCHER2) - available to the WSI Community via the HEC-WSI
- HEC-WSI Access Modes:
  - Porting & Benchmarking (PB) - < 3 months, < 2000 CUs (always open)
  - Code Development (CD) - < 6 months, < 4000 CUs (always open)
  - Project Access (PA) - < 12 months (6 monthly calls)
  - Early Career Researcher (ECR) - tbc
- Technical development of WSI tools
  - Optimisation of key WSI codes
  - Interoperability/coupling of solvers
  - AI/ML surrogate modelling tools (informed by high-fidelity WSI simulations)

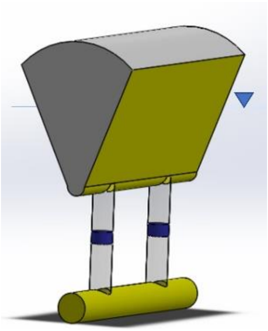


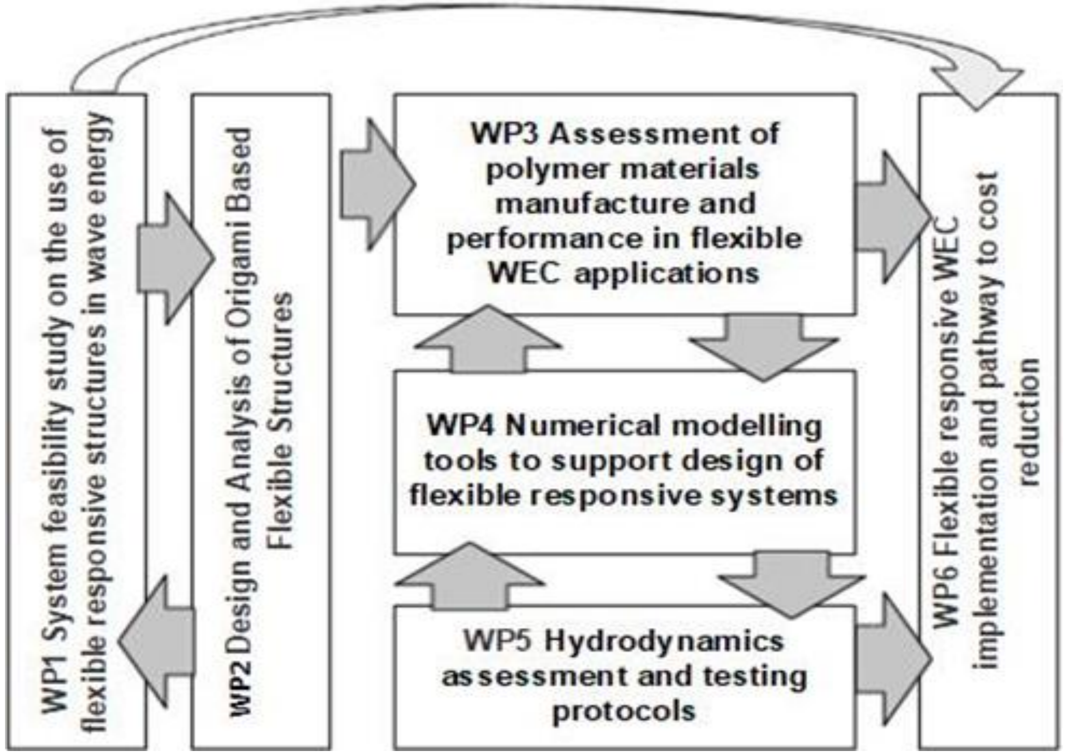
Join the CCP-WSI, HEC-WSI and SIG-WSI Community Mailing List at
https://hec-wsi.ac.uk/contact/

Flexible Responsive Systems in Wave Energy: FlexWave

EPSRC EP/V040367/1 2021 – 2024







Jingyi Yang, Krishnendu Puzhukkil, Xinyu Wang, Alistair Borthwick, Edward Ransley, John Chaplin, Martyn Hann, Maozhou Meng, Robert Rawlinson-Smith, Shanshan Cheng, Siming Zheng, Zhong You, Deborah Greaves

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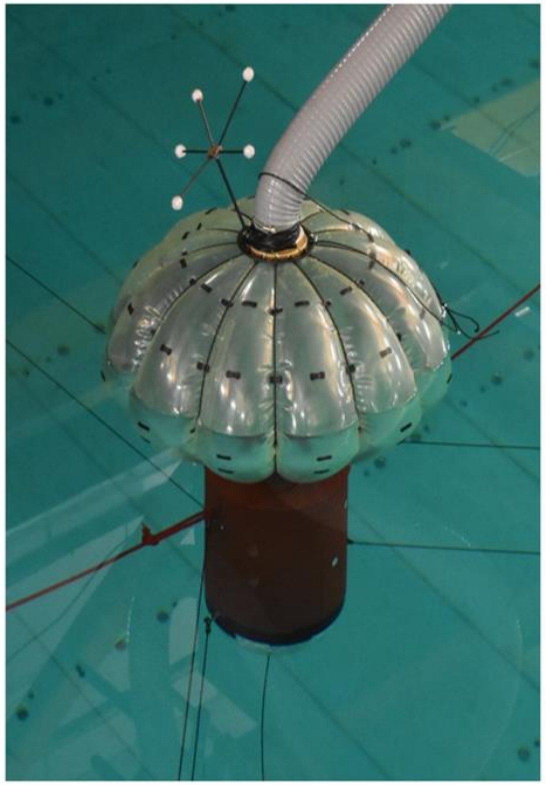
Why FlexWave?

Demonstrate step change reduction in cost of energy and pathway to utility scale and niche application WEC designs through the use of Flexible Responsive Systems in Wave Energy.

- Flexible fabric WECs can be smaller and lighter than rigid counterparts.
- May be tuned to suit incident wave conditions by controlling internal fluid pressure.
- Controlled non-linear deformation can accommodate or shed high loads without reaching critical stress concentrations, improving survivability and reducing installation and lifetime costs.
- A range of PTO types could be utilised, such as air turbine, electro active polymers or novel distributed embedded energy converters.
- Lightweight flexible structure is unlikely to cause collision damage, so a low risk option for co-location with offshore wind



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Outer shell design of the flexible Origami WEC

- The origami WEC model design
  - Two origami WEC sections are attached on each side of the central frame;
  - Each origami WEC section has a range of motion $0 < \theta < 60°$.

- Minimal strain design of the origami WEC section
  - Concentrate strain on the red facets;
  - Optimise the geometry of the origami WEC section to obtain minimal strain on the red facets.

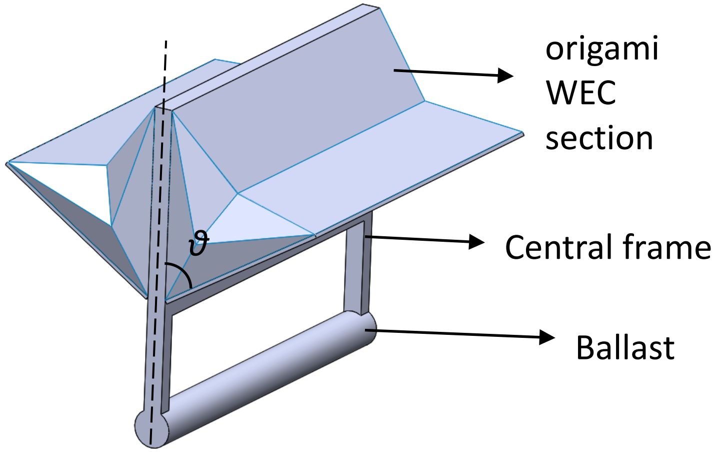


Figure 1. The origami WEC model design

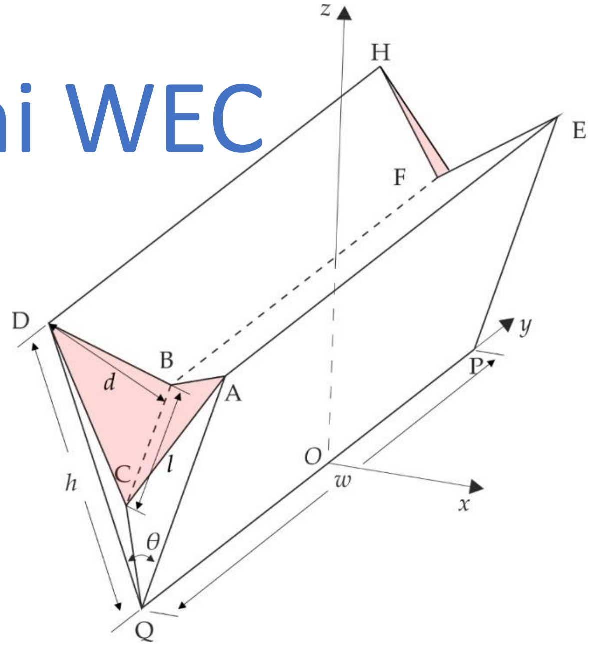
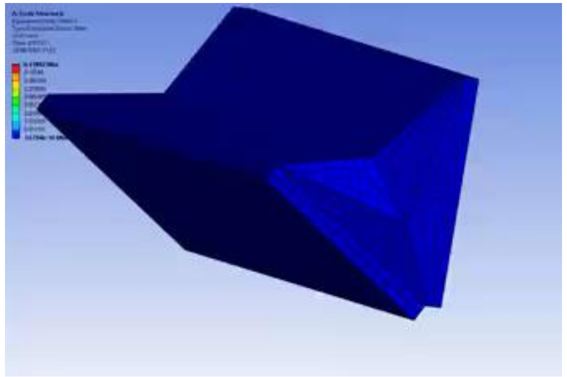
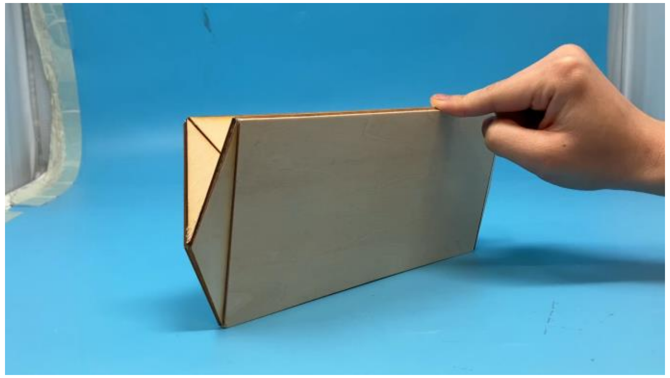


Figure 2. Minimal strain design of one origami WEC section.



Video 1. FEA of the flexible origami WEC .



Video 2. A physical prototype of an origami WEC section.

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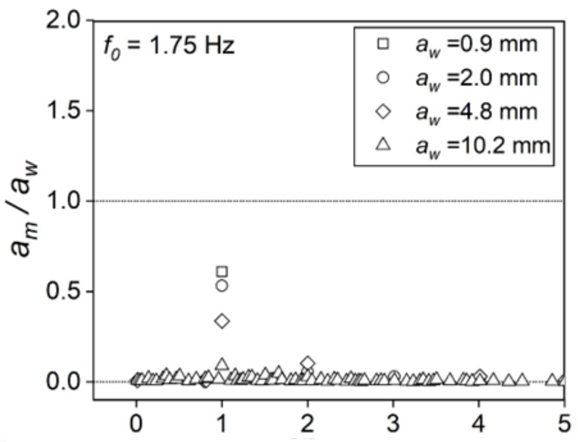
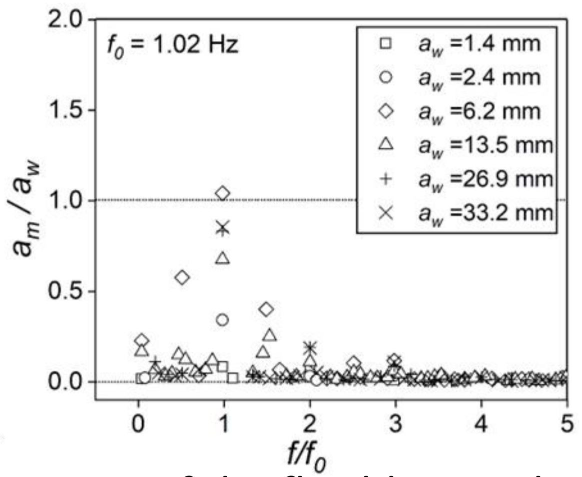
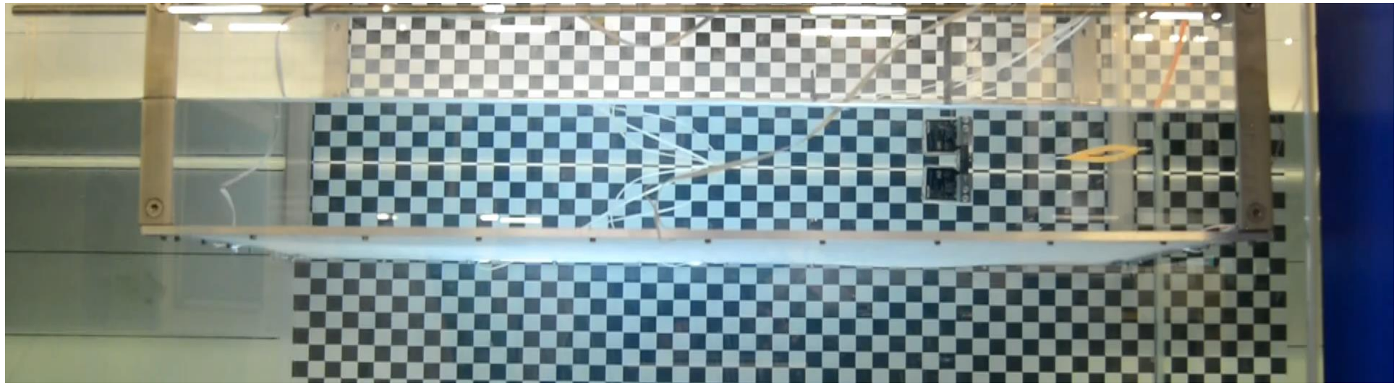
Hydro-elastic response of flexible membranes





- Hydro-elastic experiments conducted in 35 m x 0.6 m wave flume at the COAST Laboratory, UoP
- Materials tested: Neoprene Rubber, Reinforced Neoprene Rubber, Silicone and Polyurethane
- Membrane samples submerged and tested in regular & focused waves
- Laser distance sensor used to measure membrane response



Interaction of Silicone membrane with regular wave

- Response of the flexible membrane is highest at $f = f_0$ for all tested wave conditions
- At 1.02 Hz the membrane is observed to be excited at subharmonic wave frequencies and this could be closest to the natural frequency of the membrane

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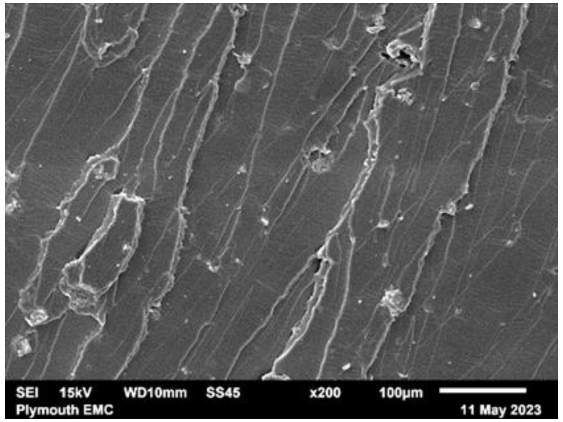
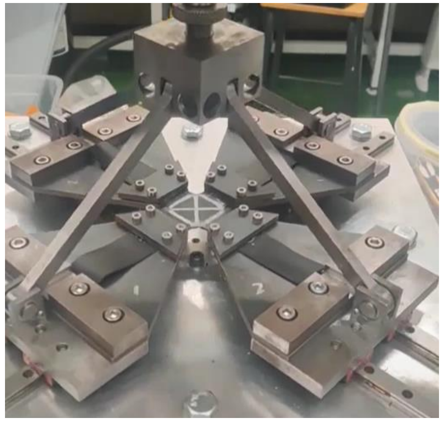
Assessment of materials manufacture & performance in flexible WECs

- Material manufacturing
  - This project explores **room-temperature curing (RTC)** elastomers to avoid using the costly rubber vulcanising method.
  - Graphene oxide (GO) with **hydrophobic treatment** is proven to have great potential as rubber reinforcement in marine environments.



The fracture surface of GO-filled PU rubber (109 % of the increase in tensile strength is achieved with 1 wt. % of treated GO)

- Material testing
  - A **database** of the **dynamic** performance of six different types of elastomers has been established based on testing results.
- Future work
  - A **visco-elastic model** describing the **dynamic** performance of the tested materials is to be developed, then verified with flume testing.



Biaxial dynamic testing setup, where materials' visco-elastic properties are investigated

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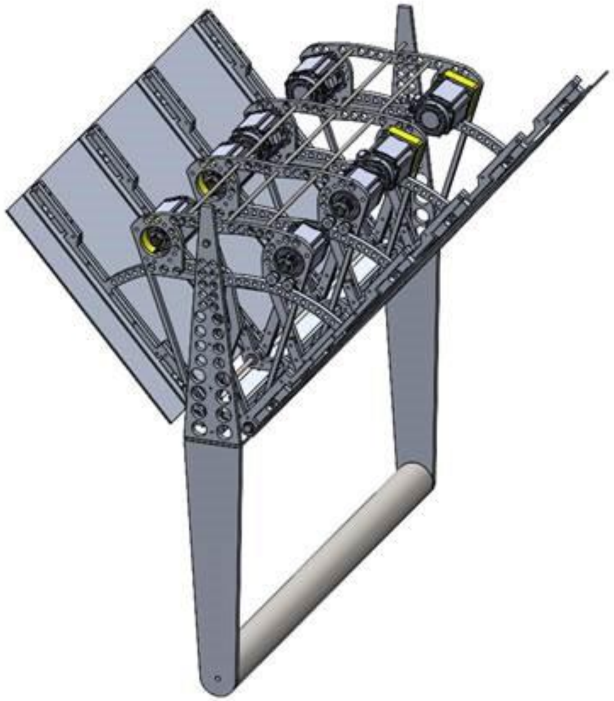
Project Progress

- An optimised outer shell design of the origami WEC has been finalised;
- Hydro-elastic responses of different flexible membranes tested in the wave flume facility;
- A database of the dynamic performance of a selection of elastomers has been established;
- A patent and three conference papers have been submitted.



Future work

- Finite element analysis to validate the optimum structural design;
- 1:50 scale prototype of the origami WEC is to be tested in the Ocean Basin;
- The cyclic response and fatigue performance of the reinforced RVT rubbers to be obtained

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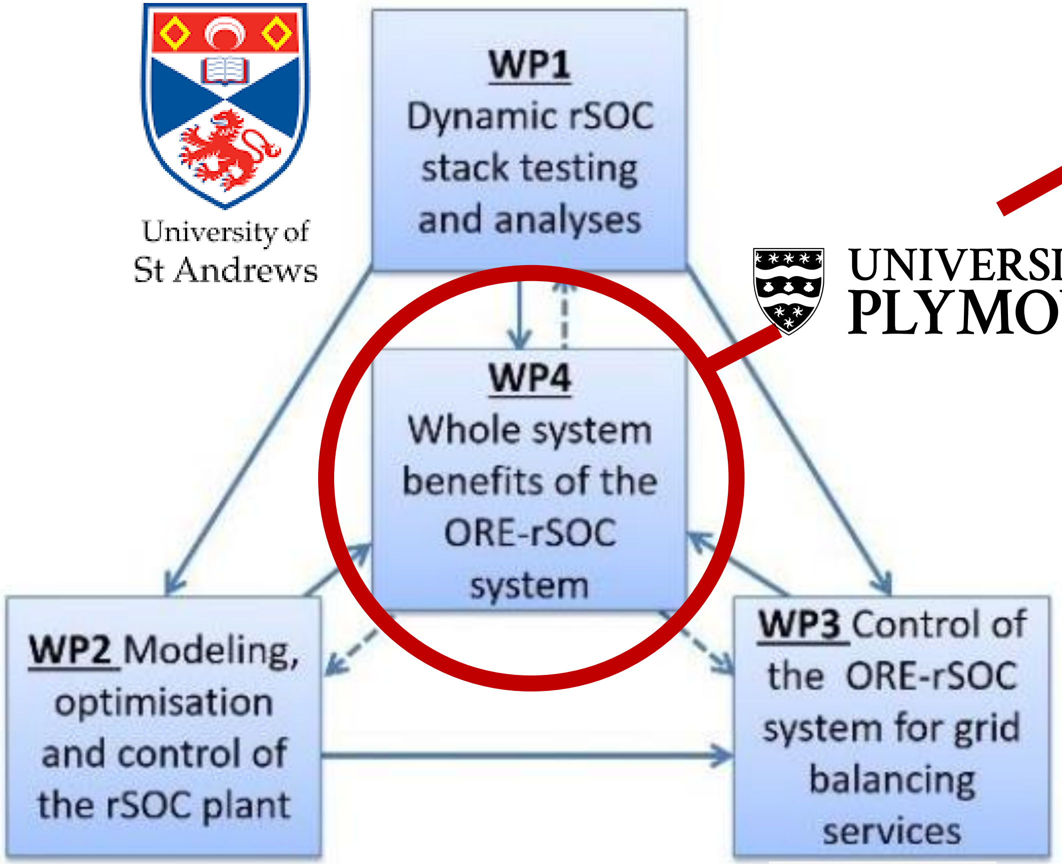
High efficiency reversible solid oxide cells (rSOC) for the integration of offshore renewable energy (ORE) using hydrogen



Socio-economic and environmental aspects of an ORE-rSOC system

Project team: *Imperial College London (lead)*: Professor Nigel Brandon, Professor Goran Strbac, Dr Huizhi Wang, PDRAs: Catalina Pino-Muñoz, Danny Pudjianto, Hossein Ameli *University of Plymouth*: Professor Deborah Greaves, Dr Robert Rawlinson-Smith, PDRA **Jessica Guichard**, PGR **Dave Pegler** *University of St Andrews*: Professor John Irvine, PDRA: Kamil Nowicki; *University of Warwick*: Professor Xiaowei Zhao, PDRA: Mostafa Kheshti

Industrial Partners: BP, Cadent Gas Ltd, Ceres Power Ltd, FTI Consulting, Health and Safety Executive, INEOS Group, National Grid, Offshore Renewable Energy Catapult, Port of Cromarty Firth, Scottish Power, Siemens, Simec Atlantis Energy, Simply Blue Energy, TechnipFMC plc (UK), The National HVDC Centre, WH Power System Consultant

EPSRC (EP/W003732/1) 2022-2025

Role of hydrogen in the context of decarbonization

- Replace fossil fuels in hard to electrify sectors (high heat applications and feedstock in industry, long distance and heavy duty transport)
- Seasonal storage of intermittent energy provided by Renewable Energy Sector
- UK has a target of net zero carbon by 2050, 5 GW of green electrolyser capacity by 2030
- Offshore wind installed capacity is expected to reach high numbers (target: 50 GW by 2030)
- Transport of energy could be done via pipelines rather than by reinforcing the electricity network

Advantages and drawbacks of rSOC technology

Advantages	• **Can be used reversibly** • **Lower cost materials** • **High efficiency**
Drawbacks	• Currently high cost • Low Technology Readiness Level • High temperature operation

Socio-economic and environmental aspects of an ORE-rSOC system

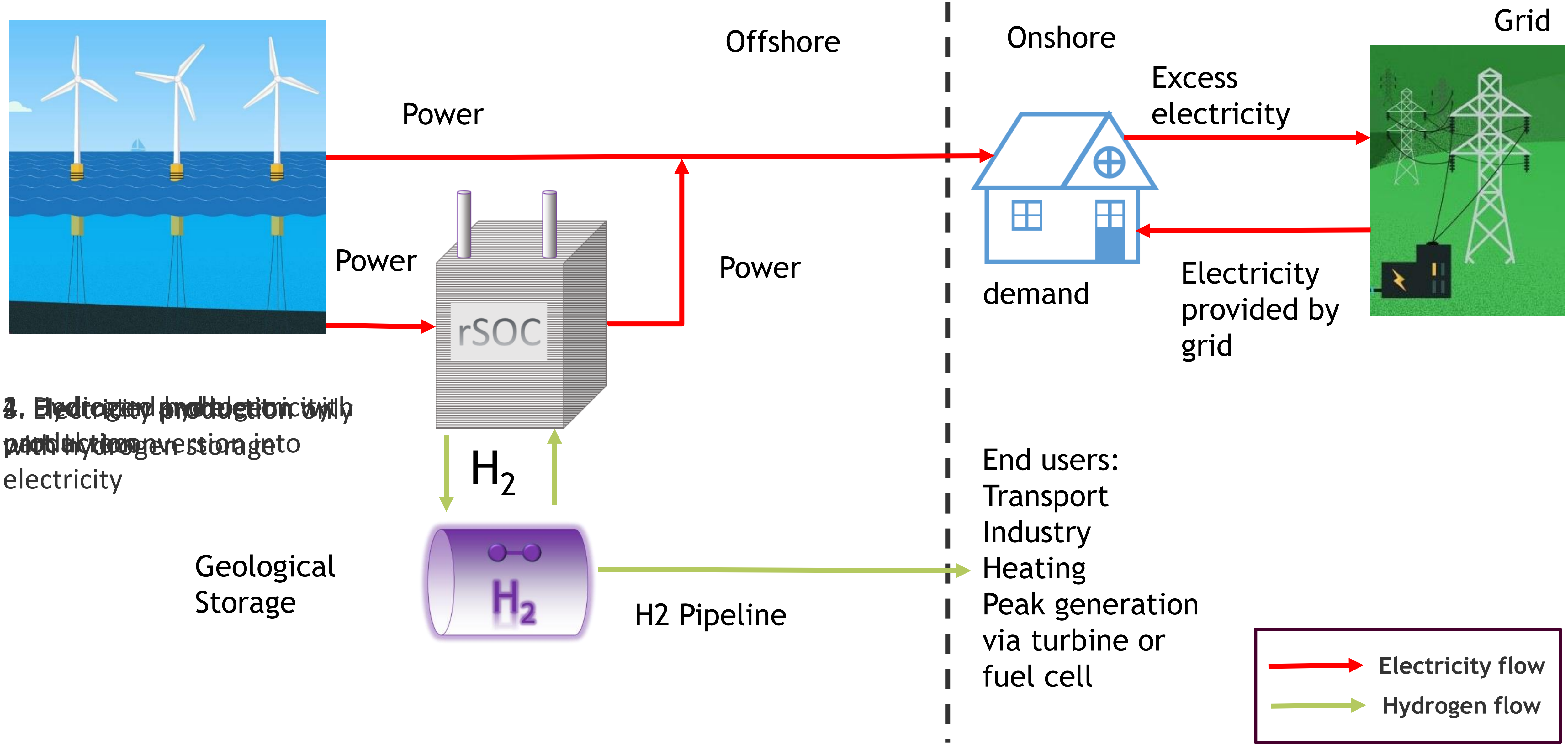
- Comparison of onshore vs offshore hydrogen production
- Hydrogen production only or reconversion of hydrogen into electricity (for peak demand)
- Geological storage vs pressurized storage
- Optimal rSOC capacity vs ORE farm capacity
- Dependency of optimal scenarios on: distance of ORE farm to shore; costs of electrolyser system, hydrogen storage and transport, and grid connection; efficiency of electrolysis; prices paid for hydrogen or electricity, hourly electricity demand

Compare local hourly electricity demand vs local hourly electricity production from Offshore Renewable Energy for one year

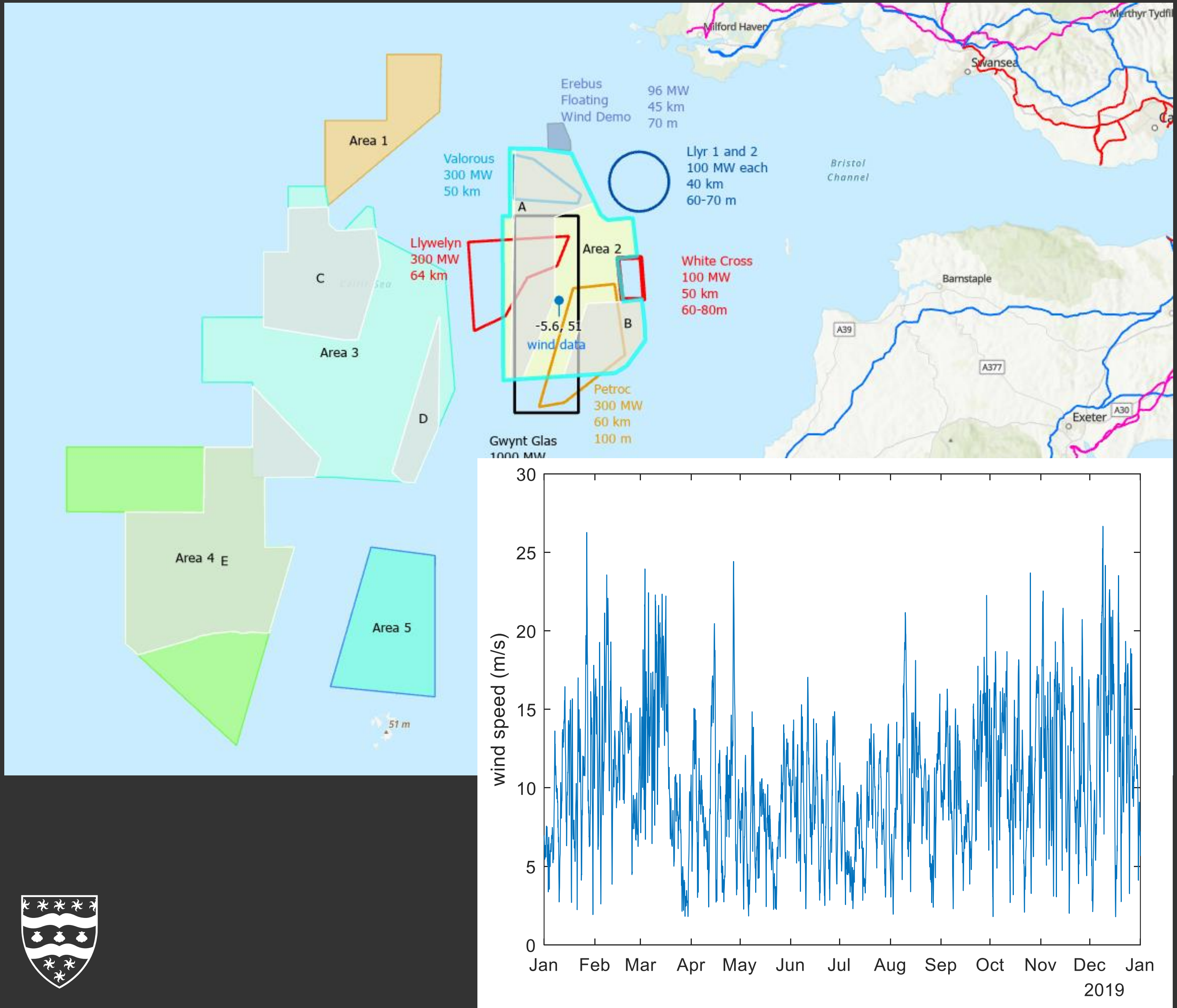
Using cost optimization as a criterion, optimize capacity of reversible electrolyser system, hydrogen storage, subsea cable

Take into account environmental impact by putting a cost on environmental impact (ex. carbon price/tax)

Offshore hydrogen production and grid balancing



Wind data



Wind data from renewables.ninja (Merra-2)

Year: 2019

<u>Location</u>: 51° latitude, -5.6° longitude

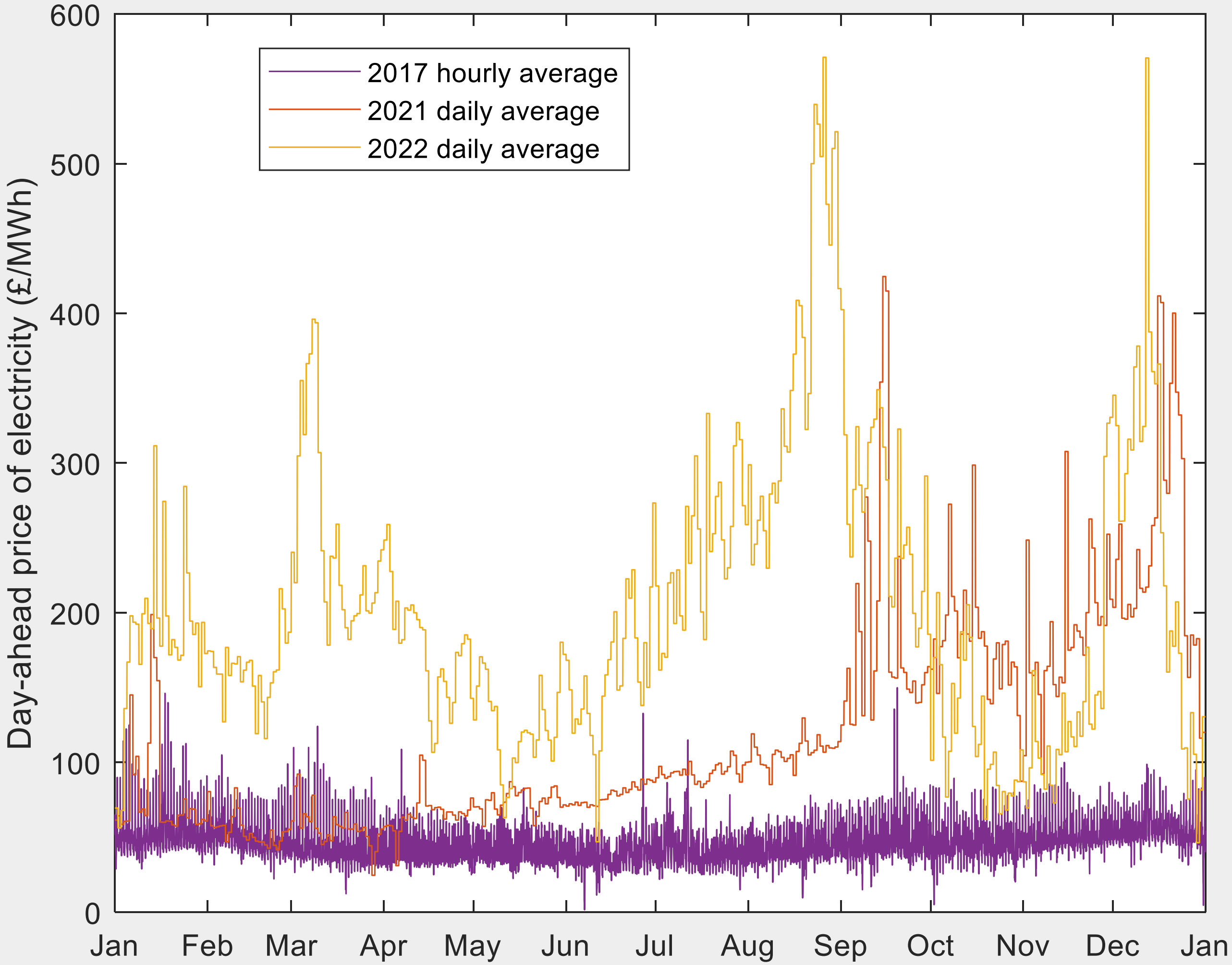
Situated in search area 2 of Celtic Sea, proposed in Crown Estate Leasing Round

150 m hub height – to correspond to IEA 15 MW reference wind turbine

Apply power curve of IEA 15 MW reference wind turbine to wind data from renewables.ninja for 40 turbines of 15 MW (Total=600 MW, corresponding to Petroc and Llywelyn)

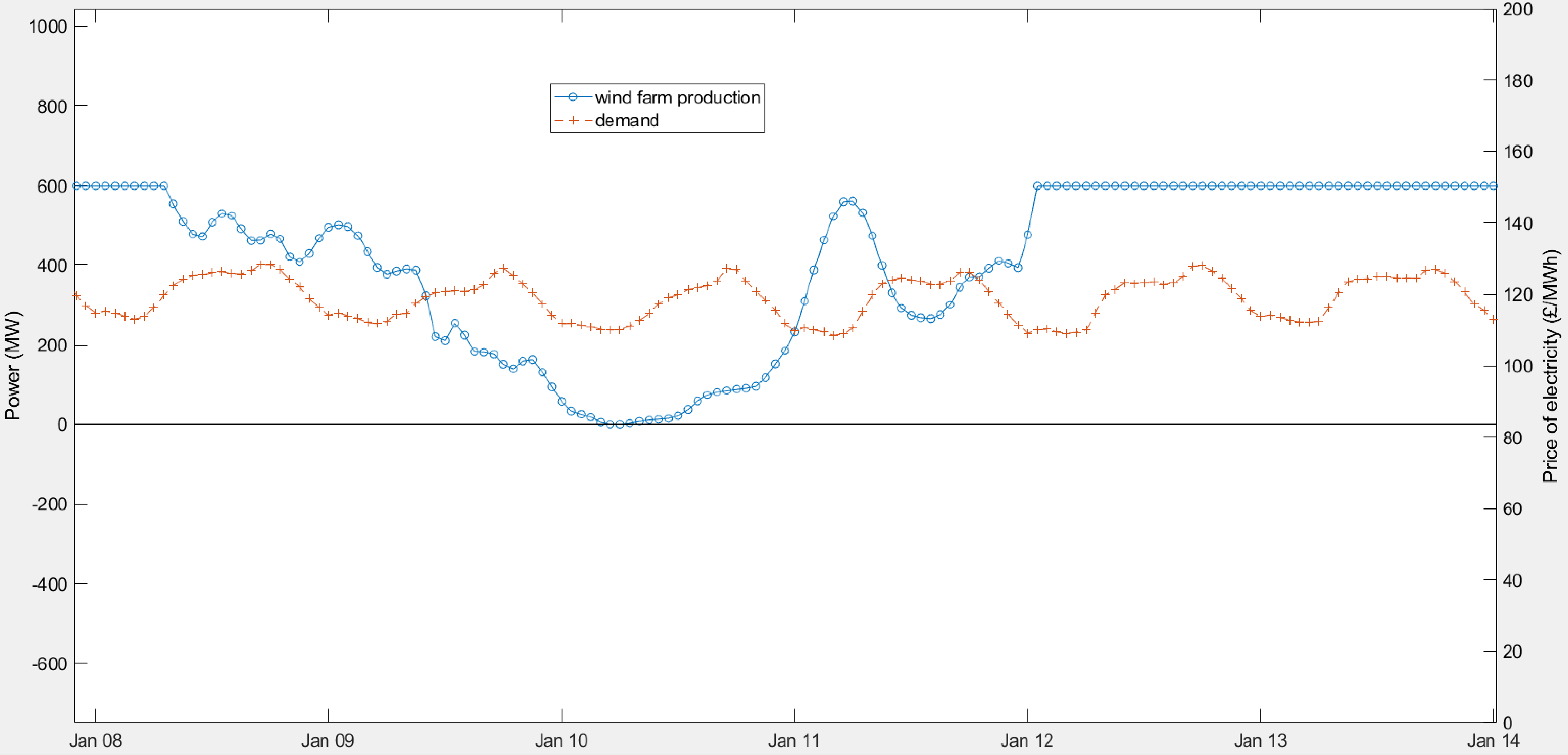
UK demand factored to local demand from https://www.futureenergyscenarios.com/2022-FES/electricity-maps.html

Day ahead price of electricity for 3 different years – 2017, 2021 and 2022

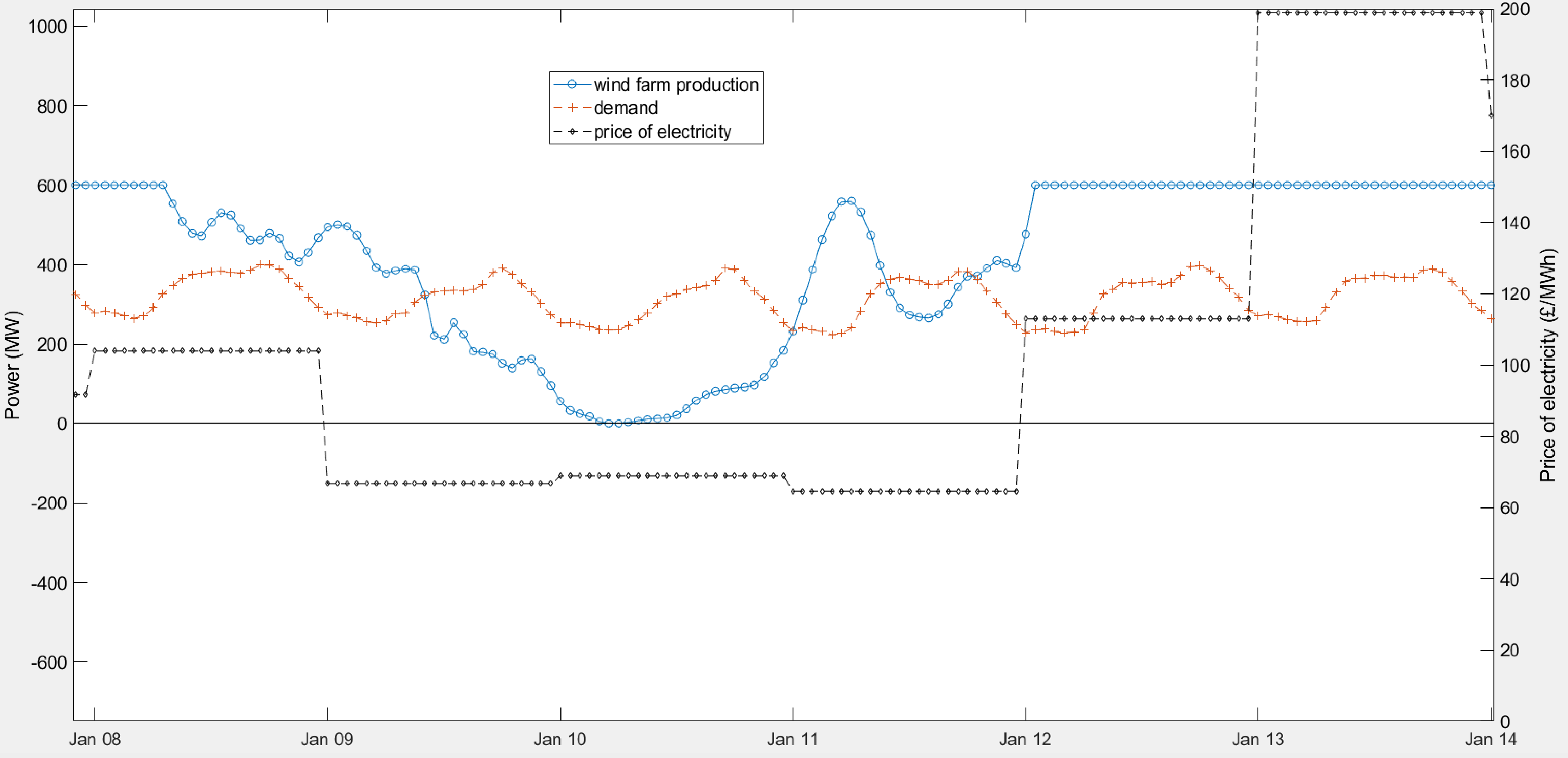


Source: Nord Pool (https://www.nordpoolgroup.com/)

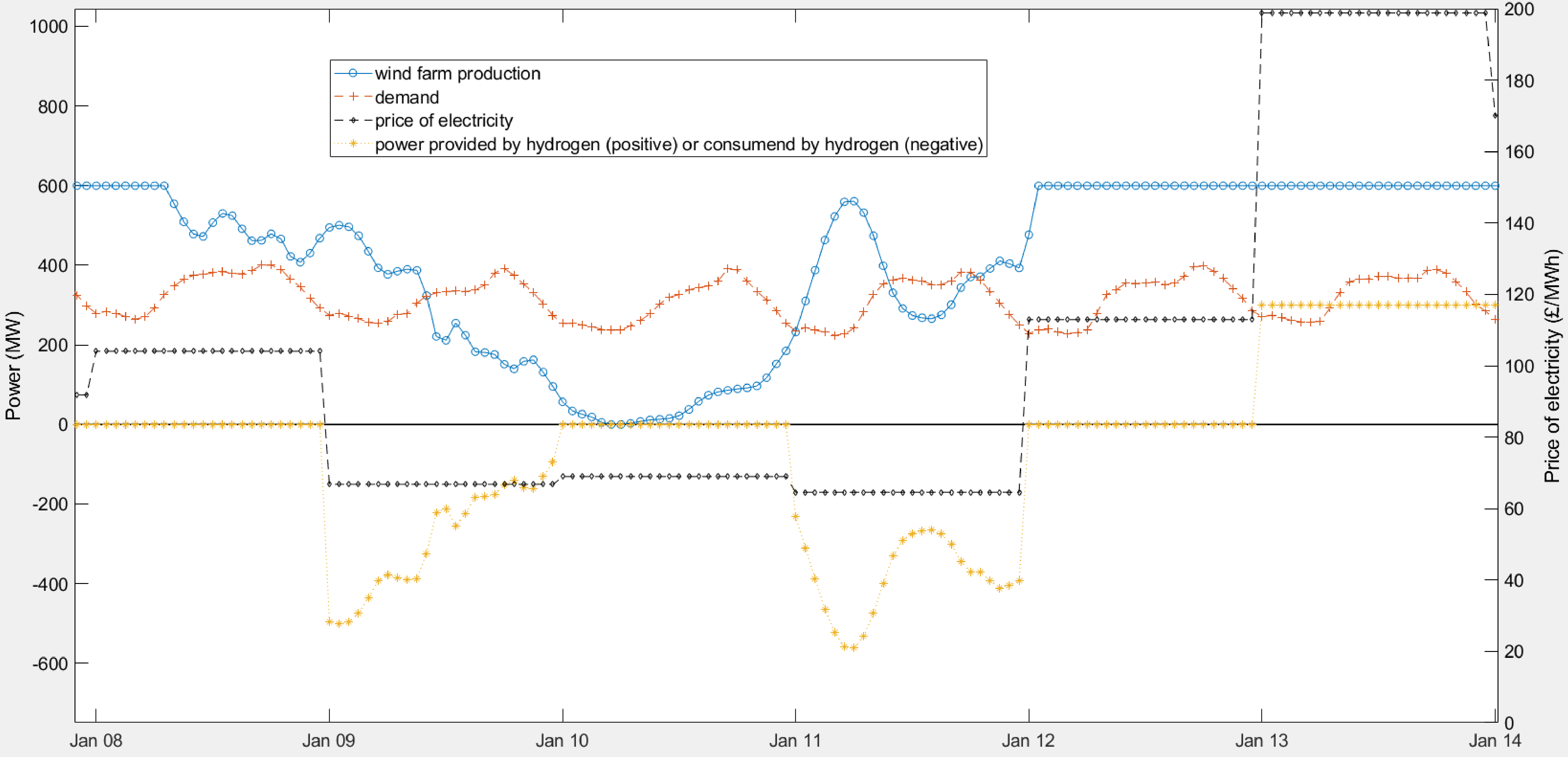
2019 wind data, 2021 electricity prices



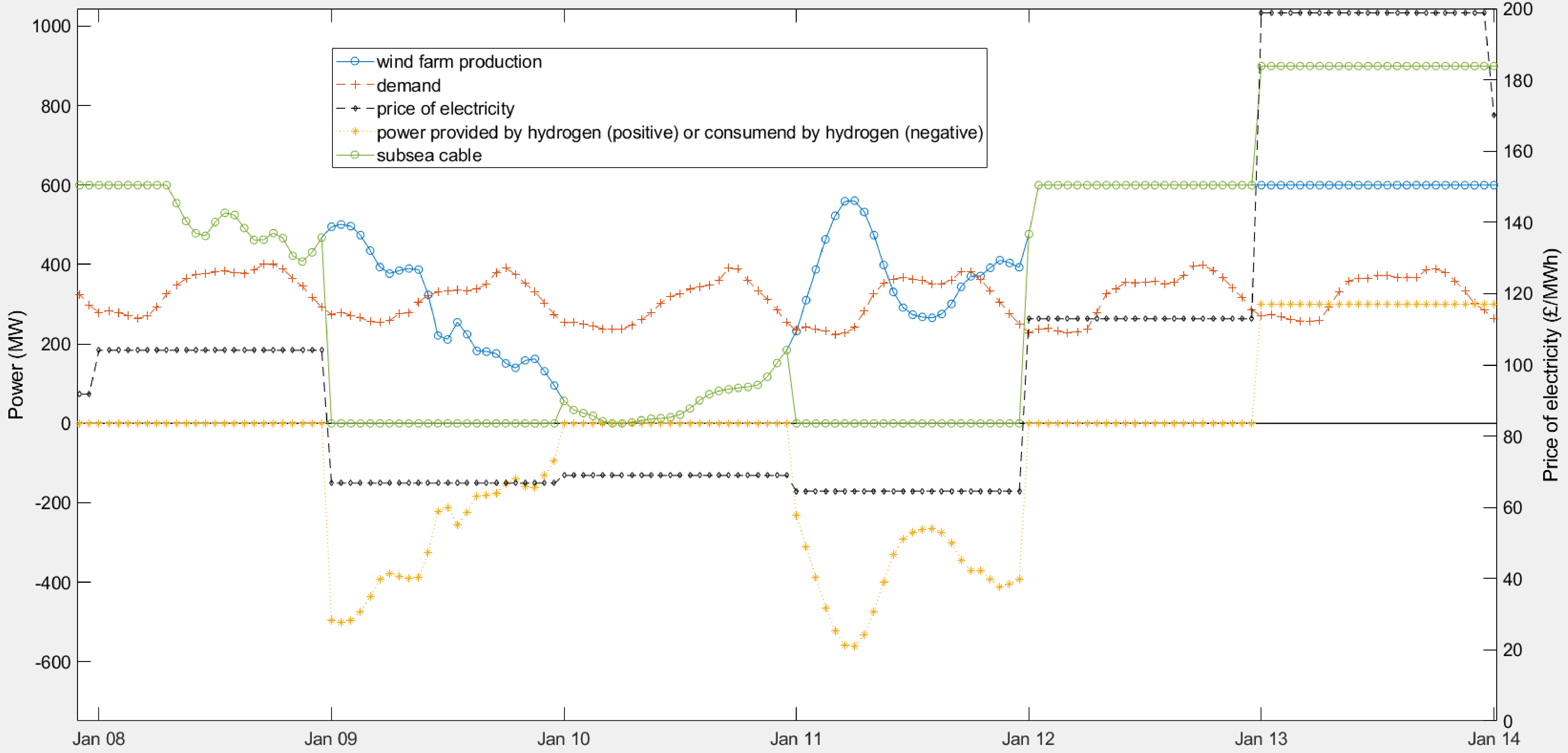
2019 wind data, 2021 electricity prices



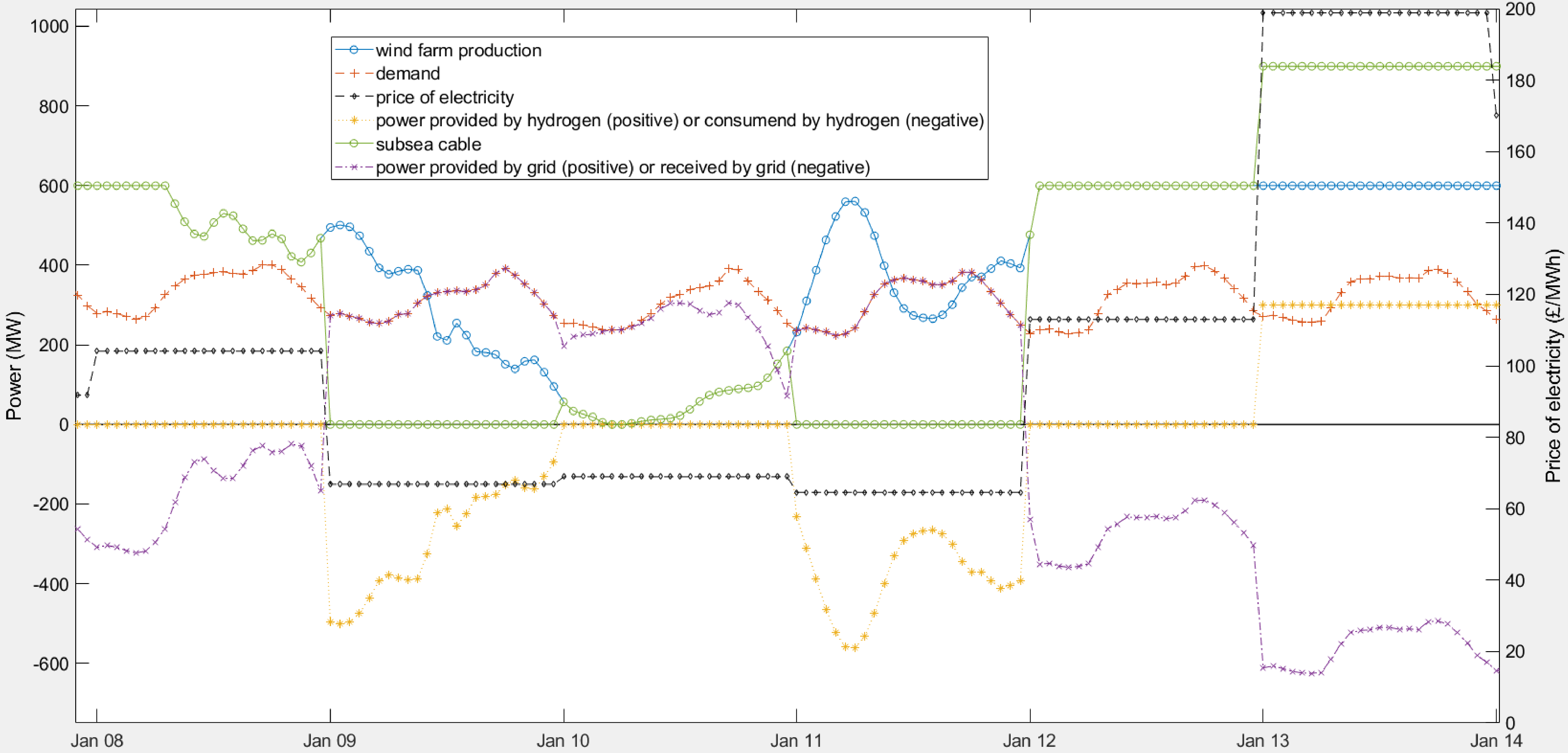
2019 wind data, 2021 electricity prices



2019 wind data, 2021 electricity prices



2019 wind data, 2021 electricity prices



Conclusion

- PyPSA model demonstrated usefulness in determining optimized electrolyser and storage capacities in the case of offshore hydrogen production combined with geological storage
- Optimized storage capacity showed high dependency on average electricity prices and duration between two periods of high electricity prices
- In certain conditions, optimized reversible electrolyser system capacity could exceed installed capacity of offshore wind farm.

Further work will

- Take into account costs for evaluating environmental impact.
- Add alternative sources for electricity: wave and tidal

Stay in touch

- www.supergen-ore.net
- @SupergenORE / #SupergenORE2023
- www.linkedin.com/company/supergenore
- supergenorehub@plymouth.ac.uk
- Deborah.Greaves@plymouth.ac.uk

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