Technology Scale Up and Proof of Concept

Tim Hurst

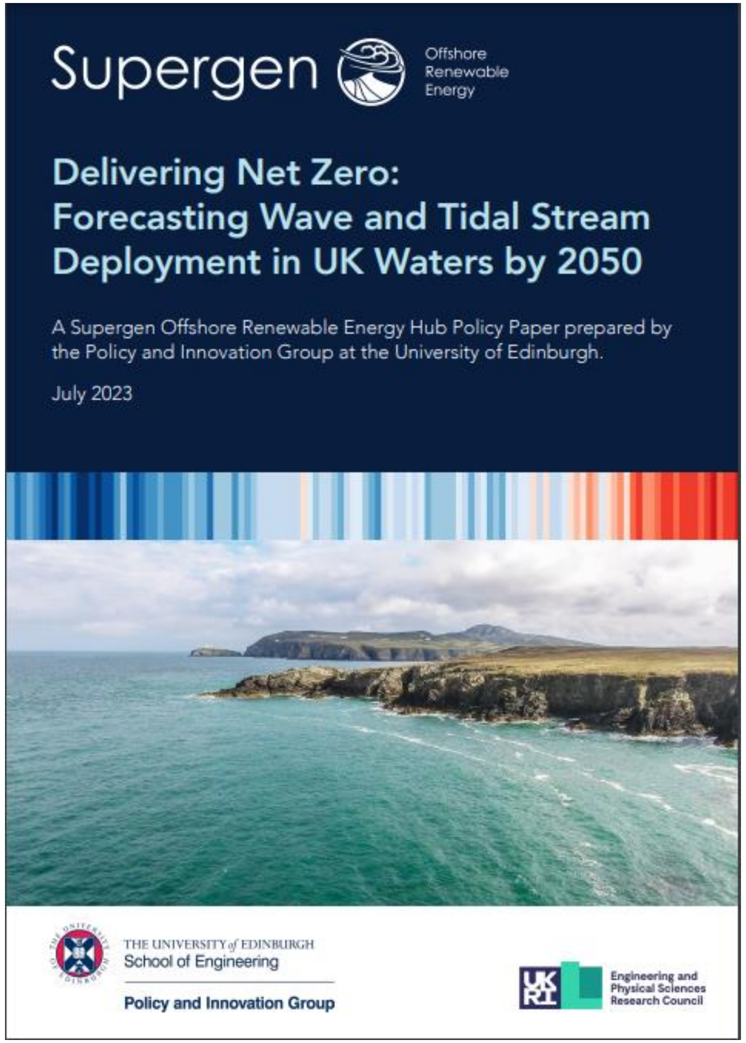
wave energy
SCOTLAND

Scaling up and Optimisation

- What we have:
  - Proof of concept devices with the right energy capture performance demonstrated in real sea conditions
  - Proven survival mechanisms to escape peak waves
- What we need to demonstrate now:
  - Pathway to the required LCOE
  - Achieve appropriate availability targets and demonstrate how this can be sustained over a 25 year life
  - Differing requirements for different markets
  - Utility scale (Wind / wave co-location) – scale , availability and O&M key issues
  - Off grid (Oil and Gas) – high system availability is the key issue

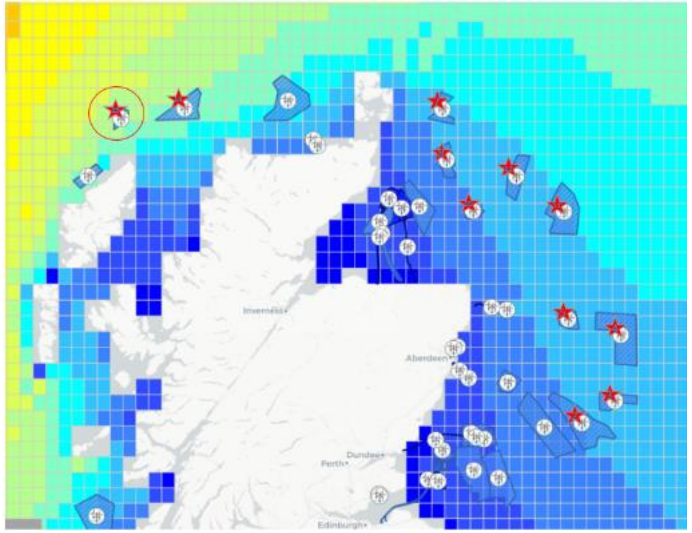
Utility Scale LCOE Requirements

- Achieve low enough costs to stimulate significant deployment for net zero impact
- Supergen study shows that an LCOE £125/MWh by 2030 will deliver 6GW of wave deployment by 2050
- £1.03bn reduction in dispatch costs per annum
- UK GVA Benefits of £2.4-4.3 bn
- Global GVA Benefits of £3.9 – 19.4 bn



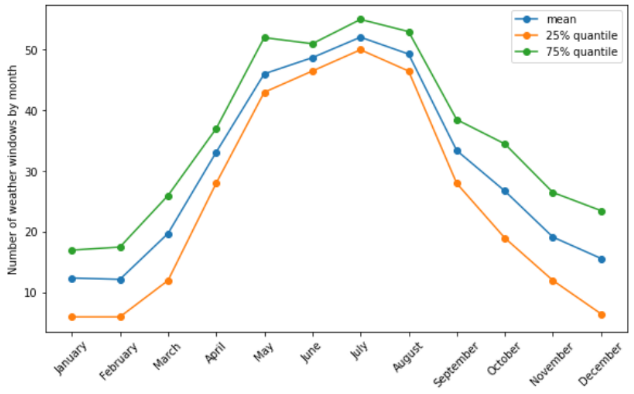
Utility Scale – requirements for floating wind/wave

- Floating wind is moving to deeper water and higher wave regimes
- Huge opportunity for sharing infrastructure – meets the Henry cost requirement!
- To capitalise on this opportunity wave energy will need to overcome:
  - Higher peak waves (>20m)
  - Deeper water > 100m
  - Greater distance to shore / major ports >100km
  - Significantly reduced maintenance windows
  - Only summer access achievable for O&M
  - Mooring/foundation constraints



Weather Windows 1994-2020 inclusive

Node 277698 (close to Magnora site) Hs<3m Tp<16s 12 hour window length



Utility Scale – Availability and Maintenance

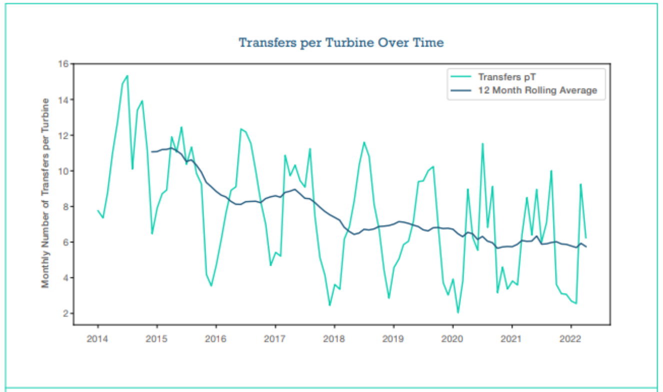
- Offshore wind has a similar level of system complexity
- Similar technology gearbox, generator, power electronics – similar maintenance requirements
- O&M is 23% of lifetime cost
- SPARTA – currently accessing turbines at least monthly
- Wave will require regular access to offshore technology
- This will drive the design and optimisation of wave devices

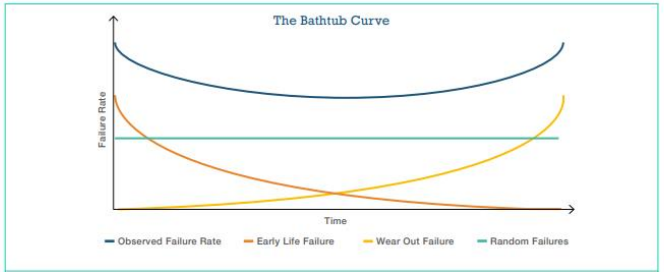
Sponsoring Organisations

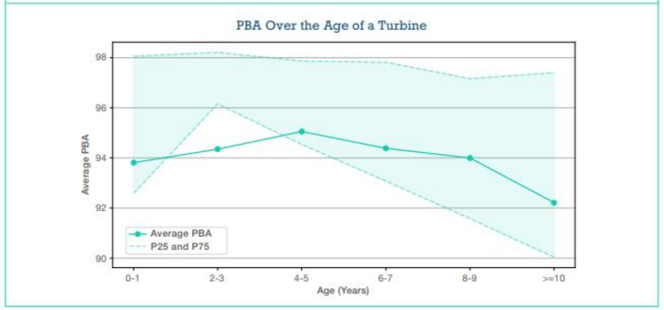
CATAPULT Offshore Renewable Energy

THE CROWN ESTATE

SPARTA System Performance, Availability and Reliability Trend Analysis



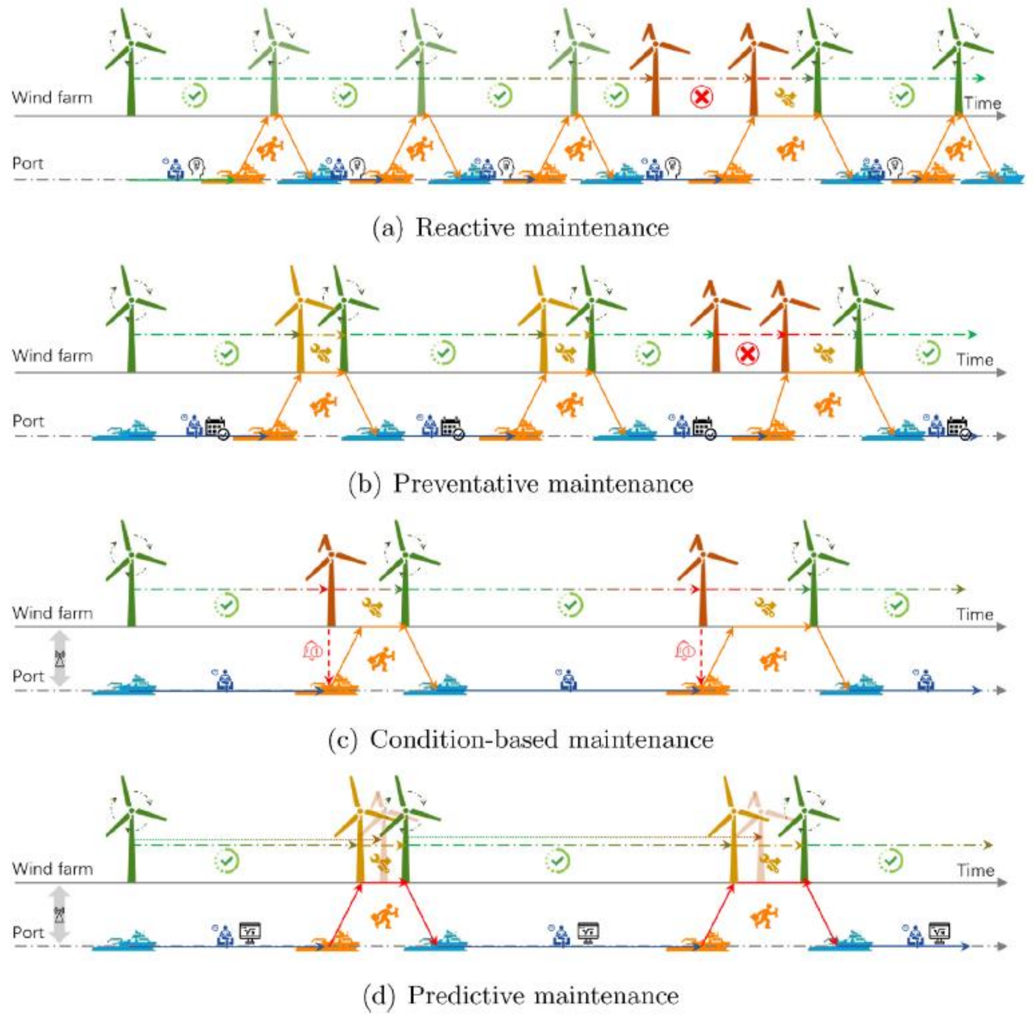




- 1607 Turbines
- 25 Windfarms
- 6.3GW Installed
- Fixed Wind
- East Coast Location
- 17 years of data

Importance of Operations and Maintenance

- Scotwind locations cannot be accessed in winter months
- At sea maintenance will be a requirement
- Maintenance strategies will need to match the required availability and access restrictions
- Major component replacements will be a significant issue
- Offshore wind is developing maintenance strategies that will be essential for success in wave energy
- WECs designed for maintenance



Offshore wind turbine operations and maintenance: A state-of-the-art review Zhengru Ren a, Amrit Shankar Verma b,c, Ye Li d,*, Julie J.E. Teuwen b, Zhiyu Jiang e

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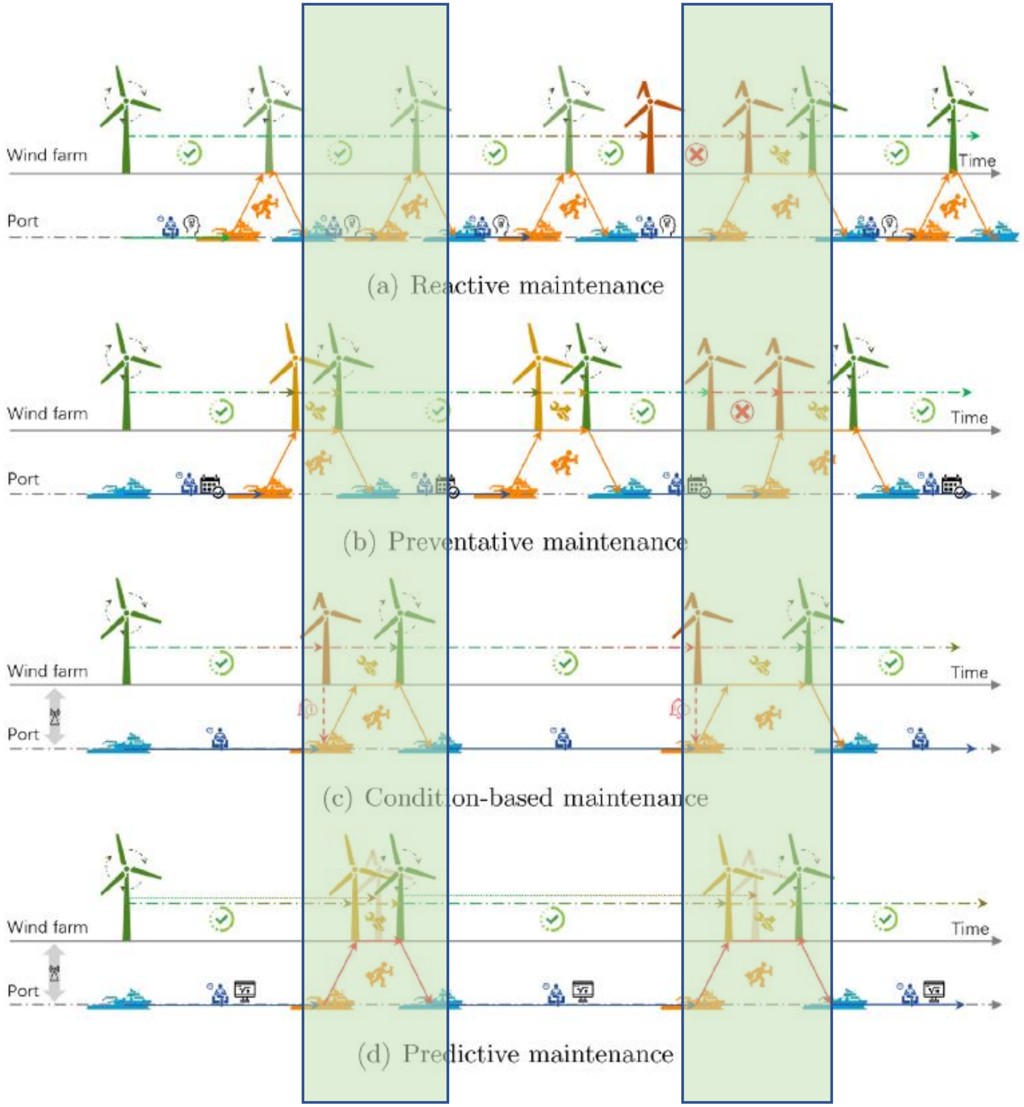
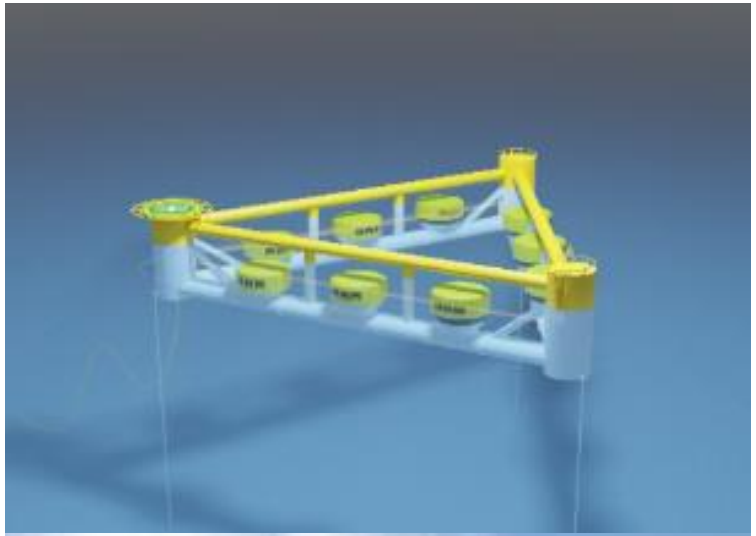


Increasing the Scale

- Significant cost reductions from scaling in offshore wind
- Wave absorbers need to be related to the scale of the wave
- Limits to the scale of many WEC designs
- Aggregation offers a potential solution
- Sharing common systems reduces cost and increases reliability and potentially access
- Larger scale compatible with FOV



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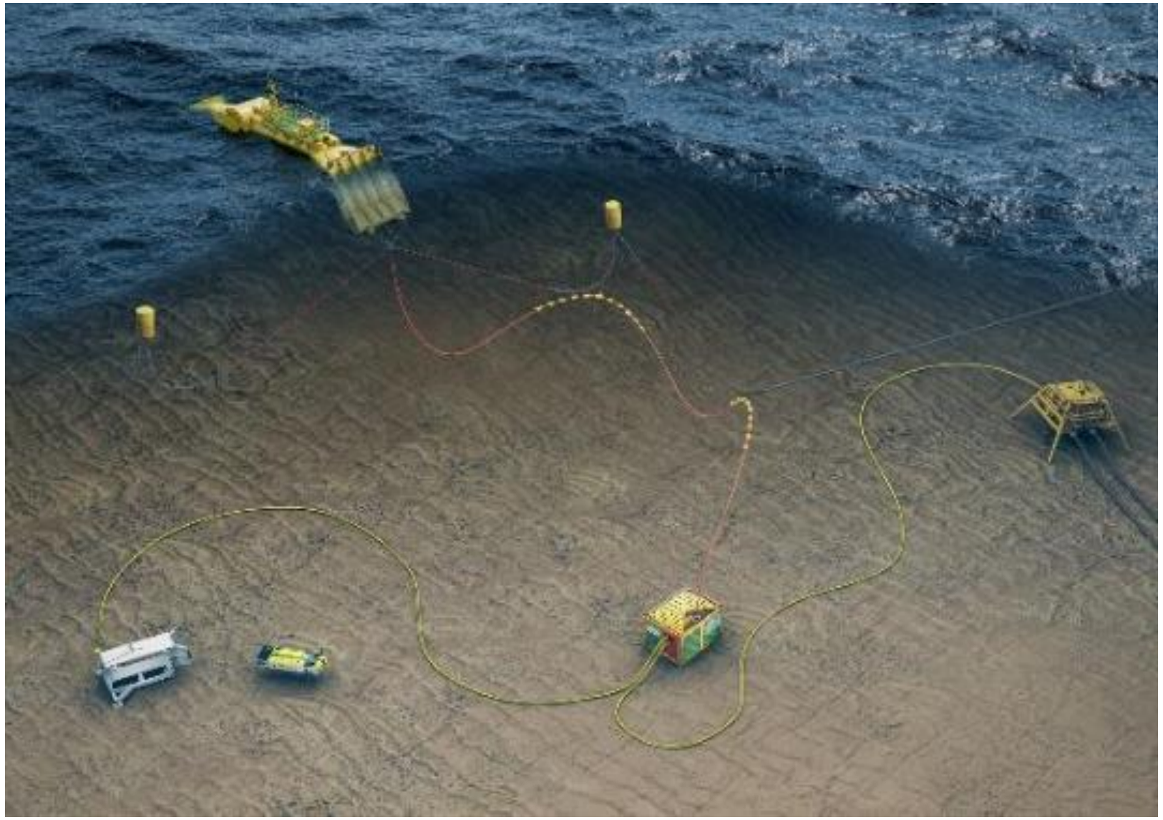
Off-grid Applications (Oil and Gas)

- Selling **Security of supply**
- System availability will be the critical factor for off-grid applications
- Higher LCOE may allow equipment redundancy strategy to increase reliability
- Require year-round generation
- Wave capability in the summer months limited– particularly in east coast locations
- Need to combine generation this with other forms of renewable generation or storage
- Solar has complimentary generation profile
- Battery and hydrogen the obvious choices for storage



Summary

- LCOE reduction and availability are key areas to address
- Co-location can significantly reduce costs, but optimised WEC designs will be required
- O&M will drive aspects of WEC design
- Scale/aggregation will further reduce cost

Thank you!

16 Nov 2023

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Floating Wind and Wave Energy Sharing Opportunities

WES Annual Conference, 15th November 2023

Kate Johannesen, Deputy Country Manager - Scotland

owcltd.com

Key Message

- There are a range of opportunities for sharing space, infrastructure, supply chain and services between wind and wave

- Clear techno-economic benefits could be accrued to wind and wave developments

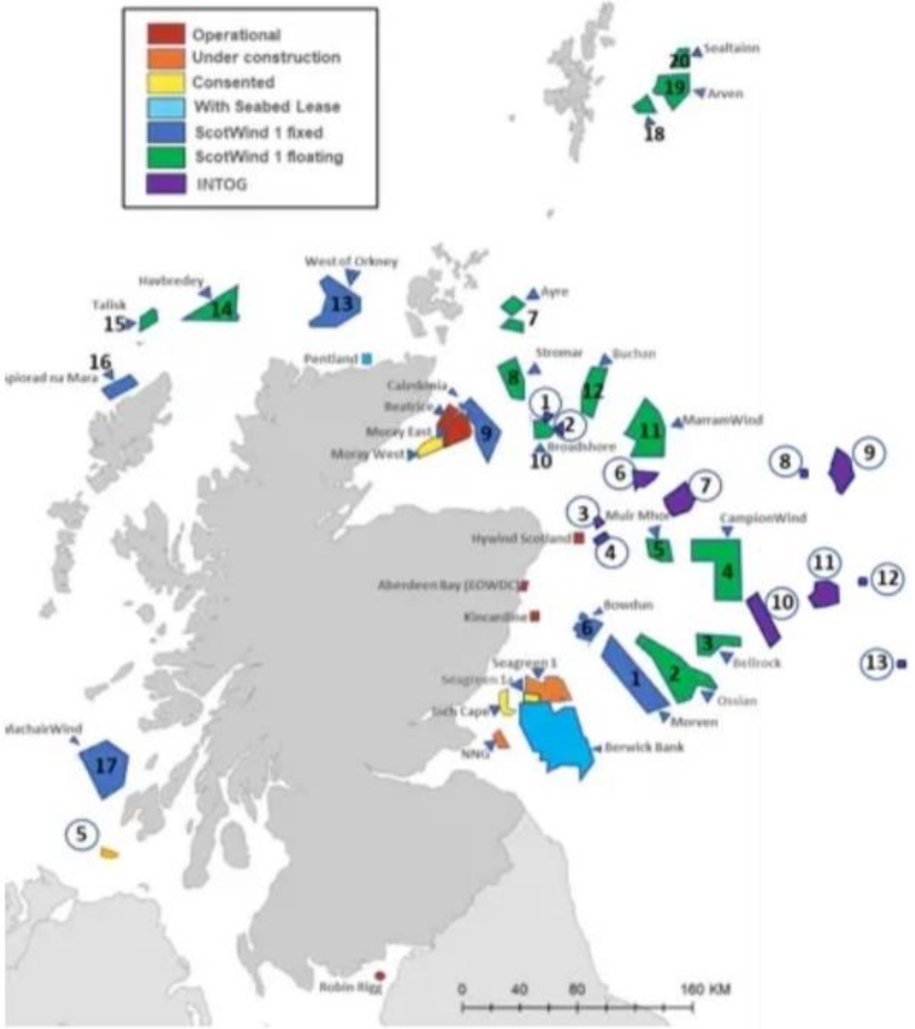
- Wider benefits, risks and feasibility require further collaborative investigation

Intro and context to the study

This study was commissioned by WES via a competitive tender process to explore whether the recent ScotWind offshore wind leasing process could offer a pathway to accelerating wave energy development to achieve commercial vaibility.

The objectives of the study were as follows:

- To identify the benefits of co-development of wave and floating wind energy for both sectors
- To identify the economic impact and market benefit of co-development, focusing on the key metric of LCOE
- To identify the wider benefits of co-development, including:
  - Supply chain development
  - Local socioeconomic benefits
  - Improved performance
  - Load reduction on floating turbines
- To identify challenges to the feasibility of co-development scenarios and identify potential solutions



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Study Approach and Structure

Part 1

Capture WES Requirements

Define Baseline Scenarios

for individual wind and wave projects

Matrix of Scenarios

- Longlist development
- Shortlisting and Selection

Part 2

LCOE Modelling

- Tailoring based on input data available
- Benchmarking, ranking

Wider Benefits Assessment

- Including Economic Impact Assessment

Ranking of Scenarios

- Combine techno-economic and wider benefits

Part 3

Feasibility Assessment

Scenarios Ranking and Conclusions

- Overall conclusions with recommendations

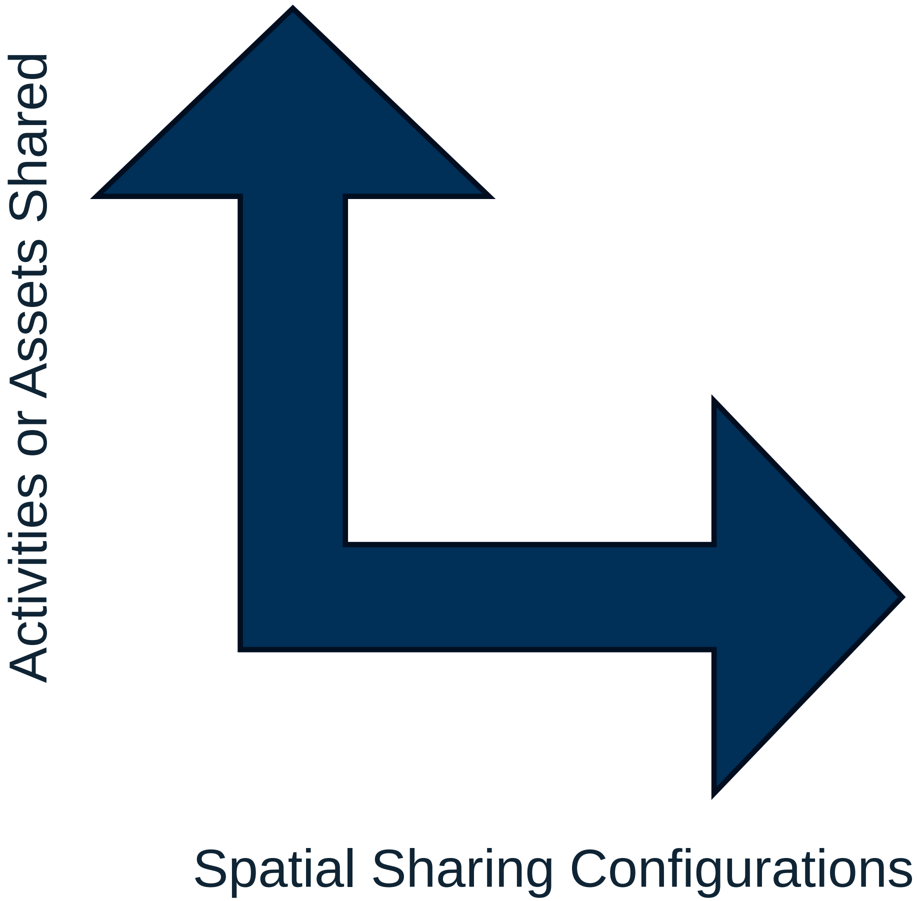
Base Cases

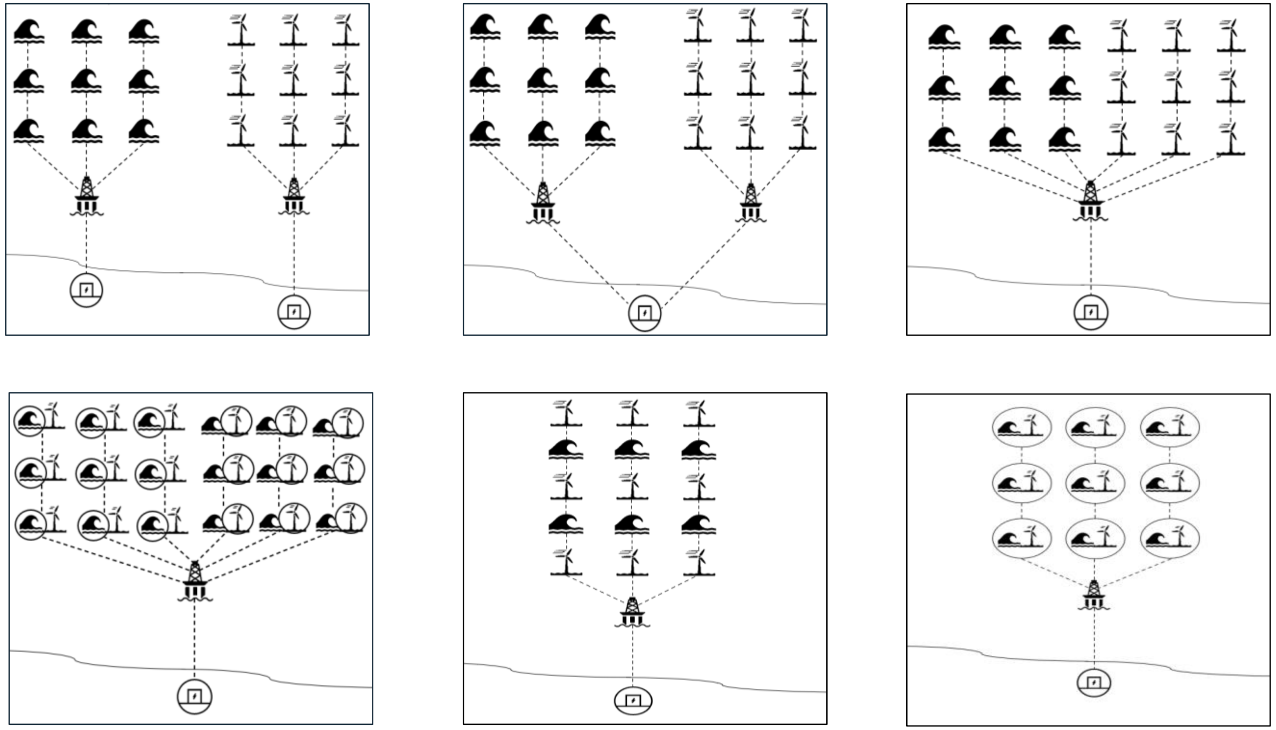
The first step in the scenario definition process is to define baseline scenarios for the wave and wind concepts in order to provide a point for comparison for the cost reduction potential assessment of the different sharing scenarios

	Wave project	Floating wind project
Total capacity	100 MW	500 MW
Quantity	129 (0.778 MW each)	33 (15 MW each)
Technology	Point absorber	Steel semi-submersible
Mooring	Taut (polyester/chain)	Taut (polyester/chain)
Anchoring	VLA	Suction piles
Transmission	HVAC, 1x 132 kV	HVAC, 2x 220 kV
IACs	11 kV	66 kV
Distance to GCP	90 km (off), 10 km (on)	90 km (off), 10 km (on)
Development	6 years	8 years
Construction	1 year	2 years
Operation	25 years	25 years

Scenarios Definition

An initial matrix of scenarios was developed, allowing a comprehensive list of possible sharing scenarios to be identified and selected from.





Different spatial configurations enable different levels of sharing from low risk options with respect to transmission system sharing only, through to fully integrated platforms.

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Scenarios Shortlist

Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Spatial							Adjacent	Adjacent	Same site	Same site	Same site	Same site	Same site	Same site	Same site	Same site
Assets				VPs	OnSS	Landfall, onshore cables & OnSS	All tran. (except IACs)	All tran. (except IACs) & VPs	All tran. (except IACs)	All tran. (except IACs) & VPs	All tran.	All tran. & anchors	All tran., anchors & VPs	All tran. & PTO	All tran. (except IACs), HPs & anchors	All tran., HPs & anchors
Development			Surveys		OnSS consent	Onshore consent and surveys	Consent for all tran.	Consent for all tran.	Lease, surveys & consent	Lease, surveys & consent	Lease, surveys, consent & design	Lease, surveys, consent & design	Lease, surveys, consent & design	Fully shared	Fully shared	Fully shared
Supply chain			Small benefit to WEC	EoS due to use of VPs	OnSS	All onshore parts	All tran.	All tran. & VPs	All tran.	All tran.	Shared except WEC platform	Shared except WEC platform	Fully shared	Shared except WEC platform	Fully shared	Fully shared
Installation			Vessels & ports		OnSS	All onshore parts	All tran.	All tran.	All tran., vessels & ports	All tran., vessels & ports	Fully shared	Fully shared	Fully shared	Fully shared	Fully shared	Fully shared
O&M			Vessels & ports		OnSS	All onshore parts	All tran.	All tran.	All tran., vessels & ports	All tran., vessels & ports	Fully shared	Fully shared	Fully shared	Fully shared	Fully shared	Fully shared
Ownership			Independent but cooperative		Wave dev pays wind dev	Wave dev pays wind dev	Wave dev pays wind dev	Wave dev pays wind dev	Wave dev pays wind dev	Wave dev pays wind dev	One project	One project	One project	One project	One project	One project

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LCoE Methodology

Approach

- Mix of **bottom-up and top-down** approaches
  - Bottom-up required to allow for sensitivity studies and to reflect differences between scenarios
- **Assumptions:**
  - Qualitative benefits excluded from model, to be picked up in wider benefits piece in Part 2
  - Quantitative (foundations, etc.) based on OWC's experience and database
  - Semi-Quantitative (economies of scale on steel weight, etc.) based on OWC's experience
  - Required assumptions such as: "assets halved if hybrid platform is used", etc.
  - No impact of mutualizing resources in the energy production.
  - Costs benchmarked and phased based on typical project programme, considering ScotWind context and anticipated level of maturity of WTG and WEC technologies in that timeframe.
  - Site conditions loosely based on ScotWind NW sites to give representative parameters but maintain applicability to other geographies.

Methodology Overview

1. Typical Site Conditions

Water depth, distance to shore, etc.

2. Definition of Technical Concept

Foundation type, transmission architecture, etc. | Energy yield assumptions

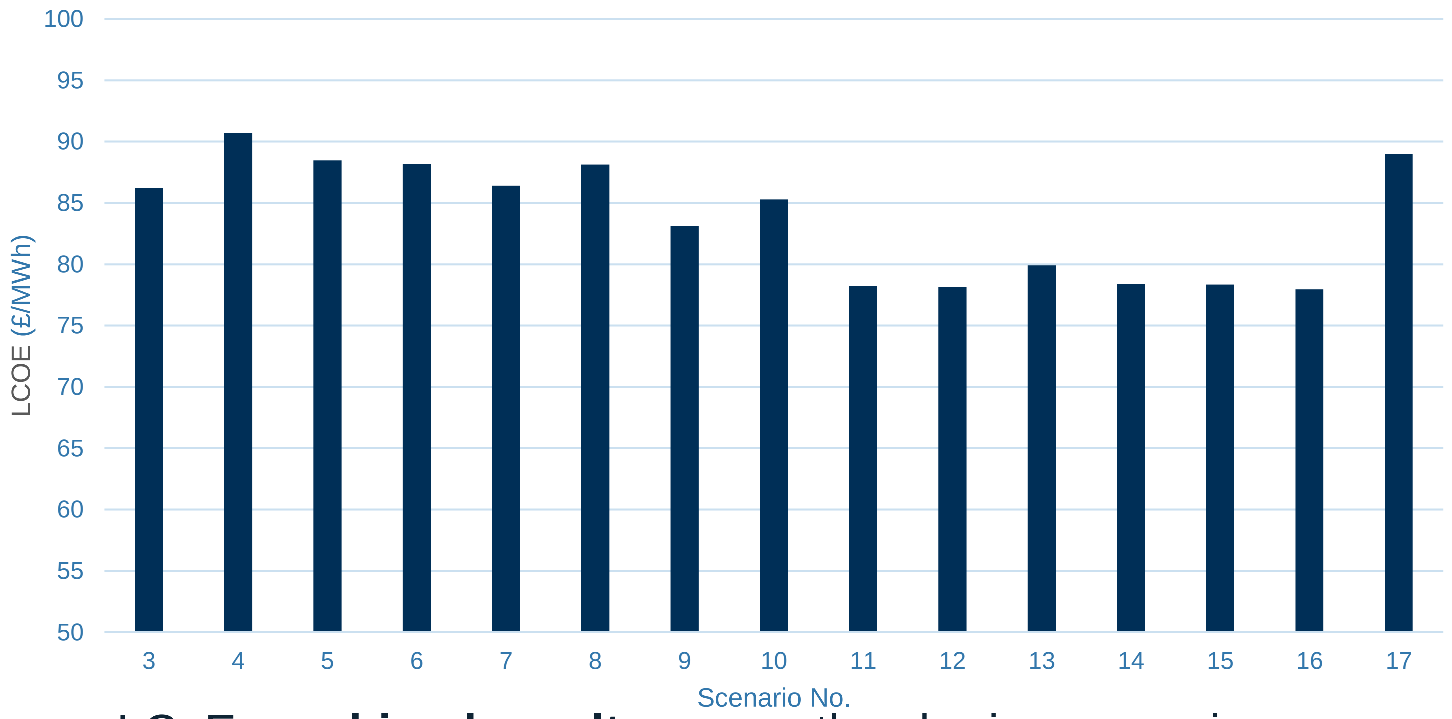
3. Definition of Sharing Scenarios and Assumptions

Generating rules and logic for modelling each of the scenarios compared to the base cases

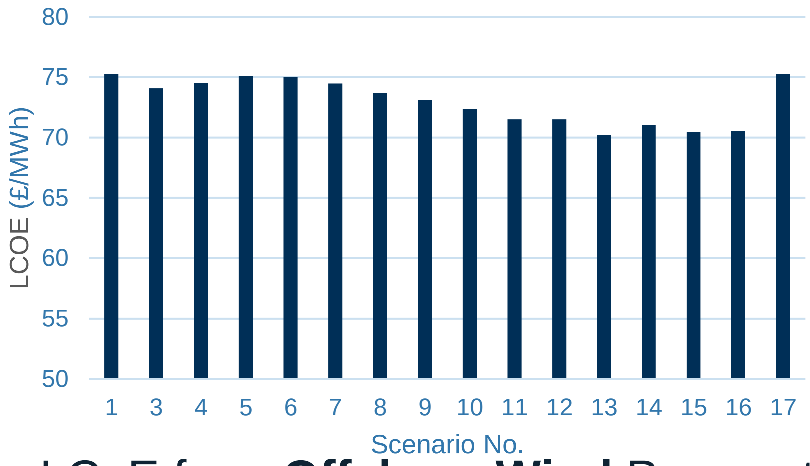
4. Comparative LCoE Estimate

Comparative assessment between scenarios, including combined (WTG and WEC) and separate WTG and WEC perspectives

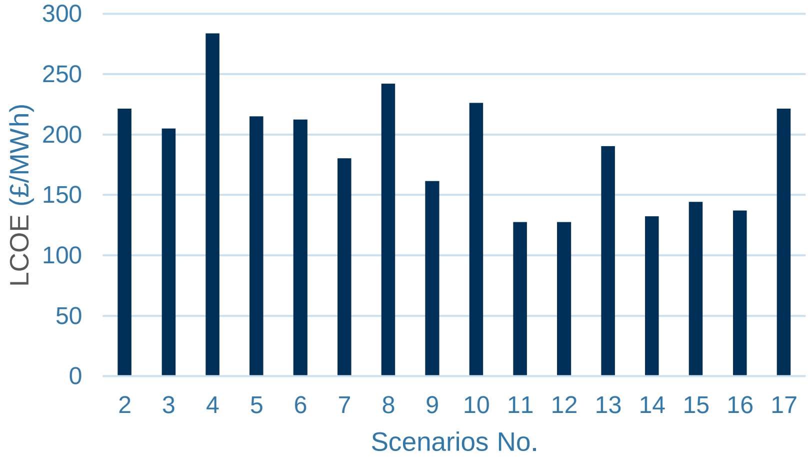
Results - LCoE



LCoE **combined results** across the sharing scenarios



LCoE from **Offshore Wind** Perspective



LCoE from **Wave Energy** Perspective

- In general, LCoE clearly reduces within sharing scenarios compared to base cases, including from the combined, offshore wind and wave perspectives
- The LCoE reduction increase with the level of sharing, however, lower risk sharing options still offer considerable benefits (e.g. transmission system only sharing scenarios)

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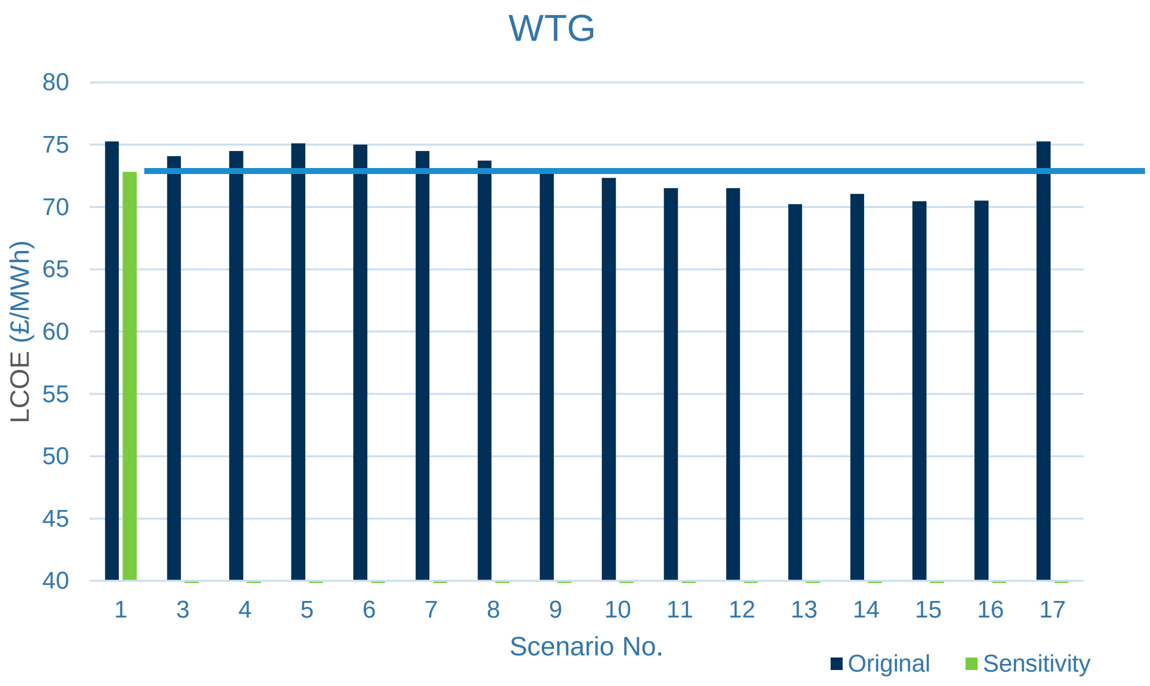
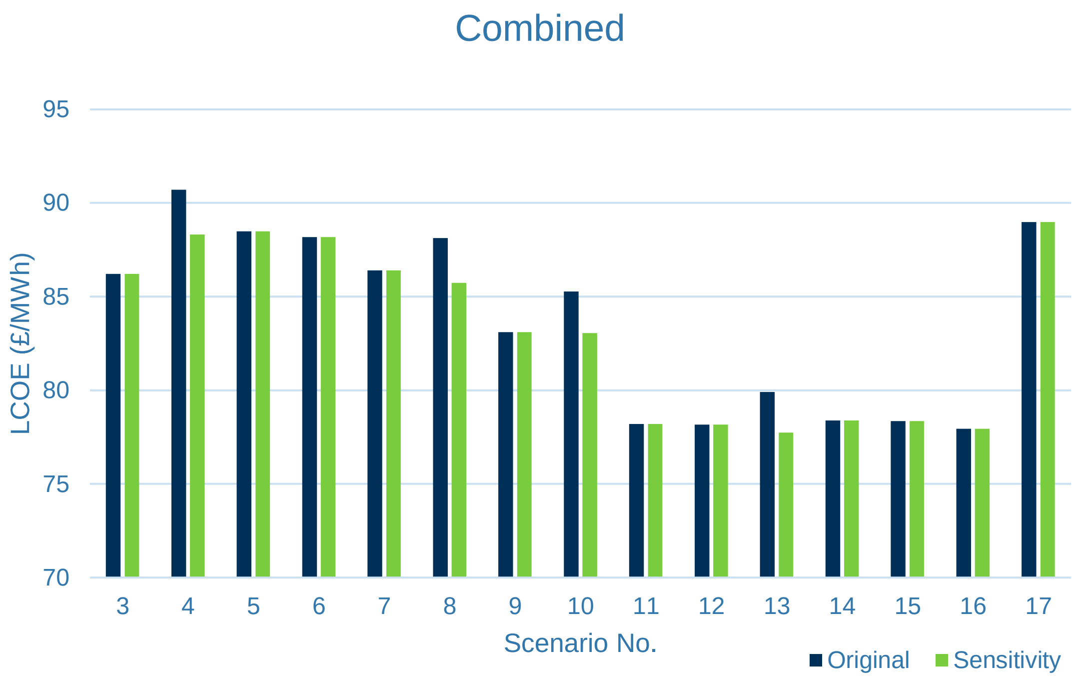
Sensitivities - LCoE

600 MW Wind Farm v 500MW Wind + 100MW Wave



Several scenarios still show benefits even when compared to a 600 MW wind project.

Sensitivity to number of WECs per Versatile Platform



High sensitivity to number of units per platform demonstrated.
Potential to alter results so that versatile platforms become optimal scenario.

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Approach and Results – Wider Benefits

Stakeholder identification → Broad impact mapping (benefits, challenges from each perspective) → Defintiion of wider benefits for each topic area → Evaluation of benefits for each topic area → Collate across topic areas to assess overall impact

Power Export/Transmission	Technology	Supply Chain	Project Development
•Power characteristics/smoothing •Capacity factor •Cable utilisation •Timeline benefits from coordinated grid connection application & shared infrastructure?	•Load reduction through platform sharing (WEC damping platform motions) •Load reduction through energy offtake (separate WECs positioned to reduce wave field at floating platforms)	•Supply chain growth •Local content •Jobs creation •GVA	•Best practices for project development •Risk reduction •Wider industry benefits •Industry project pipeline •Seabed usage •Overall environmental impact reduction?

Key Points:

- Significant potential benefits through simplifying grid connection and OFTO process and better system utilisation
- A range of interesting opportunities for improved performance and/or availability through careful placement of wave devices in proximity to floating wind structures
- Significant potential to help kick-start local supply chain with a wide range of shared/common components

Approach and Results – Feasibility

Topic areas

- Infrastructure and logistics
- Supply chain
- Stakeholders and suppliers
- Economics and risk
- Environmental and regulatory
- Technology readiness

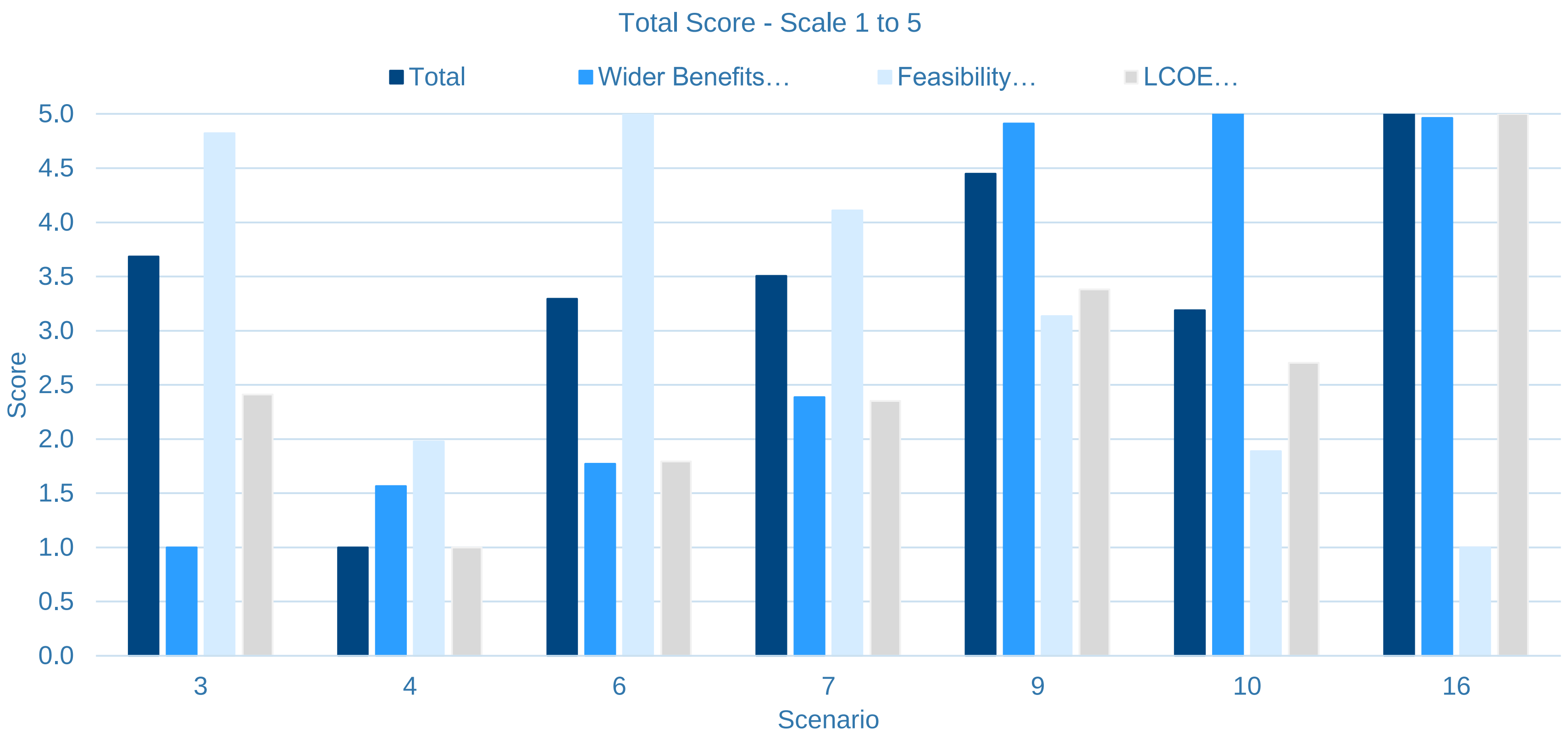
Detailed assessment of challenges, barriers and potential solution options for each topic area across each scenario

Key risks and mitigations

Stakeholder	Risk description	Risk Level	Mitigation options
WTG Developer	Added complexity to what is already considered a high risk project	High	Strategies that limit risk for WTG (more independence in project development). Stakeholder engagement, dissemination, detailed studies.
WEC Developer	WECs and WTGs cannot connect to shared IACs	High	More detailed electrical studies required to determine if this is feasible. The added cost and weight of transformers may be unacceptable. Alternative sharing options may be preferable and can still provide benefits to both parties.
WEC and WTG developers	Novel nature of project reduces bankability in the eyes of investors	High	Stakeholder engagement, dissemination, detailed studies. Incremental increases in sharing over a portfolio of projects.
WTG developer	Lack of perceived benefit to them	Medium	This study has helped to demonstrate that the benefits are likely to be mutual between WTG and WEC developers, regardless of the level of sharing. Dissemination and raising awareness of the benefits to all stakeholder groups from an early stage is key.
WEC Developer	Baseline LCoE assumed in model may not be achievable within timeframe modelled.	Medium	Requires 1GW deployment worldwide. Investigate sensitivity of model results to changes in baseline LCoE. Understand route to market for combined projects.

Final Scenario Ranking

LCOE Scoring + Wider Benefits Weighted Criteria Matrix + Impact Assessment Scoring + Feasibility Weighted Criteria Matrix = Conclusions



Key Conclusions

There is potential for significant cost reductions to be achieved from both the WEC **and the FOW** perspectives:

Cost reductions of ~7% could be achieved for FOW developers by sharing aspects of their projects with WEC developers

Cost reductions close to 40% could be achieved for WEC developers

From a combined project perspective, **the cost reduction could be around 12%.**

- The model demonstrated strong sensitivity to the assumptions around use of versatile platforms. These have the potential for significant cost savings, but the number of units per platform and the platform weight need to be carefully optimised.

- There is a broad range of sharing scenarios that generate cost reduction, providing flexibility in terms of selecting which to prioritise, factoring in the feasibility, stakeholder perspectives, percieved risks and wider benefits aspects.

- Achieving stakeholder buy-in through dissemination and engagement activities will be key to successful implementation of sharing scenarios

Next Steps

- Clear techno-economic benefits of sharing space, infrastructure, supply chain and services.
- Wider benefits, risks and feasibility require further collaborative investigation

The Roadmap consists of 4 key themes for successfully progressing to implementation of shared projects:

- Dissemination
- Detailed Studies
- Stakeholder Engagement
- Strategy Development and Refinement

Timeline:

- Relevant ScotWind projects expected to go for 2029 CFD
- Key engineering/supplier engagement ~ from 2027
- WEC project needs to start process ~ 2024/25

To end 2023 — Results Validation and Strategy Development

- Dissemination of results to generate interest with stakeholders
- Initial engagement with offshore wind developers
- Initial engagement with other key stakeholders
- Initiate detailed studies to validate results, answer concerns raised by stakeholders and prove feasibility

Q1-Q2, 24 — Refine and select target sharing scenarios

- Refine conclusions to focus on most viable sharing scenarios based on stakeholder feedback and outputs of detailed studies, including review and revision of LCoE scenario assumptions
- Dissemination of detailed study results
- 2nd round of stakeholder engagement

Q3-Q4, 24 — Finalise Strategy for Implementation

- Disseminate a final set of recommended options and development plans for the most favourable sharing scenarios
- Target offshore wind and wave developers for initiation of collaborative projects
- Seek to secure support from wider stakeholders for collaborative projects

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Multi-Wave Absorber Platform

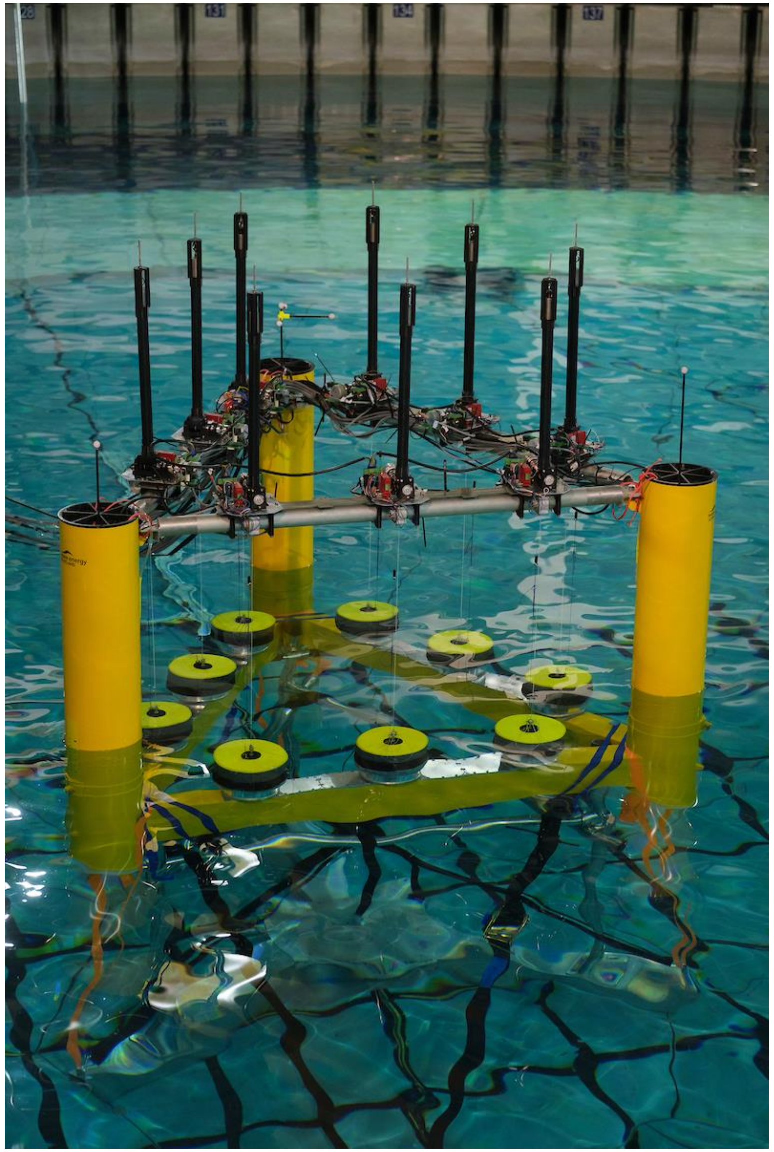
Matthew Holland

Elva Bannon, Niall McLean

wave energy SCOTLAND

Overview

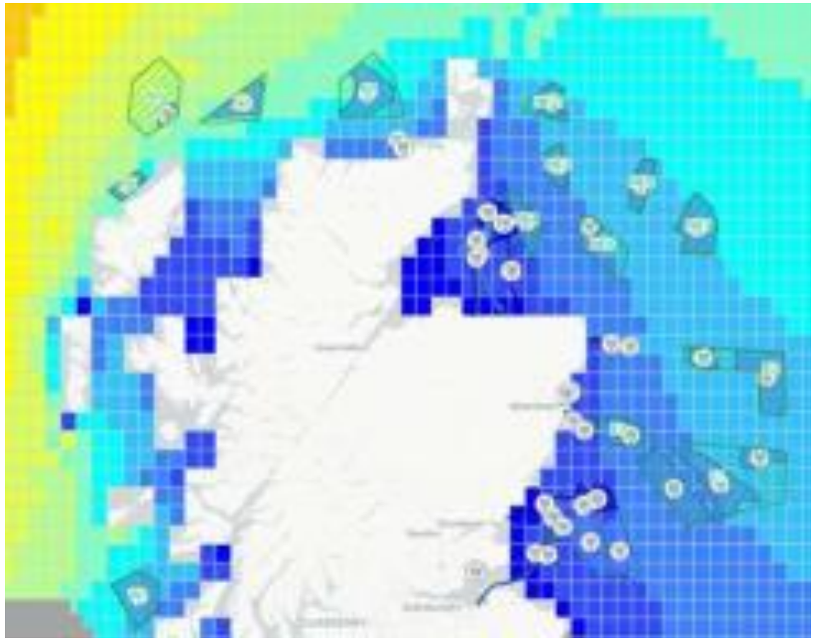
- Project motivations
- Design choices
  - Platform
  - WEC
  - Mooring
- Modelling
  - Physical modelling
  - Numerical modelling
- Initial testing
- Summary and future work



WES

Project motivations

- Growth potential of the floating offshore wind sector
- Synergies with between floating wind and wave energy
  - Floating wind sites are also attractive for wave deployment
  - FOW platform manufacturers could also manufacture WEC hosting platforms.
- Opportunities for cost reduction to floating wind and wave energy
  - Study undertaken by Offshore Wind Consultants (OWC)
  - LCOE reduction of <40% for wave and <10% for wind
- Opportunities from deploying multiple WECs on a single platform
  - Sharing of systems between WECs
  - Support for at-sea maintenance and deployment/retrieval of multiple WECs
  - Shared moorings and electrical connection
- How attractive is the performance of a closely packed array of WECs on a platform?



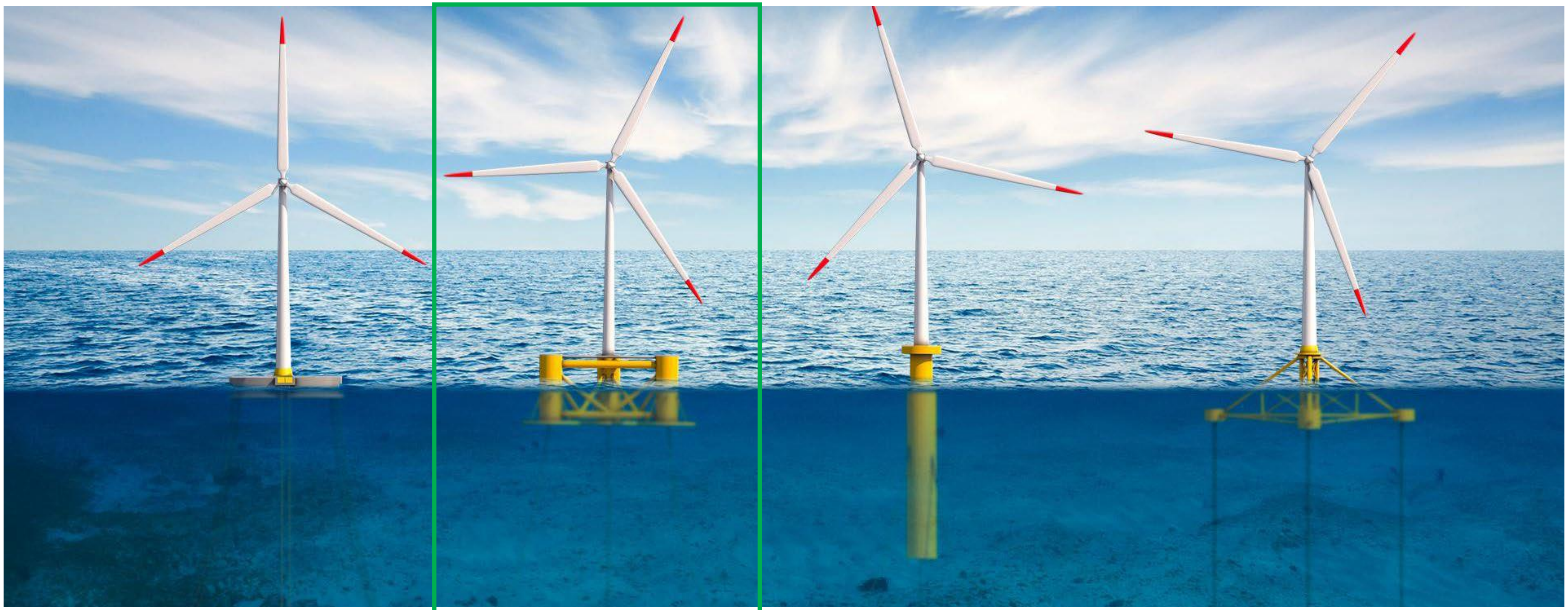
WES

Project set up

- Collaboration between

- Physical modelling completed at FloWave
  - WEC devices built in-house at FloWave
  - Platform fabricated at Deevek
  - Control hardware from Sequentec
- Numerical modelling completed by the University of Edinburgh

Design – FOW platform choice



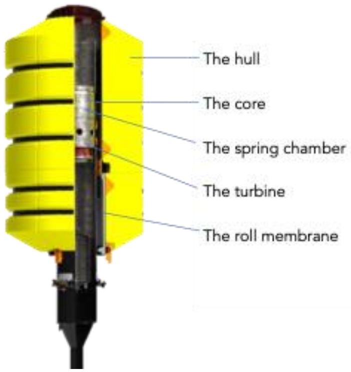
Barge | Semi-sub | Spar | TLP

Design – WEC Choice

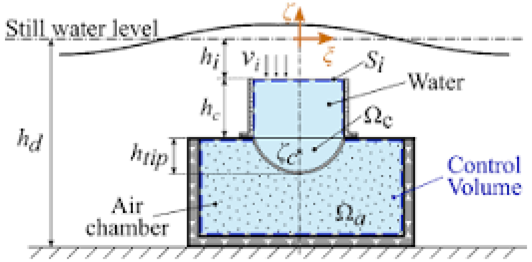
- Pressure Differential WEC selected as the WEC-type
  - Suitability for multi-absorber deployment on a platform
  - Simple implementation
  - Current activity in developing this type of WEC

- Open to other WECs being tested using existing platform and tools in the future

Waveswing
AWS Ocean Energy
(WES – NWEC Stages 1, 2 and 3)



Symphony Wave Power
Teamwork Technology

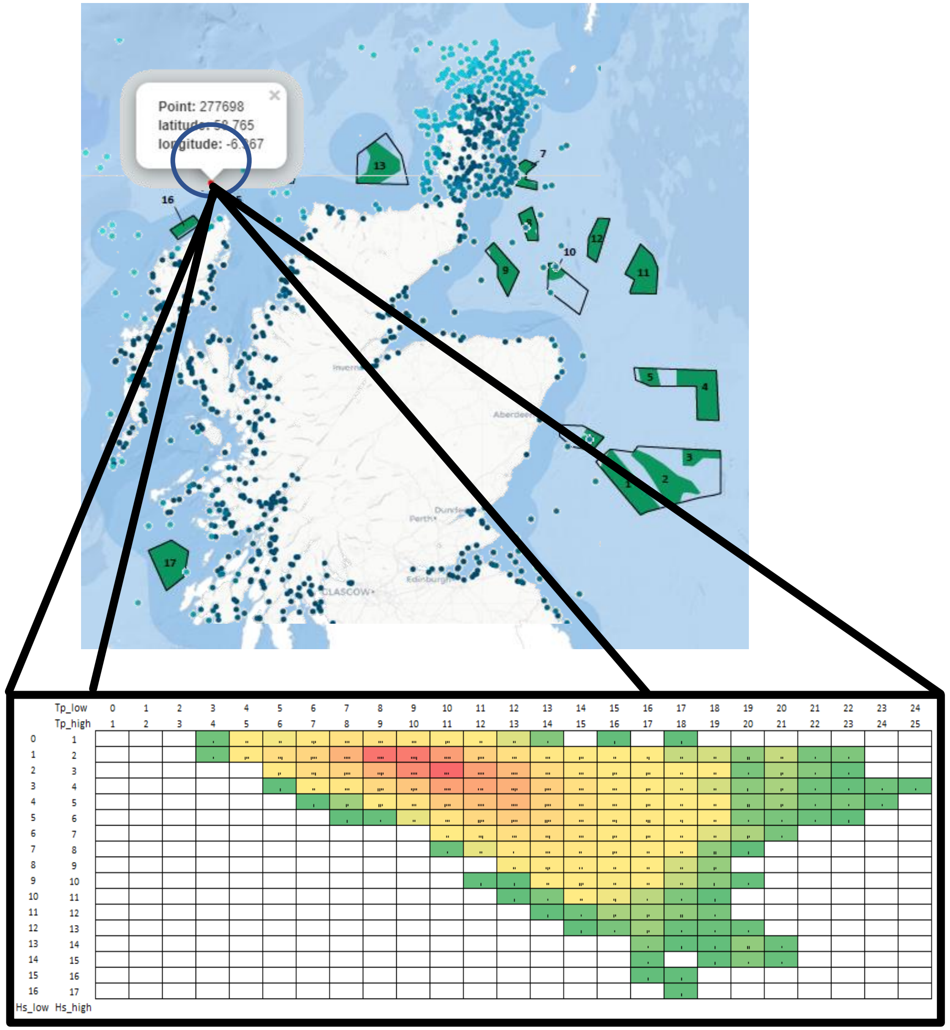


DEG WEC
Scuola Sant’Anna Pisa
(WES – PTO Stages 1 and 2)

Physical Modelling – Conditions

- Reference site = ScotWind N15 (Magnora)
- Wave data obtained from ResourceCode

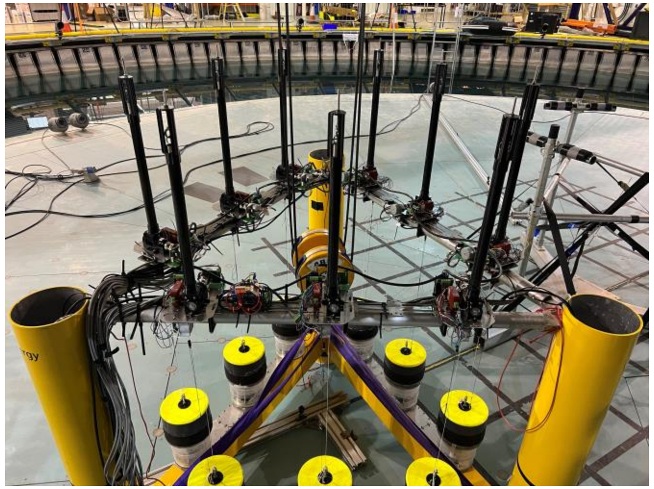
- Tank testing conditions maintaining compliance with IEC 62600-103
  - Sweeps of 10x frequencies at constant amplitude
  - 10x long-crested, P-M sea states identified to represent resource
  - Short-crested seas with more realistic wave spectra may be used in the future

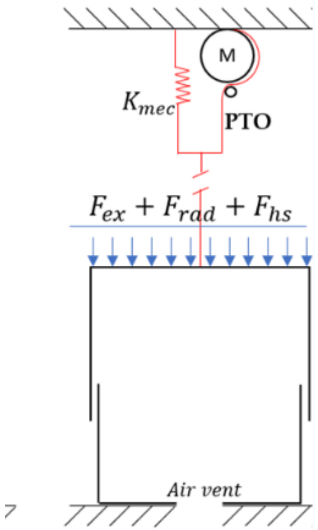


Physical Modelling – Model design

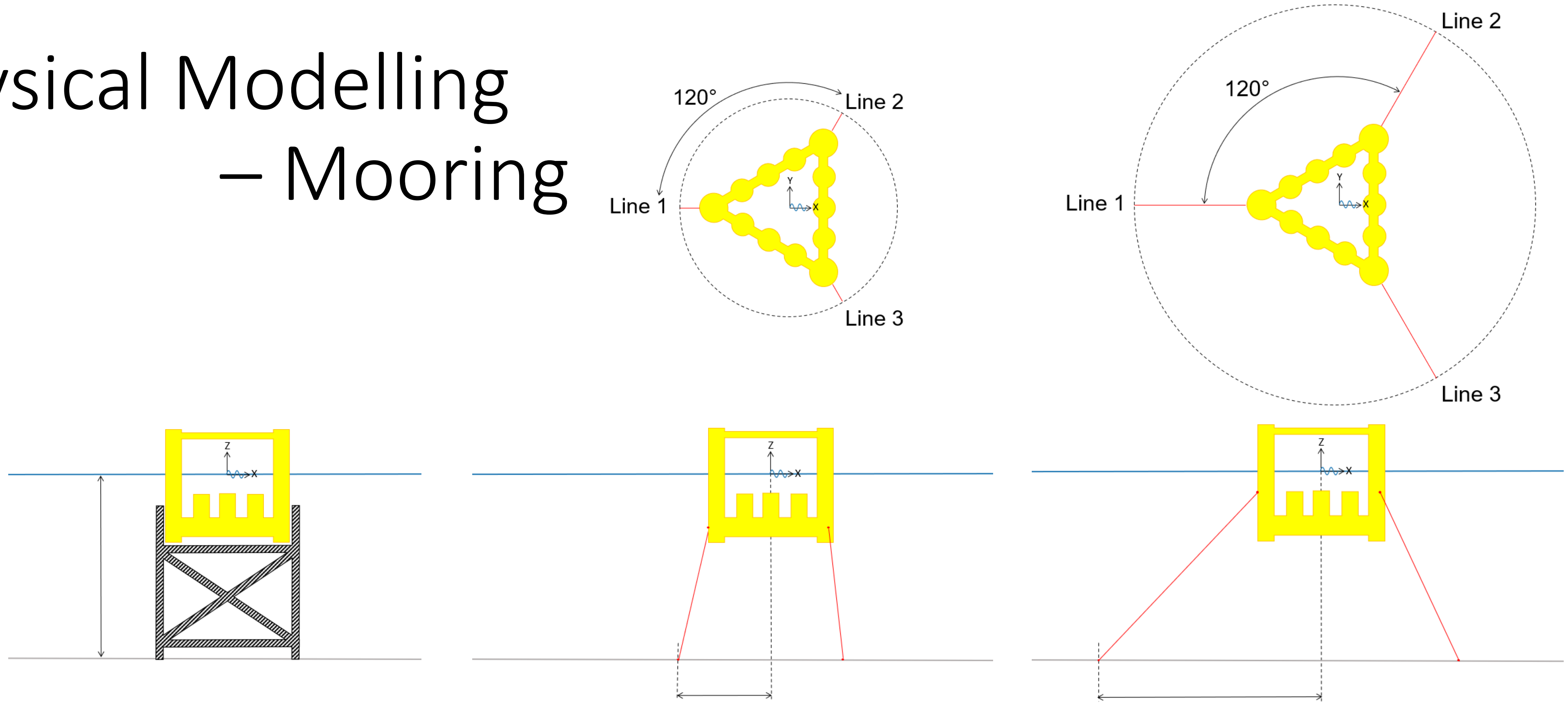
- Model notionally 1:50
  - Tank depth
  - Model handling

- Challenge of modelling PTO
  - Air does not Froude scale
  - Scaled air spring usually involves air compensation volumes => Challenging to implement for multiple absorbers on a moving platform
  - Instead, use mechanical springs to model functionality of air spring response



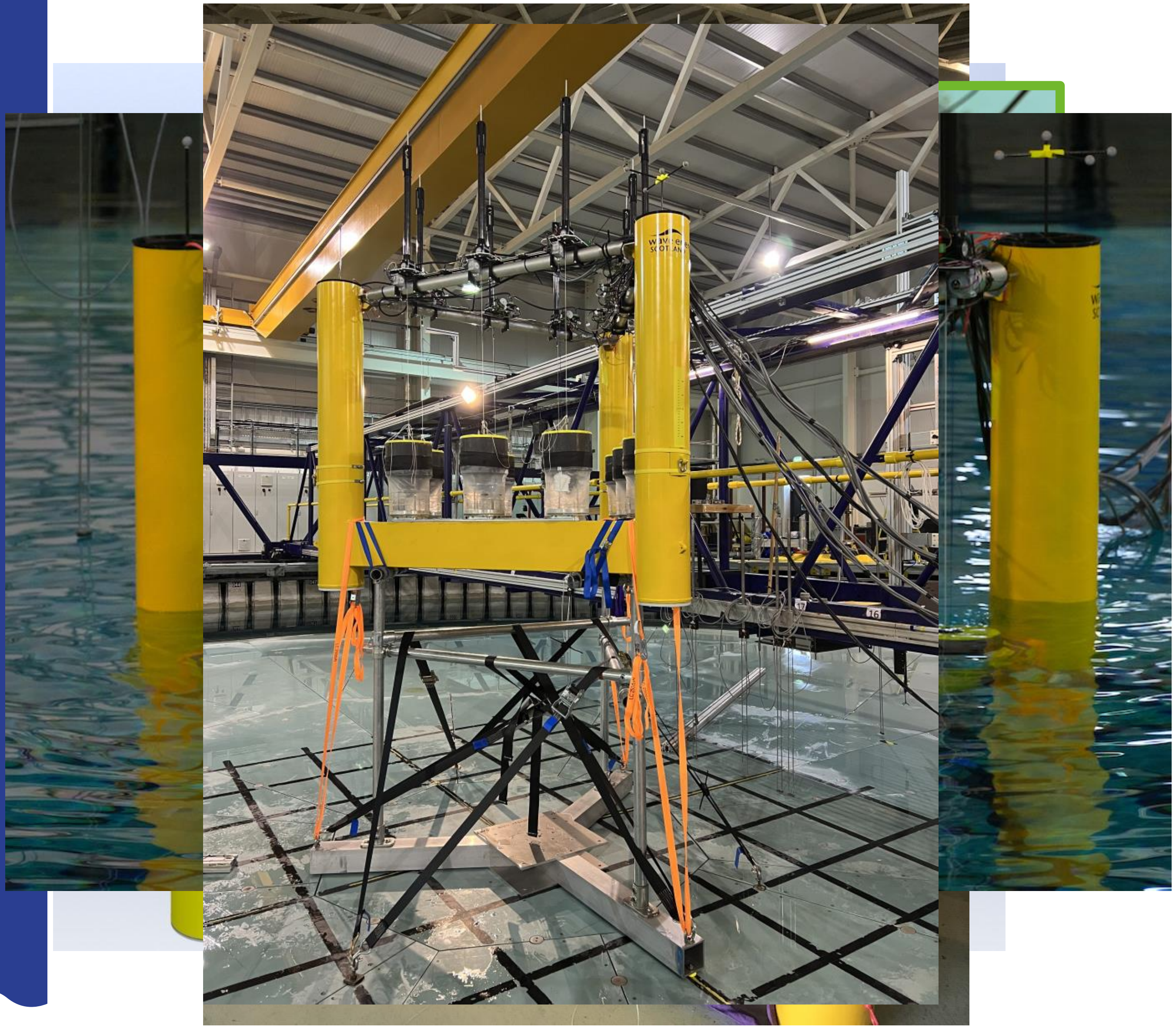


Physical Modelling – Mooring



- Mooring design using ORCAFLEX
- Initial validation of mooring simulations carried out using platform with locked WECs in survival sea states

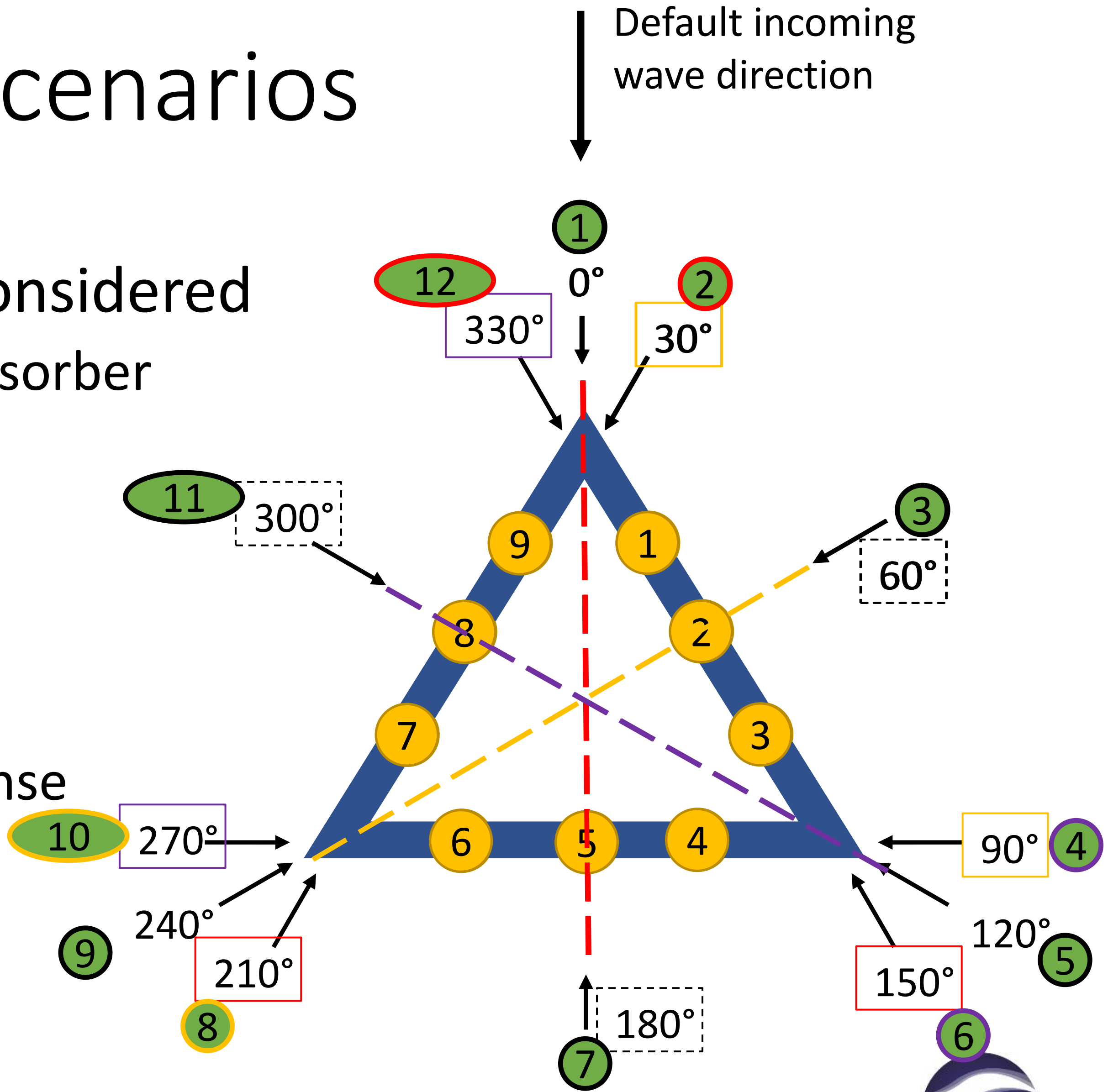
Physical Modelling – Model design



- Platform designed to allow variable number of absorbers per side
- WEC and column have same Ø
- 3x WECs per side gives 2Ø spacing
- PTO components mounted on upper beam, above splash zone

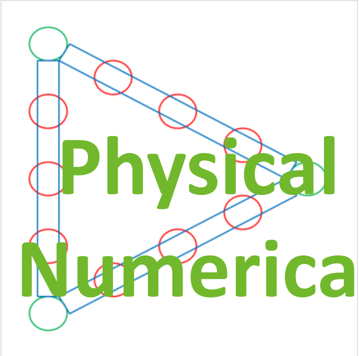
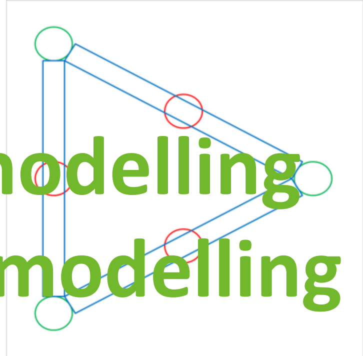
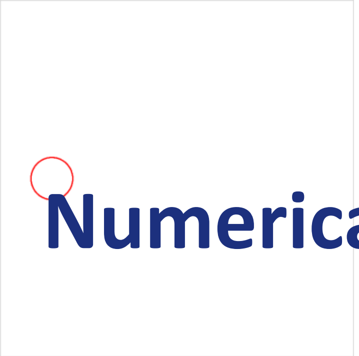
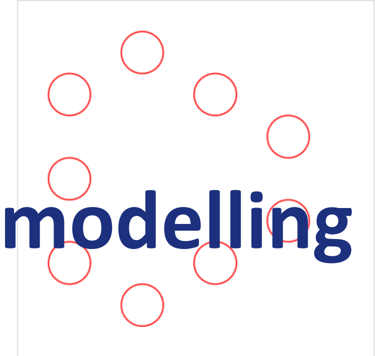
Physical Modelling – Test scenarios

- 12x incident angles at full 360°sweep considered
  - Confirm symmetry and predictability of absorber behaviour
  - Focus on 3x unique angles in future
- Vary PTO settings
  - Determine influence of damping on response



Numerical Modelling

- Focus on frequency domain currently
- CAD -> WAMIT -> Matlab
- Model validation against physical modelling outputs
- Four primary cases initially considered to compare…

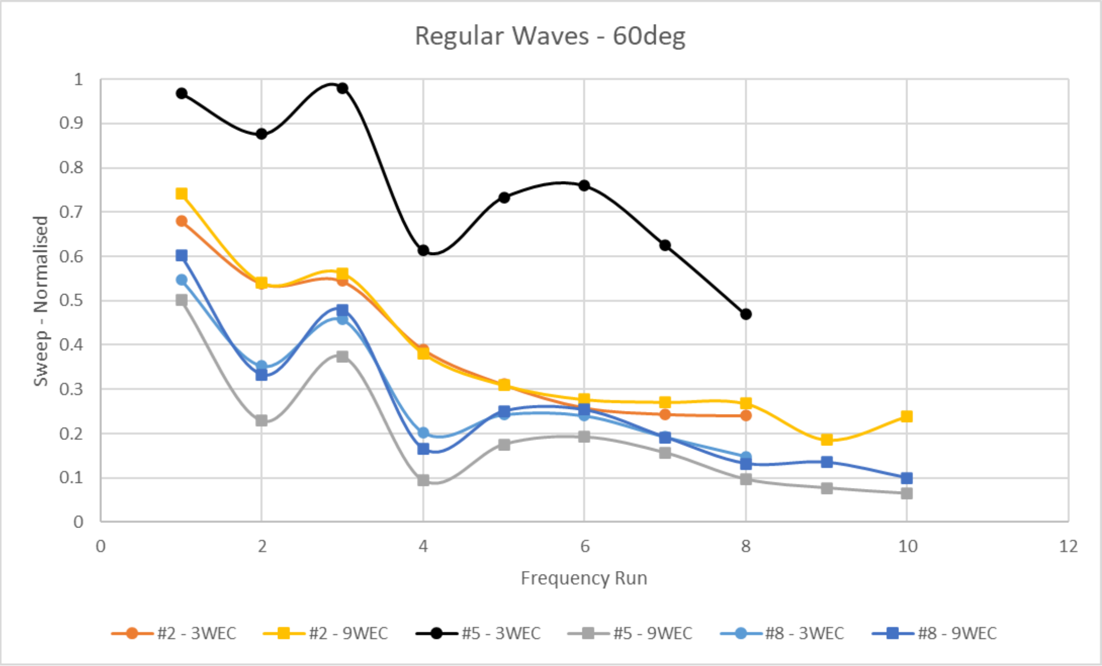
MWAP Case 1	MWAP Case 2	Single Absorber Baseline	Smaller Array Baseline
			
• Fully fixed/Taut Compliant/TLP platform mooring	• Fully fixed/Taut Compliant/TLP mooring	• Inextensible tether mooring • With/without pitch and roll	• Inextensible tether mooring • With/without pitch and roll • Absorber position as MWAP Case 1

Physical modelling
Numerical modelling

Numerical modelling

Initial observations

- Absorber behaviour appears to change little with varying angle
- Little interaction between absorbers
  - 9x absorber behaviour appears comparable to 3x absorber behaviour
- Columns appear to have greater effect on behaviour than neighbouring absorbers
  - Absorbers sheltered behind column generally perform less well than those furthest from column



Future Work

- More tank testing scheduled for Autumn/Winter 2023
  - Further characterisation
  - Model validation
  - Focus on conditions of interest
- Numerical model validation
- Continued numerical modelling
  - Comparison of MWAP systems with baseline systems
  - Consideration of MWAP control strategies amenable to Frequency Domain modelling
  - Time Domain model development
- PhD – Thomas Giles has started a PhD jointly supervised by FloWave and WES
- EWTEC 2023 paper
- Engagement with floating offshore wind stakeholders

Thank you!

16th November 2023

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WES

Session Four: Steps to success

Case study: Renewables for Subsea Power (RSP) project

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Wave Energy Scotland Conference – Edinburgh
16th November 2023

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How do we go from electrons ...

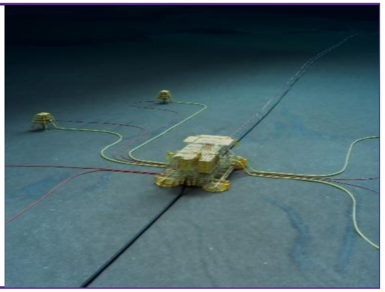
... to solutions ?

The challenge

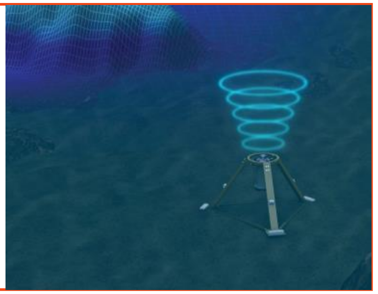
Decarbonisation, electrification & economics

Long cable offsets

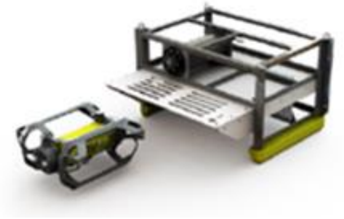
Umbilical remediation



CCS & leak detection



Subsea vehicle residency



Marine awareness

Asset decom_ missioning

Wave energy = ENABLER

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Renewables for Subsea Power

RSP is a **Net Zero Technology Centre flagship project:**

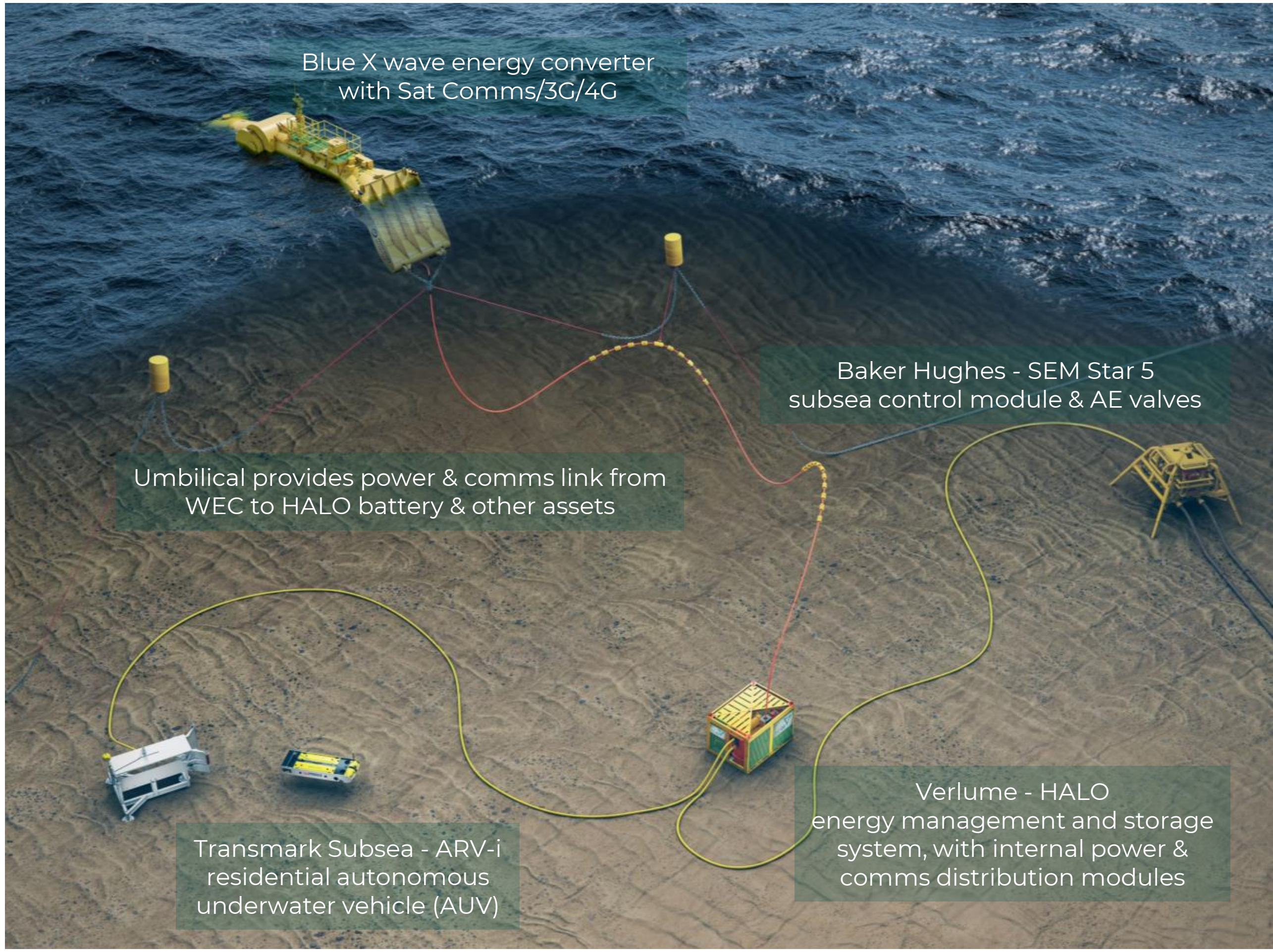
- **"First-of-a-kind" commercial full-scale system** to provide renewable power & communications offshore
- Demonstrates cross-industry collaboration and Net Zero alignment between developers, integrators & operators

8 months 'on the clock', aiming for >12-month deployment

- Qualification to an overall **system TRL 6-7 (API scale):** *actual system completed & qualified via test and demo*

AIMS:

1. Boost industry confidence in the proposed solution
2. Pave the way to **wider carbon mitigation** via systems scalable in size and number across off-grid applications



Net Zero Technology Centre – Technology Driving Transition | Harbour Energy | SERICA ENERGY | PTTEP | Baker Hughes | mocean energy | verlume | Transmark Subsea

RSP Highlights

Commercial traction

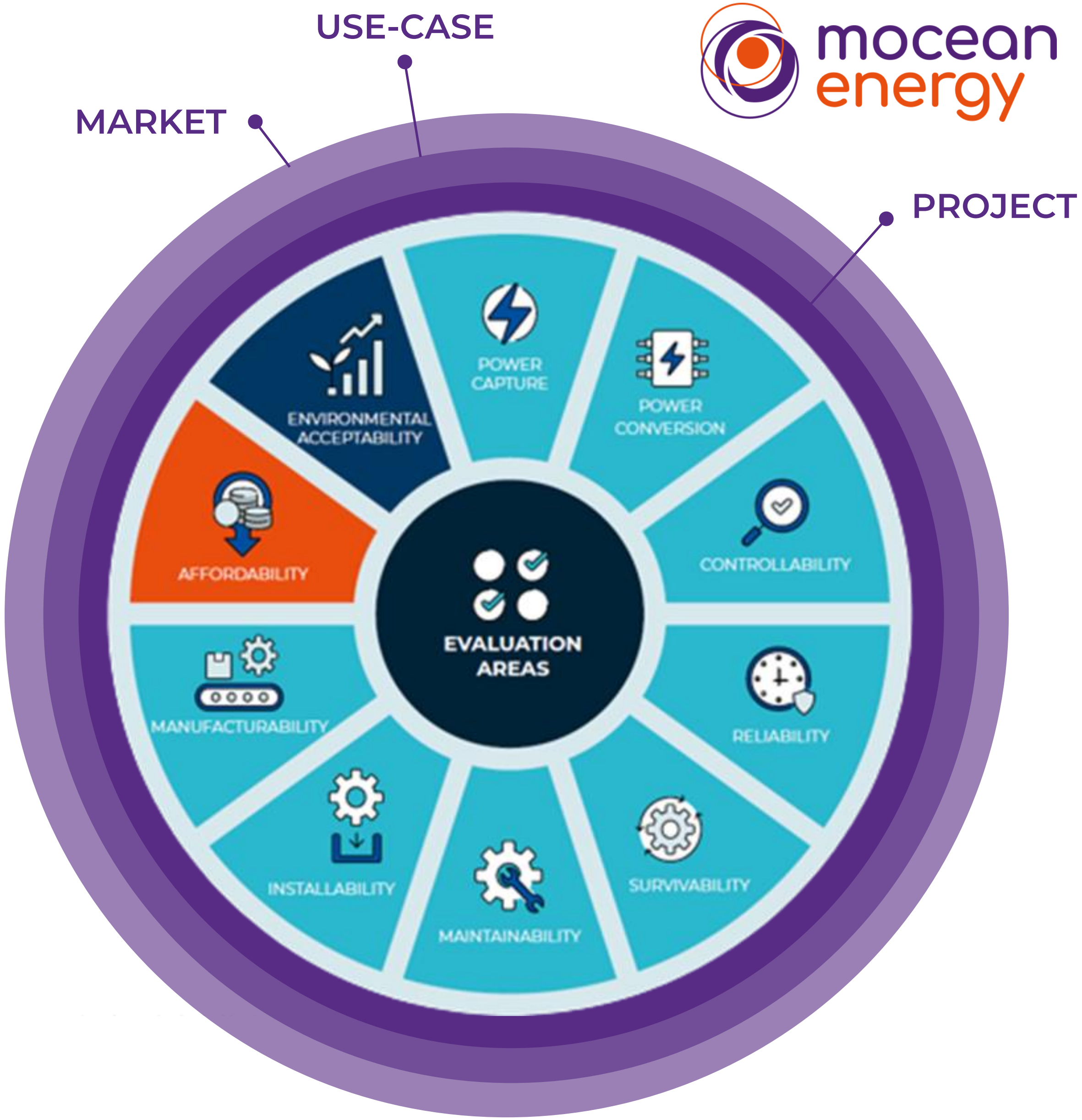
Credibility depends on robust demonstration of success in each of the IEA-OES metrics.

AFFORDABILITY

- Increase performance, decrease CAPEX & OPEX
- Adding **value** – this depends on the market:
  e.g. uninterrupted year-round power provision with minimal drop-outs & appropriate redundancy levels
- Societal cost of carbon?

ENVIRONMENTAL ACCEPTABILITY

- Life Cycle Analysis
- 5-month monitoring program at Scapa Flow – no harm; positive marine impacts measured in BlueX deployment
- Dedicated env. interactions workstream as part of EuropeWave project for Blue Horizon development & future arrays



Evaluation Areas included in the Evaluation and Guidance Framework.

Streamlining commercial deployments

It all started with innovation funding!

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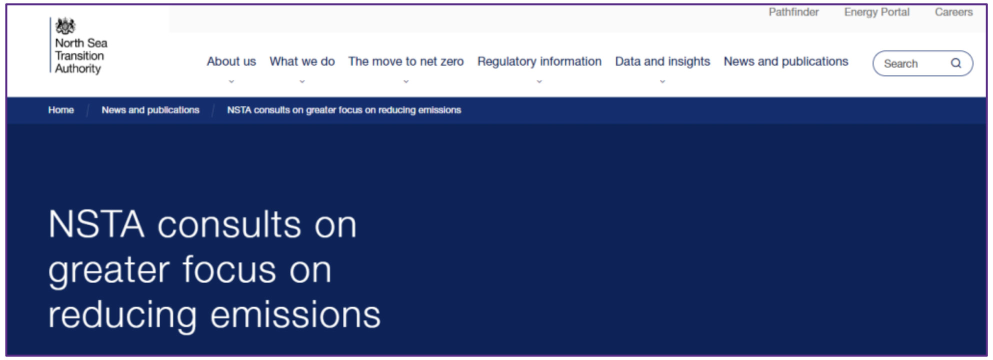
Next steps – Rollout

Build on market pull (bottom up):

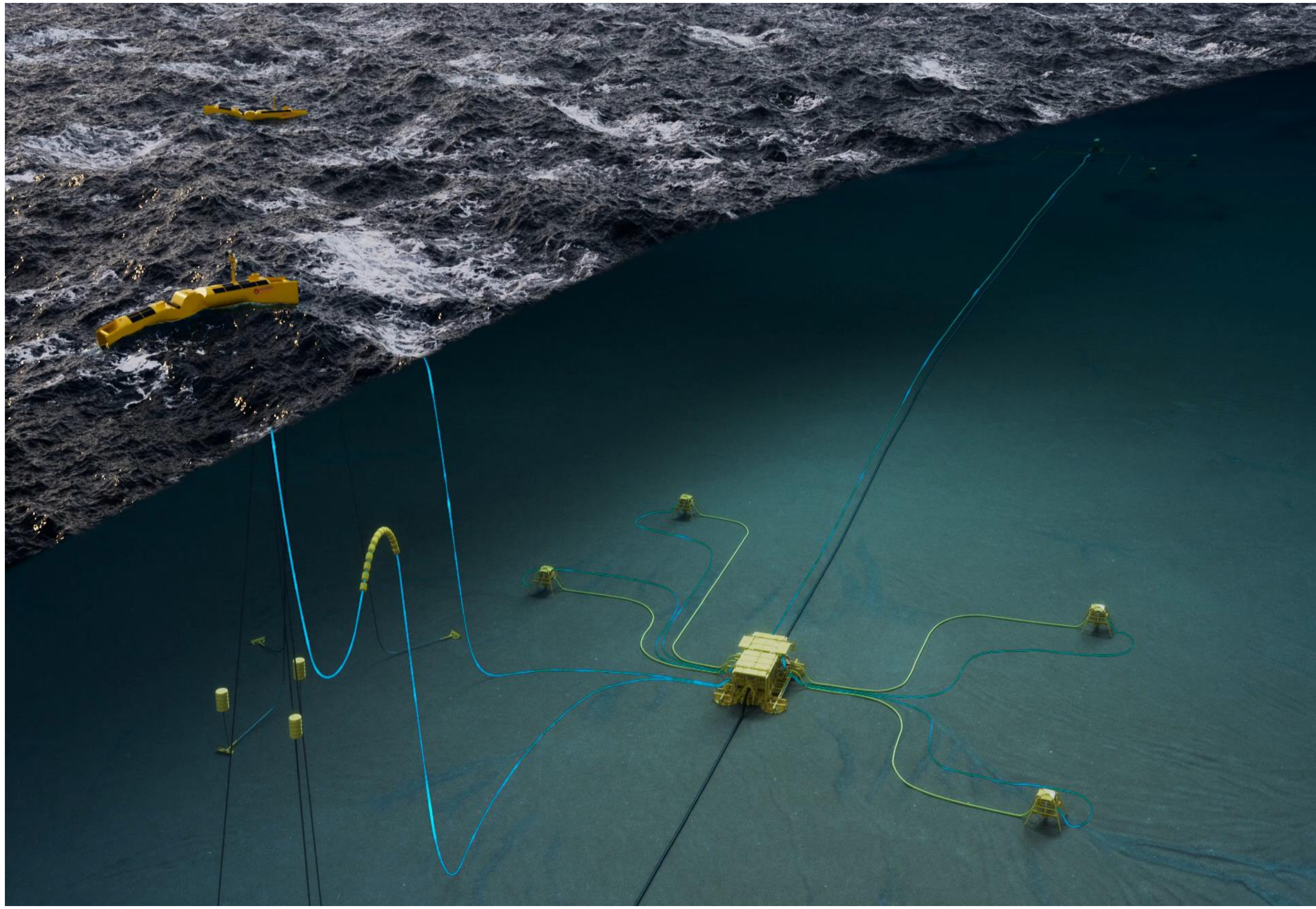
- Extension of RSP beyond 12 months
- Moving system to an operator site
- Near-term commercial WEC sale

Ensure we address policy push (top down):

- NSTA Nov '23 consultation includes query on: *Platform electrification and low carbon power*
- Sets 2030 conditions for North Sea O&G licenses



https://www.nstauthority.co.uk/news-publications/nsta-consults-on-greater-focus-on-reducing-emissions



A typical RSP-type islanded renewable energy system powered by wave energy (Courtesy of Baker Hughes).

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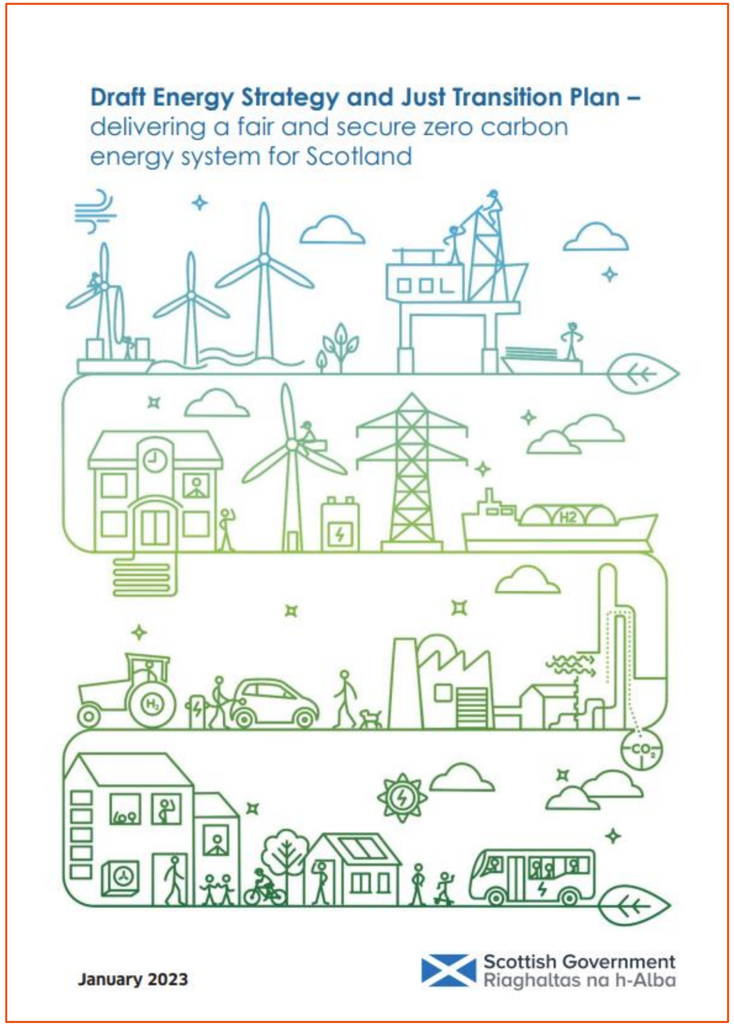
Next steps – Scaling up

Larger scale decarbonisation opportunities:

- **Mocean awarded £3.2m via EuropeWave** to build, deploy & test FOAK Blue Horizon 250kW WEC:
  - Demonstrate grid-connected electricity at EMEC Billia Croo
  - Targeting TRL7 (1-9 scale) by 2026
- **Adopt and adapt RSP model to Blue Horizon program**
  - Seeking industry partners to financially support & participate in development program
- **Policy seascape will be crucial to enable scale-up & continuity:**
  - WES support instrumental in enabling Blue X & RSP
  - Gaps exist – e.g. innovation funding for array demonstrations (links to ESJTP 2023)

We are at a crucial juncture for the sector.
Let's keep building on this growing momentum!



Draft Scottish Gov. Energy Strategy & Just Transition Plan, ESJTP (2023).

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10 years

- 200 ocean technology projects enabled
- 20 communities empowered by ocean energy
- Flagship wind wave farms
- Mitigate 200,000 TCO2 per year

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