ACOWE
Australian Centre for Offshore Wind Energy

ACOWE Technical Symposium 2026

Proceedings

20 August 2026
Federation University Australia, Churchill Campus, Victoria

Preface

Offshore wind plays a critical role in Australia's energy transition. As the sector continues to evolve, collaboration and knowledge exchange remain essential to building a sustainable and globally competitive industry.

The Australian Centre for Offshore Wind Energy (ACOWE) brings together researchers, industry, government and community stakeholders to advance the knowledge, capability and workforce needed to support Australia's emerging offshore wind sector. Reflecting ACOWE's Mission, Vision and Values, the proceedings showcase the breadth of research and innovation being undertaken across the offshore wind lifecycle.

Our Mission:

ACOWE will deliver evidence-based solutions and a new, skilled workforce to enable sustainable offshore wind development for the benefit of Australia.

Our Vision:

ACOWE will be the foremost research and training pathway for offshore wind energy and contribute positively to the decarbonisation of Australia.

Our Values:

ACOWE will ensure that Australian offshore wind development is pursued in an equitable, inclusive, socially, culturally and environmentally responsible manner.

Building on the success of the inaugural ACOWE Technical Symposium in 2025, the 2026 symposium, *Delivering the Offshore Wind Lifecycle in Australia*, brought together researchers, industry, government and other key stakeholders to share insights and foster collaborations.

Organised in collaboration with the Gippsland New Energy Conference 2026 (GNEC26), the event commenced with a welcome reception at the Morwell Innovation Centre on 19 August 2026. The symposium was then held at Federation University's Churchill Campus on 20 August, featuring five keynote presentations, five themed sessions, panel discussions, and a student poster showcase. Adopting a whole-of-lifecycle perspective, the programme spanned across planning, design and construction, operations, maintenance and decommissioning, concluding with a panel discussion on Australia's offshore wind legacy and future directions.

We thank all contributors, presenters, and participants whose insights and engagement made the 2026 ACOWE Technical Symposium a success. As offshore wind development continues to evolve, ACOWE will continue to serve as a trusted platform dedicated to research and innovation across all stages of offshore wind development.

Acknowledgements

The ACOWE Steering Committee thanks the Gippsland Climate Change Network (GCCN) for their invitation to participate in the Gippsland New Energy Conference (GNEC) through the delivery of the ACOWE Technical Symposium 2026.

We are grateful for the support provided by the GNEC Organising Committee and the opportunity to provide a platform for researchers and key stakeholders to share knowledge.

We acknowledge ACOWE university partner Federation University who hosted the Welcome Event at the Morwell Innovation Centre and Symposium at their Churchill campus in addition to providing event management expertise.

ACOWE Technical Symposium Committee

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Professor Andrew O'Loughlin, Federation University
Professor Ty Christopher, University of Wollongong

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Keynote Speakers

Professor Britta Bienen

Professor of Geotechnical Engineering, University of Western Australia

Britta Bienen is a Professor of offshore geotechnical engineering at the University of Western Australia. With more than a decade of experience in offshore wind, her research focuses on foundation and anchoring solutions. Britta has delivered keynotes at major international conferences, co-authored by colleagues from industry. This includes the recent state-of-the-art lecture on geotechnics for offshore wind developments. Britta is also actively involved in the development of international guidelines and has brought the public engagement initiative OffshoreWind4Kids to Australia.

Dr Chris Gillies

Chief Executive Officer, Offshore Biotechnologies

Dr Chris Gillies is the CEO of Offshore Biotechnologies, a Gippsland-based nature technology company that develops practical solutions to integrate marine development and environmental outcomes. He is also a Director of SeaGen Aquaculture, a marine bioproducts company producing shellfish, seaweeds and marine invertebrates for aquaculture, restoration and biotechnology applications. Chris has authored more than 50 scientific publications, is an Honorary Associate Professor at James Cook University, and serves as a Director of Seafood Industry Victoria. His work focuses on creating practical, scalable solutions that deliver benefits for both nature and industry.

Lauren Little

Senior Stakeholder Advisor, Ørsted, UK

Growing up amongst the fishing docks and heavy industry in the town of Grimsby in the UK's Humber region, Lauren Little has spent much of her career focused on supporting the region's transition to the largest offshore wind operations and maintenance port in the world. For the past eight years, this has focussed on leveraging offshore wind to deliver lasting social and economic benefit to local communities. Working with local government, political representatives, businesses, membership organisations, education and skills providers, and the next generation has been central to the success of Lauren's work.

Alistair Parker

Chief Executive Officer, VicGrid

Alistair is the CEO of VicGrid, leading the planning and development of Victorian Renewable Energy Zones. He has over 35 years' experience in the energy industry, including a decade of executive leadership roles at AusNet Services in Victoria and the Power and Water Corporation in the Northern Territory. Alistair's early career in the UK comprised 15 years with National Grid, as an engineer and in commercial roles. He was then a consultant with Ernst & Young in New Zealand and PricewaterhouseCoopers in Australia.

Professor Irene Penesis

Research Director, Blue Economy CRC

Professor Irene Penesis is Research Director of the Blue Economy CRC, providing strategic leadership across research, innovation and industry collaboration. She drives initiatives advancing offshore renewable energy, sustainable seafood production and integrated ocean use, building capability and partnerships to support the sustainable growth and global competitiveness of Australia's blue economy.

Programme

WEDNESDAY, 19 AUGUST 2026	
5:30 - 7:30 PM	**Welcome Reception** *A/Professor Shiaohuey Chow, Director of ACOWE* *Professor Andrew O'Loughlin, Federation University* *Stephanie Sabrinskas, Gippsland Climate Change Network*
THURSDAY, 20 AUGUST 2026	
8:00 - 8:30 AM	**Registration**
8:30 - 8:50 AM	**Welcome to Symposium** | *A/Professor Shiaohuey Chow, Director of ACOWE* **Welcome to Country** **Opening Address** | *Professor Iven Mareels, Federation University*
Session 1 | Planning Part 1 **Session Chair** | *Professor Andrew O'Loughlin, Federation University*	
8:50 - 9:10 AM	**Keynote | The Power of Partnerships: How Collaboration Can Solve the Energy Transition's Biggest Challenges** *Alistair Parker, Chief Executive Officer, VicGrid*
9:10 - 9:20 AM	**Not Just for and Against: A Multidisciplinary Approach to Unpacking the Complexity of Stakeholders' Attitudes to Offshore Wind Developments** *A/Professor Michelle Voyer, University of Wollongong*
9:20 - 9:30 AM	**Environmental Monitoring of Offshore Wind Projects: A Whole Life Cycle Approach** *Dr Daniel Machado, Iberdrola*
9:30 - 9:40 AM	**Outcomes and Reflections from the Geomorphology and Benthic Characterisation RERI Projects** *Aero Leplastier, Geoscience Australia*
9:40 - 10:00 AM	**Q&A Session and Discussion**
10:00 - 10:30 AM	**Morning Tea**
Session 2 | Planning Part 2 **Session Chair** | *A/Professor Michelle Voyer, University of Wollongong*	
10:30 - 10:50 AM	**Keynote | UK Case Study: Driving Long-Term Commitment and Local Benefit Through Offshore Wind Clusters** *Lauren Little, Senior Stakeholder Advisor, Ørsted, UK*
10:50 - 11:00 AM	**What Does It Mean To Be a Good Host? Preparedness of the Yarram Community for Offshore Wind** *A/Professor Jessica Reeves, Federation University*
11:00 - 11:10 AM	**Refined Offshore Wind Farm Collision Risk for Albatrosses and Petrels** *Professor Rohan Clarke, Monash University*
11:10 - 11:20 AM	**The Application of Underwater Acoustics for Offshore Wind: from Impact Assessment to Construction** *Craig McPherson, JASCO*
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11:40 - 11:50 AM	**Student Showcase** Alexander Fejer, University of New South Wales and BMT | Alireza Asgari Motlagh, University of Wollongong | Amin Ghotbi, Royal Melbourne Institute of Technology *Dilan Weerasooriya, Royal Melbourne Institute of Technology | Qinming Qu, University of Western Australia | Reza Khodayari, University of Melbourne* Shane Richardson, Murdoch University | Yuze Yan, Adelaide University
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1:20 - 1:30 PM	**Whole Life Risk-based Design for Subsea Cables - Where Early Design Decisions Can Provide Benefit** *Dr Jack Jorgensen, Aurora Offshore Engineering*
1:30 - 1:40 PM	**Holistic Economical Offshore Wind Turbine Solution for Australia** *Dr Massoud Sofi, University of Melbourne*
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2:00 - 2:30 PM	**Afternoon Tea**
Session 4 | Operation, Maintenance and Decommissioning **Session Chair** | *Professor Ty Christopher, University of Wollongong*	
2:30 - 2:50 PM	**Keynote | Ecological Science as a Core Design Discipline: Integrating Nature Across the Lifecycle of Offshore Wind** *Dr Chris Gillies, Chief Executive Officer, Offshore Biotechnologies*
2:50 - 3:00 PM	**Application of Concrete Mattresses in Offshore Wind Projects** *Dr Bingchang Zhang, University of Western Australia*
3:00 - 3:10 PM	**Illawarra Clean Energy Roadmap: Workforce and Circular Economy** *Dr Makrita Solitei, University of Wollongong*
3:10 - 3:30 PM	**Q&A Session and Discussion**
Session 5 | Next Steps **Session Chair** | *A/Professor Shiaohuey Chow, University of Melbourne*	
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3:50 - 4:20 PM	**Closing Panel Discussion | Begin with the End in Mind: Designing Australia's Offshore Wind Legacy** **Moderator** | *A/Professor Shiaohuey Chow, University of Melbourne* **Panelists** | *Professor Britta Bienen, University of Western Australia | Dr Chris Gillies, Chief Executive Officer, Offshore Biotechnologies* *Professor Irene Penesis, Research Director, Blue Economy CRC | Michael Skeeles, Senior Associate, Star of the South*
4:20 - 4:30 PM	**Closing** | *Dr Jana Orszaghova, ACOWE Technical Symposium Chair, University of Western Australia and Blue Economy CRC*

Application of Concrete Mattresses in Offshore Wind Projects

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Keywords: monopile; subsea power cables; scour; scour protection; concrete mattresses

1. INTRODUCTION

Concrete mattresses are widely used in the offshore industry as a practical and robust solution for pipeline and cable protection [1]. They typically consist of interconnected concrete blocks linked by synthetic ropes, allowing the mattress to conform to uneven seabed profiles while providing sufficient weight and coverage to resist hydrodynamic loading from waves and currents. Their modular form, proven offshore installation feasibility, and ability to provide immediate protection make them valuable solutions for secondary stabilisation and scour protection in offshore wind projects.

It is critically important to understand the stability of concrete mattresses in subsea environments. The stability design of subsea concrete mattresses is commonly based on a force-balance approach that compares the hydrodynamic actions imposed by waves and currents with the available stabilising resistance of the mattress [2]. The hydrodynamic force coefficients of subsea concrete mattresses are controlled by a combination of flow conditions, mattress geometry, seabed interaction and installation configuration. The main coefficients required for stability design are the drag coefficient (C_D), lift coefficient (C_L) and inertia coefficient (C_M). Unlike simple structural elements such as circular cylinders, concrete mattresses have complex block geometry, surface roughness, gaps between blocks and a semi-flexible articulated form. Therefore, their force coefficients are unlikely to be constant values and should instead be treated as functions of multiple governing parameters.

The first group of control parameters is related to the hydrodynamic conditions. These include near-bed flow velocity, wave orbital velocity, flow acceleration, turbulence intensity and boundary-layer thickness. In non-dimensional form, the key parameters include Reynolds number, Keulegan-Carpenter number, wave-current velocity ratio, relative boundary-layer thickness and flow orientation. The second group of parameters is related to mattress geometry. These include mattress thickness, block size and shape, surface roughness, gap width between blocks, porosity, edge shape, plan area, aspect ratio, and the flexibility of the connecting ropes or cables. The projected area used in the definition of force coefficients is also important and must be clearly defined. For example, the drag coefficient may depend on whether the projected area is taken as the gross mattress area, the frontal block area, or an effective hydraulic area that accounts for openings between blocks. Similarly, the lift coefficient can be strongly influenced by pressure differences generated across the mattress, flow separation at the leading edge, and flow passing through or around the mattress blocks. The third group of parameters is associated with seabed contact and embedment. These include seabed sediment type, interface roughness, mattress embedment depth, local scour development, seabed slope, mattress settlement, and the presence of gaps between the mattress and seabed. A mattress lying flat on a smooth rigid bed may experience very different forces from one that is partially embedded in sand or placed over an uneven seabed. Embedment and sediment infill can reduce exposure to flow and increase stability, while local scour at the mattress edge can increase uplift and sliding risk. Therefore, force coefficients should not be measured or applied without considering seabed conditions. Several studies have reported on the stability design of concrete mattresses [1-8], but the available knowledge remains insufficient for reliable design across the wide range of applications encountered in offshore engineering.

2. APPROACH

In this work, we report a systematic research program aimed at improving understanding of the hydrodynamic force coefficients acting on concrete mattresses using both physical model testing and numerical simulations.

First, hydrodynamic force coefficients will be measured using physical models fitted with load cells for a range of mattress configurations. These tests will provide direct measurements of hydrodynamic drag and lift forces, which can then be converted into the force coefficients required for stability design. The second component of the research will focus on visualising the flow field around concrete mattresses using computational fluid dynamics. The numerical tool will provide an opportunity to examine the complex flow structures and understand the fundamental mechanisms that govern mattress stability. The third component will examine the interaction between concrete mattresses and an erodible seabed. This is also an important consideration when designing concrete mattresses for offshore engineering applications. Concrete mattresses may induce local scour, sediment accumulation, sinking and self-burial, or free-spanning over pipelines or other subsea structures. These studies will support feasibility assessment for applying concrete mattresses in the Australian offshore wind industry.

3. DISCUSSION

Based on the Star of the South coastal processes and sediment transport report [9], there is credible potential for scour and seabed mobility around both subsea cables and monopile foundations. The offshore wind farm area is located in a relatively shallow continental shelf environment, with seabed depths ranging from approximately 15 to 53 m and an average depth of about 30 m. The seabed is mainly composed of gravelly sand, sand, shell-rich material and carbonate-dominated sediments. The presence of sand waves, particularly near the north-east corner of the offshore wind farm area in water depths of about 24-28 m, indicates locally mobile seabed conditions. These mobile sediments are important for scour assessment because they can be reworked by waves and currents, leading to local seabed lowering, cable exposure, or changes in burial depth over time.

The metocean conditions described in the report [9] further support the need for careful scour assessment. Tidal currents are generally directed parallel to the coast and are typically less than 0.5 m/s near the coast, although higher currents occur near embayment entrances. Wind-driven and storm-related currents are also relevant, and near-seabed conditions are reported to be sufficient to mobilise sediment for a large proportion of the time. The wave climate is also important: while ordinary significant wave heights are often moderate, Bass Strait is exposed to energetic storm waves and swell, and frequent wave disturbance is expected in the shallower parts of the offshore wind farm area.

For monopiles, local scour is expected to be a key design issue because the foundation obstructs near-bed flow and can generate horseshoe vortices, wake vortices and local sediment erosion. The report [9] recognises that bottom currents may cause scour around monopiles and jackets, and states that scour protection will be installed where required. Cables are planned to be buried where possible, but some sections may encounter hard or rocky seabed, cable crossings, or other conditions where burial is difficult. In these areas, concrete mattresses may be required for secondary stabilisation and protection.

The report [9] therefore indicates that concrete mattresses are likely to be relevant to addressing some of the engineering challenges in the Star of the South project. However, there is currently no widely adopted industry guideline specifically for the design of concrete mattresses in offshore wind applications. This is a challenge for industry, but it is also a valuable opportunity for research organisations, offshore industry and classification societies to work collaboratively to address the knowledge gap. Such collaboration would benefit the offshore wind industry in Australia and globally.

4. CONCLUSIONS

Concrete mattresses are already used in the offshore industry as scour protection and as a measure for secondary stabilisation, but there is currently no widely adopted industry guideline available for their design in offshore wind applications. Concrete mattresses could play an important role in addressing challenges such as scour and on-bottom stability in the Australian offshore wind industry. However, limited research constrains their effective application. Collaborative research is therefore needed to address these challenges, improve design reliability, and support the broader development of offshore wind in Australia and globally.

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Minimization of Environmental Risks of Offshore Wind Energy – Lessons from Mature Markets

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Keywords: Offshore wind energy; mitigation hierarchy; strategic biodiversity initiatives; standardized environmental monitoring

1. INTRODUCTION

Offshore wind energy is a cornerstone of the global energy transition and is expected to play a significant role in achieving climate neutrality targets in many countries. While offshore wind provides substantial environmental benefits through the replacement of fossil fuel-based electricity generation, concerns remain regarding its potential impacts on marine biodiversity. As offshore wind deployment accelerates globally, particularly in emerging markets such as Australia, there is increasing interest in identifying approaches that can effectively minimize environmental risks while maintaining project viability and meeting climate goals.

Environmental impacts associated with offshore wind developments are commonly addressed through the mitigation hierarchy, which prioritizes avoidance, minimization, restoration, and offsetting of impacts (Figure 1). However, the effectiveness of this approach depends heavily on decisions made during the earliest stages of project planning. This paper examines lessons from mature offshore wind markets, particularly Denmark and the United Kingdom, and explores how strategic initiatives can improve environmental outcomes beyond the requirements of conventional environmental legislation.

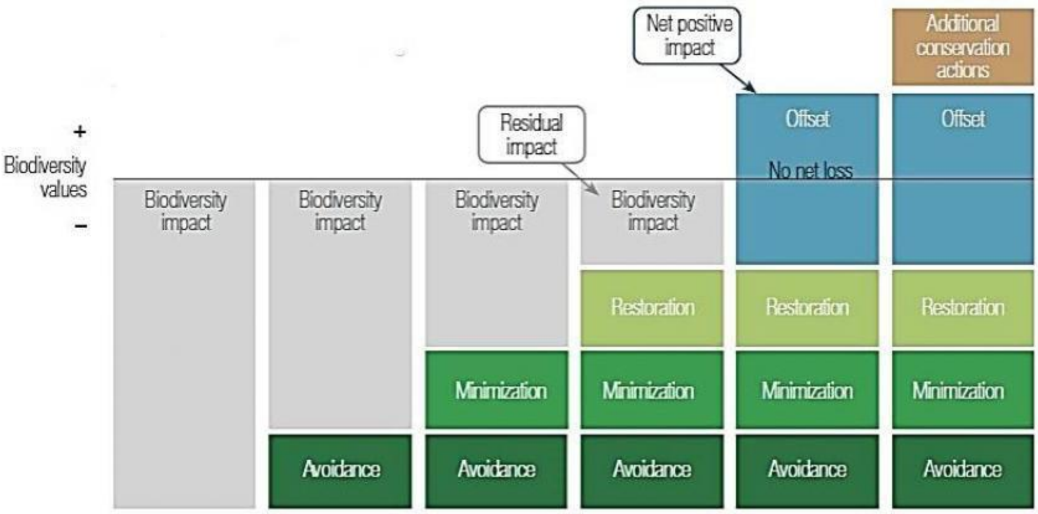

Figure 1 Mitigation hierarchy, adapted from UN Global Compact and IUCN[4]

2. BACKGROUND

In mature offshore wind markets, governments typically designate development zones through leasing or auction processes, a key phase to apply the first step of the mitigation hierarchy—avoidance. This places responsibility on governments to integrate environmental considerations into marine spatial planning and locate renewable energy zones away from biodiversity hotspots and other sensitive habitats.

While Environmental Impact Assessments (EIAs) remain essential for assessing construction and operational impacts, they generally occur after key planning decisions have been made. As a result, there is growing recognition that environmental risks should be assessed earlier in the planning process to improve impact avoidance and reduce project risk.

3. APPROACH

This study reviews environmental risk management approaches implemented in mature offshore wind markets and evaluates strategic initiatives that extend beyond traditional project-level environmental assessment requirements. Particular attention is given to government-led mechanisms that facilitate early identification of environmental risks, improve ecological knowledge, and support coordinated conservation outcomes.

The analysis focuses on three key areas:

1. Strategic environmental assessments and marine spatial planning.
2. Standardized biodiversity monitoring and environmental data sharing.
3. Regional approaches to biodiversity enhancement and marine restoration.

Examples from Denmark and the United Kingdom are given to showcase initiatives, that may support environmentally responsible offshore wind expansion in both mature and emerging markets.

4. DISCUSSION

Environmental risk minimization is most effective when integrated into the earliest stages of offshore wind planning. Strategic marine spatial planning enables governments to apply the avoidance principle before development zones are allocated by considering ecological sensitivities alongside technical and economic factors.

A recent Danish initiative illustrates this approach through sensitivity mapping of future offshore wind zones, covering birds, bats, marine mammals, fish, benthic habitats, and hydrodynamic conditions[2]. By identifying environmentally sensitive areas early, this approach supports more informed site selection and reduces uncertainty for developers and regulators.

Another key lesson from mature markets is the value of coordinated environmental monitoring. Denmark has established standardized monitoring requirements spanning baseline, construction, and operational phases, covering hydrography and sediment transport, water quality, marine litter, underwater noise, invasive species, marine mammals, fish, bats, birds, and benthic flora and fauna[1]. Monitoring data are submitted to a centralized national database, supporting cumulative impact assessment, long-term ecological research, and broader marine conservation objectives.

Early identification of environmental risks also provides project benefits by improving cost predictability and allowing mitigation measures to be incorporated into project design and financial planning. Environmental risk assessment therefore serves not only as a biodiversity protection measure but also as a project de-risking tool.

A further lesson concerns biodiversity enhancement and restoration. While compensation measures are often implemented at individual project level, ecosystem-scale initiatives generally provide greater ecological benefits. The United Kingdom's Marine Recovery Fund[3] demonstrates a strategic approach by coordinating regional conservation actions. Similar large-scale restoration initiatives, such as the Wilder Humber project and the Native Oyster Restoration Alliance, highlight the advantages of regional approaches over fragmented, project-specific measures.

5. CONCLUSIONS

Experience from mature offshore wind markets shows that minimizing environmental risks can benefit from approaches beyond traditional project-level environmental assessments. While Environmental Impact Assessments remain essential for evaluating construction and operational impacts, they should be regarded as the minimum requirement rather than the sole mechanism for environmental risk management.

More effective outcomes are achieved when planning authorities apply the mitigation hierarchy at a strategic level through marine spatial planning, sensitivity mapping, coordinated monitoring, and regional conservation initiatives. This enables the avoidance principle to be applied before development zones are allocated.

Lessons from Denmark and the United Kingdom highlight the importance of early risk identification, standardized monitoring, centralized data systems, and ecosystem-scale restoration. Together, these approaches improve biodiversity outcomes, reduce uncertainty, and support a more sustainable offshore wind development.

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Low Installation Noise Foundations in Australian Carbonate Sediments

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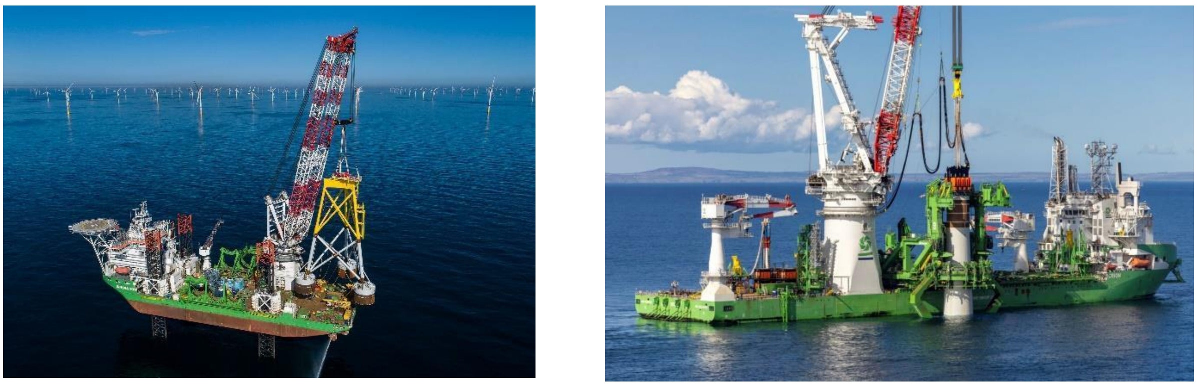
Keywords: Offshore foundations; carbonate sediments; vibro-driven piles; suction buckets

1. INTRODUCTION

Foundations for offshore wind turbines have traditionally been designed for capacity and stiffness, with checks to ensure successful installation. Installation has increasingly moved into focus, with environmental constraints, adaptation to complex geotechnics and logistical efficiency contributing to the consideration of a wider range of installation methods and foundations solutions. Noise mitigation at the source and/or by means of bubble curtains through the water column, often in combination with soft starts of impact driving of (mono)piles to allow marine mammals to move away from the area have become standard. Bubble curtains require additional vessels with diesel powered compressors for the air that is released through perforated hoses laid on the seabed around the installation site, which is not only costly but also considerably increases the CO_2 footprint of the operation.



(a) (b)

Figure 1 (a) Suction bucket jacket (source: DEME Offshore), (b) monopile with vibro-driver (source: DEME Offshore).

Suction bucket jackets (Fig. 1a) offer a low installation noise alternative that has been employed at a number of offshore wind farms in the North Sea but also off China and Taiwan. Neither suction buckets nor jackets are new, both having originated in the offshore oil and gas industry, but their first use as the foundation solution in an offshore wind farm only dates back to 2014 at Borkum Riffgrund I (Shonberg et al. 2018), with Bienen et al. (2025) providing an overview of research and practice of suction buckets in the offshore wind space. Requiring only pumps in addition to their self-weight, suction bucket jacket installation does not require noise mitigation measures. Suction bucket jackets have more recently been installed in complex soil conditions at Seagreen (Hamdan et al. 2023) and Changhua 2b and 4, with installation times of only about 5 hours on average per suction bucket jacket required at the latter.

Monopiles have remained the default foundation type to date, owing to their industrialised fabrication and robust supply chain. Pile installation by vibration (Fig. 1b) rather than impact hammering has recently received growing attention. The acoustic signal from vibro-driving is lower in intensity, such that additional noise mitigation is not required, and resembles a continuous hum rather than percussive blows. A further advantage of vibro-driven pile installation is the direct connection that is maintained between pile and vibro-driver through a number of clamps and between vibro-driver and the crane, which mitigates the risk of pile run or rapid uncontrolled pile penetration. Pile run incidents during impact-hammered installation have been reported in the offshore wind industry in complex soil conditions in Asia. In Australia, costly experience with pile run dates back to the early days of the oil and gas industry (Senders et al., 2013), resulting from variably cemented carbonate seabed sediments which may present as competent materials in situ but their strength can rapidly degrade during shearing. Conversely, cemented layers pose the risk of pile tip damage and extrusion buckling (Nietiedt et al., 2023).

The Centre for Offshore Foundation Systems (COFS) at UWA has focused on carbonates since its formation in 1997, with emphasis on element response, approaches to characterise material properties, and the installation and in-place performance of a range of foundation and anchor types – with most conducted in collaboration with industry to ensure practical applicability and to facilitate uptake (Randolph et al., 2021, Watson et al., 2019, Erbrich and Randolph, 2025, Bransby et al., 2025). Our current work concentrates on providing inputs to offshore wind farm projects worldwide and connecting up geotechnical research in Australia through the ACOWE initiative. This abstract highlights a small selection of ongoing work, focusing on solutions with low acoustic emissions during the installation process which is investigated in Australian carbonate sample conditions. The examples were selected for their relevance to Australian offshore wind developments and their intersections with other disciplines (which include environmental, hydrodynamic, logistic and supply chain considerations).

2. VIBRO-DRIVEN PILES IN UNCEMENTED CARBONATE SAND

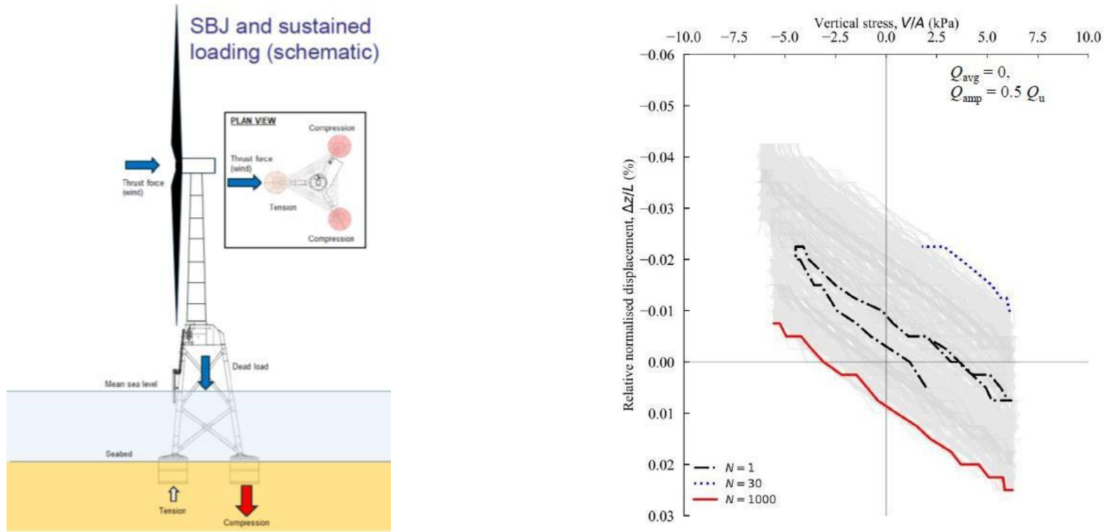
Vibro-drivers to install the large heavy tubular offshore wind monopiles need to fit the size of the piles and apply much higher dynamic forces than required to drive e.g. sheet piles onshore, hence larger vibro-drivers were developed for the offshore wind industry. To understand the governing mechanisms underpinning the dynamic soil-pile interaction, a model vibro-driver was also developed for experimentation in a geotechnical centrifuge at UWA (Hein Mazutti et al. 2025, Fig. 2b), with findings in siliceous sand reported in Hein Mazutti et al. (2026) and comparisons with predictions summarized in El Haffar et al. (2023) and Bienen et al. (2025). Successful pile installations in uncemented carbonate sand (Fig. 2a) have recently been performed using the same apparatus.

(a) (b)

Figure 2 (a) Details of carbonate sand captured with µCT (NGI), (b) vibro-driven pile testing in the NGCF centrifuge at UWA

3. SUCTION BUCKET PERFORMANCE IN CARBONATE SAND

Suction buckets have been shown to be installable in a range of soil conditions, including dense sand, with predictions using established methods matching measured resistance well (Bienen et al., 2025). Experience has in sandy soils been gathered primarily in siliceous material, including in the field. Recent collaborative centrifuge tests performed at the National Geotechnical Centrifuge Facility at the University of Western Australia, undertaken with the University of Melbourne and KU Leuven, have delivered physical data of suction bucket installation in carbonate sand, including pressure-cyclic installation, which allows the performance of predictive methods to be evaluated for this sediment as well. Following installation, the individual suction buckets of a suction bucket jacket may experience sustained mean loading with cycles into tension or compression as illustrated in Fig. 3a. The response to both is important to understand for design optimisation and to ensure serviceability of the offshore wind turbines over their lifetime.



(a) (b)

Figure 3 (a) Suction bucket jacket with sustained loading (schematic, Bienen et al., 2025), (b) suction bucket vertical displacement relative to the installed depth over 1,000 load cycles (example centrifuge test result)

4. OUTLOOK

This contribution provides an overview of some of the research activity being conducted that is targeted to provide information for the Australian offshore wind industry. The research is designed to reduce risks and the broader activities encompass the life cycle from site characterisation to decommissioning and include solutions for floating infrastructure such as drag and helical anchors. Ongoing activity also already investigates variably cemented carbonate sediments. This and future collaborative research is needed to avoid similar costly lessons from early oil and gas developments in the offshore wind industry in Australia.

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blue v Blue: Competing Visions of Offshore Renewables and Ocean Futures

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Keywords: blue economy, relational ethics, energy transition, blue justice, ocean policy

1. INTRODUCTION

The rapid expansion of offshore renewable energy has exposed new fractures in environmental politics. While these tensions are often framed as a conflict between climate mitigation and marine conservation – a Green versus Blue debate – this paper argues that such framings remain insufficient. Instead, the presentation proposes a "blue versus Blue" lens: a contest between competing visions of the ocean's future. On one side lies a global climate agenda advancing industrial-scale offshore renewables under the banner of decarbonisation; on the other lie relational and place-based understandings of the ocean grounded in biodiversity protection, cultural sovereignty, stewardship, and regenerative futures. Situating these tensions within broader Blue Economy discourse, the paper explores how ecological, cultural, and ethical attachments complicate the rollout of offshore energy infrastructures. It further examines the risks of carbon reductionism and bluewashing, whereby oceans are increasingly governed as carbon spaces rather than living relational systems. Drawing on emerging debates in ocean ethics and governance, the paper argues for a more relational and ethically grounded approach to marine based energy transitions – one capable of integrating climate imperatives with ecological integrity, First Nations and community values, and long-term ocean stewardship.

2. BACKGROUND

This presentation is based upon my forthcoming article of the same name, in *Environmental Science and Policy.* The acceleration of offshore renewable energy development has become central to global decarbonisation strategies following the Paris Agreement (2015) and broader net-zero commitments. Governments increasingly position offshore wind, green hydrogen, and marine energy as essential components of the emerging Blue Economy. However, the expansion of industrial-scale marine infrastructure has generated growing tensions between climate mitigation objectives and marine conservation priorities. These conflicts are particularly visible in coastal and marine regions where ecological significance, cultural identity, fisheries, tourism, and community attachment intersect with energy development agendas.

Existing debates as witnessed across communities during our own offshore wind rollout in Australia, often politicise and frame these tensions as a "Green versus Blue" conflict between climate action and ocean protection. This presentation argues that such framings oversimplify the issue. Rather than a conflict between environmentalism and conservation, many disputes reflect competing "blue" imaginaries concerning how oceans should be valued, governed, and related to. The paper situates these debates within broader concerns regarding ocean governance, marine spatial planning, bluewashing, and the ethical implications of reducing marine systems to carbon mitigation assets within emerging blue economy frameworks.

3. APPROACH

This presentation adopts a transdisciplinary and critical ocean governance approach drawing from environmental ethics, Blue Economy scholarship, marine governance literature, and emerging debates surrounding offshore renewable energy. It combines conceptual analysis with relational and place-based perspectives to interrogate the ethical assumptions underpinning contemporary marine transitions.

Central to the analysis is the development of a "blue versus Blue" framework, which distinguishes between competing ocean value systems embedded within offshore renewable energy debates. The presentation will critically examine how dominant climate mitigation narratives frequently prioritise carbon reduction metrics while marginalising ecological relationality, cultural sovereignty, and local marine attachments. It further engages with literature on bluewashing, social licence, marine conservation conflicts, and Fist Nations and local community perspectives to explore how governance systems privilege particular forms of value and knowledge.

Rather than rejecting offshore renewable energy transitions, the paper seeks to identify pathways toward more ethically grounded and blue-conscious approaches capable of integrating decarbonisation with marine stewardship, ecological integrity, and community legitimacy.

4. DISCUSSION

The "blue versus Blue" framing reveals that offshore renewable energy conflicts are not simply technical disputes over infrastructure placement, but deeper ethical and ontological contests concerning the future of the ocean itself. While offshore renewables are frequently framed as environmentally progressive, their industrialisation can reproduce extractive governance logics if climate mitigation objectives are pursued without sufficient regard for marine relationality, biodiversity, and cultural values. In the presentation arguments will be made that prevailing carbon-centric approaches risk narrowing ocean governance to questions of emissions reduction alone, thereby marginalising broader ecological and social dimensions of ocean life. Such reductionism may contribute to new forms of bluewashing, where sustainability narratives obscure unresolved tensions surrounding marine industrialisation and governance legitimacy. A more relational and ethically grounded Blue Economy requires moving beyond purely technocratic approaches toward governance models that recognise oceans as living cultural and ecological spaces rather than solely carbon infrastructures. This includes integrating First Nations and community perspectives, strengthening stewardship frameworks, and foregrounding questions of responsibility, reciprocity, and long-term ecological care within marine policy and planning.

5. CONCLUSIONS

The Blue vs Green debate is fundamentally about scale and relationality: global climate priorities often clash with local ecological and cultural imperatives. Recognizing the unique qualities of oceans spatial, ecological, and cultural reveals that offshore renewable projects intersect with more than carbon targets; they engage with the lived experiences of communities and the ethical stewardship of marine spaces. The *blue vs Blue* framework reframes the debate from one of opposition to one of integration. By emphasizing shared values, place-based ethics, and regenerative technologies, policymakers and communities can reconcile renewable energy development with marine conservation, fostering cooperation across political, ideological, and ethical divides. Ultimately, oceans are not merely spaces of industrial opportunity they are places of meaning, culture, and life, demanding careful stewardship even as we transition toward a low-carbon future.

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The Ethical Wrongdoing of Morally Objectionable NIMBYs: Key Variants and Practical Takeaways

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Keywords: NIMBY; environmental justice; offshore wind energy; social acceptance; ethics

1. INTRODUCTION

NIMBYism refers to locals objecting to an unwanted nearby development, especially when they are open to it proceeding elsewhere. The term is a morally disapproving one, implying NIMBYs are objectionably self-interested or hypocritical. Yet prior scholarship has shown that alleged NIMBYs can have legitimate concerns and pro-social motivations. This paper aims to delineate the specific ethical failing of Morally Objectionable NIMBYs (and different ways this failing can occur—including excusable naivety) and to distinguish them from Enlightened NIMBYs. Despite the situation's complexity, we derive clear practical responses to the ethical challenges posed by NIMBYism.

Throughout, we use offshore wind farms as an example of different types of NIMBYism.

2. BACKGROUND

NIMBYism—an acronym for 'Not In My BackYard'—is controversial (Eranti, 2017, pp. 285-288). From its very beginnings, the charge of 'NIMBY' has been used to imply that the local objectors are irrational, self-interested or hypocritical, and that they inappropriately block necessary projects (Welsh, 1993, p. 16).

Yet decades of social science findings (Devine-Wright, 2009; Gibson, 2005; Johnson & Scicchitano, 2012; Wiersma & Devine-Wright, 2014) and ethics scholarship (Feldman & Turner, 2010; Gillroy, 1991; Quigley, 2023; Schwenkenbecher, 2017) have cast doubt on this generalisation, showing that the situation is complex, and that alleged NIMBYs can have legitimate concerns and pro-social motivations.

3. APPROACH

In this paper we develop a classification system along moral lines, drawing on the discipline of applied moral philosophy. We begin by distinguishing NIMBYs from other types of local objectors. We then tease apart (what we will term) the 'Morally Objectionable NIMBY' from the 'Enlightened NIMBY'. While we contend that the Morally Objectionable NIMBY instantiates a specific ethical failing, we argue that there are different ways of succumbing to this failing.

Despite this complexity, we derive clear and actionable responses to two important questions: How can we personally avoid becoming a Morally Objectionable NIMBY? And: how should we as fellow citizens, developers, or policymakers respond to someone we think is a Morally Objectionable NIMBY?

4. DISCUSSION

We argue that an Enlightened NIMBY is one who is objecting to a local development on the basis of legitimate 'FAGE' concerns. These are impartial, morally relevant, intersubjectively accessible moral concerns based on Fairness, (Place) Attachment, Governance, and Environment. A NIMBY mounting legitimate FAGE concerns is not doing anything morally suspect or hypocritical and should not be dismissed or criticized for their position.

However, not all NIMBYs are Enlightened NIMBYs. We argue that the Morally Objectionable NIMBY violates the following ethical principle:

> When engaging in public affairs and democratic deliberations, citizens should put forward and act on positions that have a baseline of equal respect for all people and are morally consistent. Specifically, this prohibits citizens behaving as if they are intrinsically politically more important than other citizens and that this inflated political importance should be reflected in policy.

We show how this principle can be violated in several different ways, giving rise to different types of Morally Objectionable NIMBY (Flagrant, Bad Faith, Rationalizing & Naïve). A characteristic moral failing of the Morally Objectionable NIMBY is that they put forward FAGE concerns that are sufficiently poor quality, so generically applicable, and/or based on such poor evidence *that any other potential site would similarly be able to avail themselves of these types of defences*. But these reasons are misleadingly presented as if they provide a special reason justifying why this development shouldn't go ahead *in this particular location*.

These positions are not carved in stone, and NIMBYs can shift between them—as well as progressing from Morally Objectionable NIMBYs to Enlightened NIMBYs.

A further consideration is *Environmental Justice*, whereby marginalized groups have unwanted developments forced on them, because—as compared with more well-heeled and well-connected communities—they do not have the political power and influence to block such developments. Even Enlightened NIMBYs can contribute to environmental injustice, but this consideration provides a further reason for concern with Morally Objectionable NIMBYs who breach the above principle: their partial, self-interested concern for their own 'backyard' inevitably leads to unfair impositions on vulnerable communities.

5. CONCLUSIONS

Despite the complexity of the normative landscape, with a wide array of NIMBY types, as well as other local objectors, supporters, and participants, we argue that the best ethical response in all such cases is to take all local objectors' concerns and positions seriously, to consider them carefully, to listen hard to their evidence and local knowledge, and to engage critically with their positions. If these objectors are engaging in the MO NIMBY's signature failings—namely that the types of reasons they are presenting could equally well be made by all local objectors, no matter where they are located—then they deserve to have that argument put to them, and to make their case against it.

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Increasing Data Availability for Quantitative Cumulative Impact Assessment: A FAIR-Secure Pipeline for Marine Environments

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Keywords: Quantitative cumulative impact assessments, FAIR data principles, secure data sharing, offshore wind, data standardisation

1. INTRODUCTION

Coastal communities depend on healthy marine environments for ecosystem services including food, energy, cultural connection, and recreation (Bennun et al. 2021). Emerging 'blue economy' sectors such as offshore wind offer societal benefits but simultaneously introduce new pressures on marine environments, joining existing stressors such as fisheries and climate change in creating potential cumulative impacts (Halpern et al. 2008; Sinclair et al. 2017). Despite growing legal requirements for Cumulative Impact Assessment (CIA) in over two-thirds of developed nations (Nelson & Shirley 2023), quantitative CIA remains rare due to data limitations (Piet et al. 2021). Two principal barriers constrain data sharing and reuse: an interoperability barrier, where inconsistent survey designs and incompatible data formats prevent integration, and a commercial barrier, where competitive concerns restrict data sharing. The FAIR data principles (Findable, Accessible, Interoperable, Reusable; Wilkinson et al. 2016) address the interoperability barrier, yet secure mechanisms for commercial data sharing remain underdeveloped. We address this gap by proposing the FAIR-Secure data pipeline: a five-stage framework combining existing FAIR-compliant tools with a secure data sharing platform to enable quantitative CIA.

2. THE FAIR-SECURE DATA PIPELINE FOR CIA HABITAT

The FAIR-Secure pipeline (Figure 1) comprises five sequential stages for benthic habitat assessment using drop-camera imagery. Stage 1 implements spatially balanced survey designs following Australia's National Environmental Science Program (NESP) Marine and Coastal Hub standards (Przeslawski et al. 2023), reducing spatial clustering and improving statistical efficiency across combined datasets. Stage 2 standardises data collection using NESP-endorsed methods — either the Benthic Observation Survey System (BOSS) or stereo-Baited Remote Underwater Video Systems (stereo-BRUVs) — reducing biases attributable to survey technique rather than ecological variation. Stage 3 applies standardised quality control via the CheckEM R package (Gibbons et al. 2026), identifying metadata errors and dataset anomalies to ensure data accuracy prior to analysis. Stage 4 uses GlobalArchive, a web-based repository providing centralised data storage with granular access permissions, enabling simultaneous hosting of open-access and private datasets. Stage 5 employs a bespoke node of the Shared Environmental Analytics Facility (SEAF), developed by the Western Australian Biodiversity Science Institute (WABSI) and the Western Australian Marine Science Institution (WAMSI), enabling integrated analyses across open-access and private datasets without accessing raw data. Together, Stages 1–3 address the interoperability barrier through standardisation, while Stages 4–5 address the commercial barrier through secure sharing and analysis.

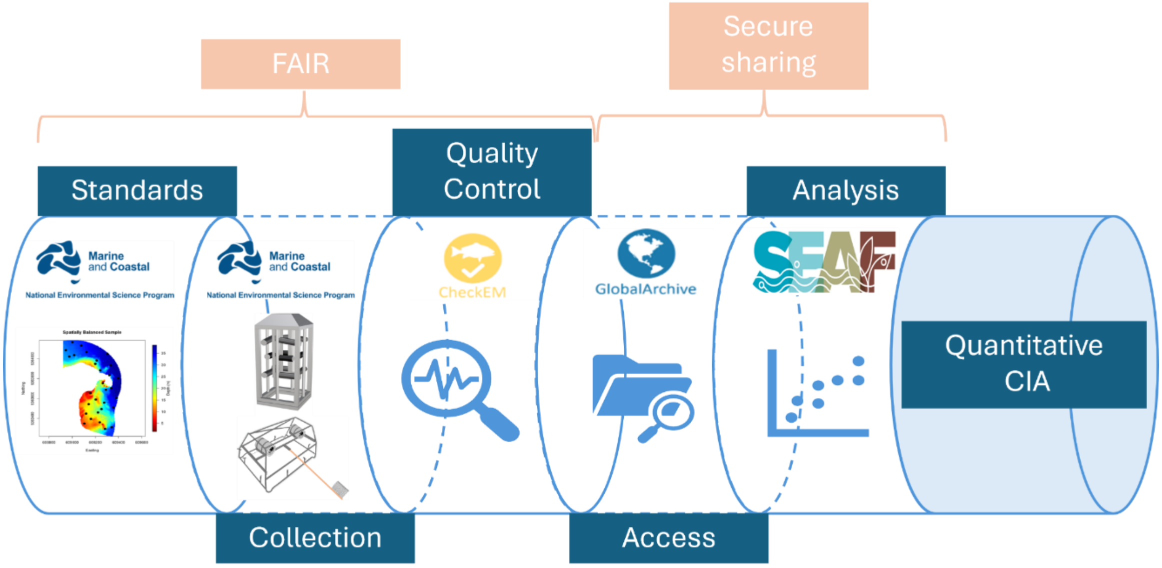

Figure 1. The FAIR-Secure data pipeline for CIA, addressing interoperability barriers (FAIR principles, Stages 1–3) and commercial barriers (secure sharing, Stages 4–5).

3. DEMONSTRATING THE FAIR-SECURE DATA PIPELINE FOR CIA

We demonstrate the pipeline in Australia's offshore wind sector, applying it to the Offshore Electricity Infrastructure (OEI) zone declared offshore Bunbury, Western Australia, in August 2024. Multiple developers are planning wind farms within this zone, requiring CIA across the full zone extent under both state (Environmental Protection Act 1986) and Commonwealth (EPBC Act 1999) legislation. The demonstration focuses on a single receptor (benthic habitat) and cause-effect pathway (physical turbine disturbance). A total of 893 sampling points were collected across three campaigns: 759 open-access points and 134 from a restricted-access private scoping study adjacent to the OEI zone. Predicted habitat maps were developed for the study area using bathymetric predictors derived from a 250 m Geoscience Australia layer (Beaman 2024). Two model sets were compared: one using open-access data only and one using combined open-access and private data accessed through SEAF. A turbine array of 931 turbines was overlaid across the OEI zone to assess direct habitat intersections, following WA EPA guidance (EPA 2016). The open-access model predicted 95% of turbines (n = 889) would intersect with reef; the combined model reduced this to 85% (n = 796), with sand intersection increasing from 5% to 15%. At the regional scale, predicted reef loss decreased from 3.23% to 2.85% under the combined model. Though modest, these differences demonstrate how incorporating spatially proximate private data, made possible through the pipeline, meaningfully improves impact prediction precision and reinforces the value of the pipeline for decision-making.

4. DISCUSSION

The FAIR-Secure pipeline provides a scalable blueprint for quantitative CIA in Australia's offshore wind sector and beyond. As multiple developers collect baseline data for individual OEI zone projects, the pipeline can continuously integrate these datasets to improve impact predictions under the adaptive CIA framework envisaged in Australian legislation (EPA 2025; DCCEEW 2024). The pipeline extends readily to other Australian OEI zones and internationally, including the North Sea (Declerck et al. 2023), where analogous data fragmentation and commercial sensitivity barriers exist. Accumulating larger spatiotemporal datasets through the pipeline would progressively enable more sophisticated CIA capabilities: ecosystem health metrics at bioregion scale, characterisation of development impact spatial and temporal extents, and identification of tipping points in ecosystem responses (Stockbridge et al. 2025). Key barriers to broader adoption include coordination challenges where legacy data systems exist, institutional mistrust, and the fundamental incentivisation problem: secure data sharing must ultimately be mandated or incentivised through regulatory frameworks, not merely enabled by technical infrastructure (ARDC 2024). Where environmental approval requires

FAIR-compliant data management and contribution to secure platforms, industries will incorporate these requirements into project planning, distributing costs and benefits more equitably while producing the regional datasets needed for robust CIA.

5. CONCLUSIONS

This study demonstrates that FAIR data principles combined with secure sharing mechanisms can address both interoperability and commercial barriers limiting quantitative CIA implementation. The FAIR-Secure data pipeline provides a practical blueprint, using tools already widely adopted for benthic habitat assessment, showing how standardised sampling protocols, quality control, and secure analysis infrastructure enable data reuse across differing spatial scales without compromising commercial constraints. The case study demonstrates tangible improvement in CIA accuracy when private data is incorporated via the secure platform. Broader adoption requires coordinated action from regulators, industry, and the scientific community: technical infrastructure enables, but cannot compel, the cultural and institutional change necessary for widespread data sharing. Regulatory frameworks that mandate standardised, secure data approaches for CIA are the essential complement to the technical solution demonstrated here.

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Extreme Wind Systems in a Changing Climate: Implications for Offshore Wind Infrastructure

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Keywords: Tropical cyclones; climate change; offshore wind infrastructure

1. INTRODUCTION

Tropical cyclones (TCs), Severe Convective Wind Events (SCWs) such as from thunderstorms, East Coast Lows (ECLs) and other extratropical systems are among the most significant natural hazards affecting Australia's offshore and coastal infrastructure (Bell et al. 2022; Brown et al. 2023; Chand 2025; Deshmukh et al. 2026; Dowdy et al. 2019). Associated extreme winds, waves, storm surge, and heavy rainfall pose substantial risks to offshore wind farms, transmission networks, and coastal assets. As offshore renewable energy development expands across Australia and the Indo-Pacific, understanding how these hazards may evolve under climate change is increasingly critical for infrastructure planning, engineering design, and long-term resilience assessment.

Although offshore engineering studies often emphasize structural design criteria based on observations in the past, climate science provides essential insight into the evolving hazard conditions underpinning metocean assessments and return-period estimates over the lifetime of planned infrastructure. Previous studies have examined observed and projected changes in characteristics of extreme wave events such as TCs, SCWs and ECLs using observations, atmospheric reanalyses, and climate models (Bell et al. 2022; Chand et al. 2019; Deshmukh et al. 2026; Dowdy 2020; Dowdy et al. 2019).While not explicitly focused on offshore engineering, these studies provide a critical scientific foundation for assessing future offshore wind and coastal infrastructure risk under a changing climate (Figure 1).

Figure 1. Schematic illustrating the dominant sources of extreme winds affecting Australian coastal regions, highlighting tropical cyclone–prone northern coasts and extratropical storm–dominated southern coasts. [Schematic generated using ChatGPT based on scientific understanding derived from studies led by Chand, Dowdy, Evans and collaborators].

2. IMPACT OF GLOBAL WARMING

TCs: Around 11 TCs occur annually within the Australian region, with nearly 40% making landfall along the Australian coastline. The Australian central basin experiences the highest landfall proportion (~75% of basin-generated TCs) owing to its semi-enclosed geography and coastal genesis locations. Long-term analyses indicate a significant decline in Australian TC frequency (Chand et al. 2019), consistent with evidence of a global decline since the mid-nineteenth century based on multiple observational and reanalysis datasets (Chand et al. 2022). TC activity is strongly modulated by the El Niño–Southern Oscillation (ENSO), with enhanced activity during La Niña and reduced activity during El Niño phases (Chand et al. 2019). Despite projected declines in overall frequency, warming oceans and increased atmospheric moisture are expected to intensify rainfall rates and increase the proportion of severe Category 4–5 cyclones (Camargo et al. 2023). Studies also suggest a poleward migration of TC intensity and associated wind fields, potentially expanding exposure to extreme wind, wave and storm-surge hazards in subtropical regions (Kruskie and Chavas 2026). Damaging winds can extend well beyond the TC track, highlighting the importance of storm structure in offshore infrastructure risk assessments (Bell et al. 2022).

ECLs: ECLs are major drivers of extreme winds, waves, storm surge, flooding and coastal erosion along southeastern Australia (Dowdy et al. 2019). These systems can rapidly intensify and generate hazards comparable to TCs. Climate projections generally indicate a decline in overall ECL frequency, particularly during cooler months, although severe ECLs responsible for damaging winds and extreme rainfall may show little change (Dowdy et al. 2019). Using pseudo-global warming simulations, Deshmukh et al. (2026) found modest reductions in peak wave height, wave period and cumulative wave power under a high-emissions scenario, while emphasising substantial uncertainties associated with regional climate processes and event-specific characteristics.

Thunderstorms: Thunderstorms are among Australia's most damaging weather hazards, producing destructive winds, lightning, hail, flash flooding and substantial infrastructure losses (Brown et al. 2023; Dowdy 2020). Severe convective wind events occur across much of the country, particularly in eastern and southeastern Australia. Climate projections suggest that a warmer, moister atmosphere will increase environments favourable for severe convection and extreme wind gusts in some regions, especially during summer. However, considerable uncertainty remains due to the complexity of thunderstorm processes and limitations in climate-model representation of convection (NESP 2019). For offshore infrastructure, thunderstorm-related wind hazards should be considered alongside TC and ECL risks when assessing future resilience.

3. IMPLICATIONS FOR OFFSHORE WIND INFRASTRUCTURE

Although the overall frequency of TCs and ECLs is projected to decline under climate change, the associated hazards most relevant to offshore wind infrastructure are unlikely to decrease proportionally. Rising sea levels will exacerbate storm surge, coastal inundation and erosion, while warmer oceans and a moister atmosphere are expected to increase rainfall intensity and the proportion of severe storms. Emerging evidence also suggests changes in storm tracks and wind and wave footprints. Because reductions are expected primarily in weaker systems, future risk may be characterised by fewer but more intense events.

For offshore wind infrastructure, extreme winds, waves and storm surge can impose substantial structural and hydrodynamic loads, while compound hazards may disrupt operations and maintenance. These evolving risks highlight the need for climate-informed engineering design, probabilistic metocean assessments and long-term adaptation planning (Figure 2).

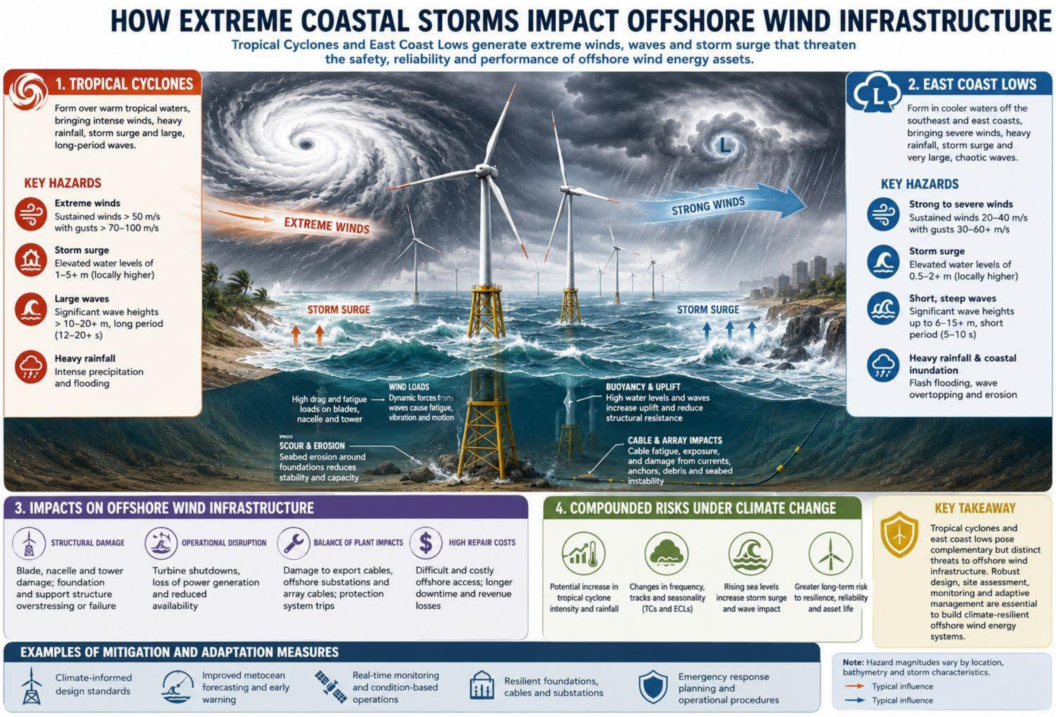

Figure 2. Conceptual schematic illustrating how TCs and ECLs influence offshore wind infrastructure through extreme winds and associated hazards. [Schematic generated using ChatGPT based on scientific and conceptual understanding derived from studies led by Chand, Dowdy, Evans and collaborators].

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Regional Seabed Scour Dynamics of Offshore Wind Turbine Foundations in Bass Strait, Australia

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Keywords: offshore wind energy; regional scour; sediment transport; TUFLOW FV

1. INTRODUCTION

Offshore wind energy is a rapidly growing sector in Australia, with the Gippsland declared area in Bass Strait containing a number of Feasibility License Areas (FLAs) with potential energy generation capacity of several GW. Understanding seabed scour dynamics around offshore wind turbine foundations and arrays is critical to safe foundation design and informing regional-scale assessments of potential cumulative impacts.

The Bass Strait is a tidally dominated continental shelf seaway, a semi-enclosed sea characterised by strong tidal currents, seasonally varying residual circulation, and substantial wave energy from local wind seas as well as long period swell propagating from the Southern Ocean and Tasman Sea. Sediment transport and scour can arise from currents alone, waves alone, or combined wave-current action. The nature of scour development is dependent on the hydrodynamic conditions and soil characteristics in which structures are placed.

This paper presents a preliminary investigation into regional-scale seabed scour dynamics for monopile foundations across the Gippsland offshore wind declared area of the Bass Strait, Australia, using coupled hydrodynamic and sediment transport modelling.

2. METHODS

Engineering Soil Classification

To inform hydrodynamic and sediment transport model parameterization an Engineering Soil Classification (ESC) map for the Bass Strait was generated. Sediment grain size point sample data from the Geoscience Australia MARS database (Nichol, 2009) was geostatistically modelled to generate four sediment fraction maps to the full spatial extent of the Bass Strait. These fraction maps were then classified using the field descriptive classification method from the Australian Standard for Geotechnical Site Investigations (Standards Australia, 2017).

Hydrodynamic Modelling

The hydrodynamic modelling was undertaken using the TUFLOW FV modelling software, which is developed and distributed by BMT (BMT WBM, 2013). TUFLOW FV is a numerical hydrodynamic model for the two-dimensional (2D) and three-dimensional (3D) Non-Linear Shallow Water Equations. The boundary conditions for the developed hydrodynamic model included atmospheric, ocean, tides and waves (Table 1). Mesh resolution in the offshore wind declared area was ~2 km. The model was calibrated against ship-mounted ADCP data from the 1997 RV Franklin voyage[1] and validated against long-term tide gauge data at Lorne and Burnie from the Australian Baseline Sea Level Monitoring Program[2].

[1] https://marlin.csiro.au/geonetwork/srv/eng/catalog.search#/metadata/a20f37ed -19d8-48b1-87da38039790762a
[2] http://www.bom.gov.au/oceanography/projects/abslmp/data/index.shtml

Offshore Wind Turbine Implementation

Turbine foundations were implemented into the hydrodynamical model with use of the TUFLOW FV Sub-Grid Blockage (SGB) module (BMT, 2025). The SGB allows the schematisation of blockages (cylinders) that are at a sub-grid resolution to the general hydrodynamic mesh. Their influence can be represented by:

- A cell centered drag force (momentum sink term)
- Source and sink terms in the vertical k-epsilon or k-omega turbulence model

The implementation of turbines assumed a single monopile design diameter (12.5 m) and drag coefficient (Cd = 0.63). Turbine density varied as per individual FLA and were assumed to be approaching maximum proposed installed capacity.

Table 1 Boundary condition models for the hydrodynamic model

Hydrodynamic Boundary Conditions	Model	Reference
Tide	FES2022	CNES (2024)
Atmosphere	BARRA – R2	Su et al. (2023)
Ocean	HYCOM	Naval Research Laboratory (2014)
Waves	CAWCR	Durrant et al. (2019)

Sediment Transport Model

A mixed (four) fraction sediment transport model was developed using the TUFLOW FV Sediment Transport Module (STM). Transport of sand and gravel fractions were modelled using the Soulsby Van Rijn equations, whereas transport of silt and clay fractions were modelled using the Mehta erosion model. The mixed fraction model was also compared to a model with a sand fraction only to assess the importance of bed soil composition on scour potential. A one-year hindcast of 2019 was selected as the simulation period for this preliminary assessment on the basis of its dominant southwesterly wave and current conditions, therefore expected to be representative of higher potential for scouring. The models were run with morphological coupling.

3. RESULTS

The impact of turbines on the seabed over the one-year hindcast were assessed for the "all sand" and "mixed soil" models (Figure 1). Figure 1 presents the change in bed thickness at the end of the Austral spring season for both models. For both models, turbines were predicted to produce both deposition and erosion of the bed. In both models deposition occurs primarily within the boundaries of the FLAs and erosion primarily occurs at the margins as well as to the far lee of the ebb tide direction. The "all sand" model predicted larger impacts on the bed compared to the "mixed soil" model, with the amount of erosion at the margins of the FLAs at times being ~2x larger. Both models indicate some level of potential erosion adjacent to the coast in the region.

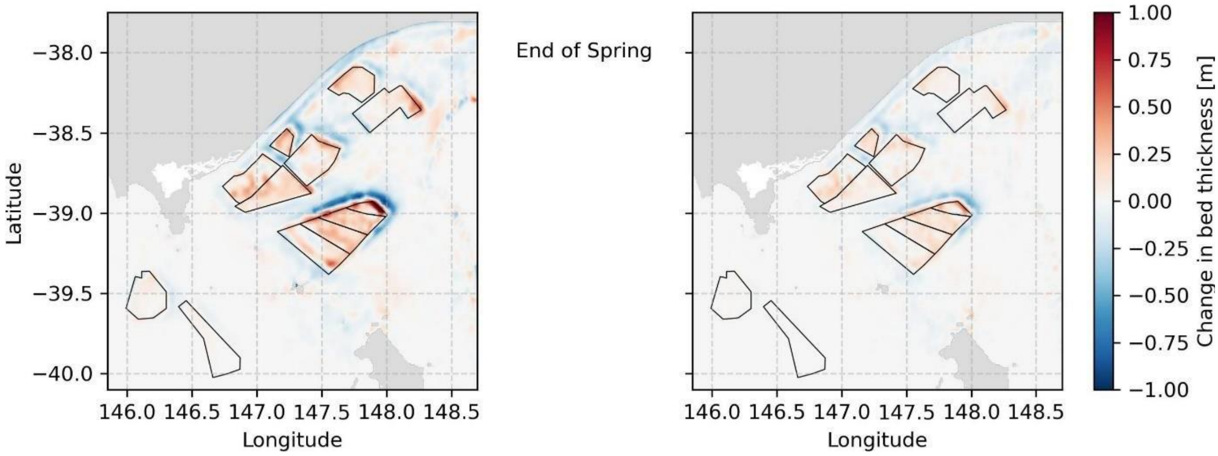

Figure 1 Comparison of the end of Austral spring change in bed thickness for the "all sands" (left) and "mixed soil" models (right).

4. DISCUSSION AND CONCLUSIONS

Offshore wind turbine foundations, modelled as sub-grid drag forces in TUFLOW FV, cause the turbine arrays to behave as large porous blockages. This deflects flows toward array margins and accelerates velocities there (on the margins), increasing bed shear stresses and sediment transport capacity — predicting regional-scale scour. Conversely, velocities and shear stresses are reduced within the arrays, promoting deposition inside in the FLAs and sediment starvation-driven erosion outside. Far-field velocity changes of roughly ±8 % extend up to ~100 km from the arrays, consistent with comparable modelling in the German Bight (Christiansen et al., 2023), with notable velocity increases in shallower coastal waters to the northeast raising awareness about potential for coastal erosion.

The one-year hindcast period seems insufficient to capture the full extent of regional scour, as bed thickness at the most affected array shows no sign of stabilising by the end of the simulation. Longer hindcast periods are needed to establish regional-scale equilibrium scour levels. Differences in scour magnitude between “all sand” and “mixed soil” model configurations suggest that bed composition and sediment mobility play a significant role in governing the regional response, warranting further investigation and consideration in both project-specific and cumulative impact assessments.

The regional-scale model simulated represents a likely upper-bound scenario, having assumed all FLAs operating at full near 25 GW capacity with uniform 12.5 m diameter monopiles (a turbine density far exceeding the Victorian Government’s 9 GW target by 2040) and without considering the effect of scour protection, which is typically used in offshore wind farms. The modelled regional scour potential impacts should therefore be interpreted as a potential maximum cumulative effect on hydrodynamics and bed morphology. At depths beyond ~40–50 m, monopile foundations would likely be replaced by jacket or gravity-based designs whose hydrodynamic drag characteristics differ, introducing further uncertainty to regional scour predictions in deeper parts of the FLAs. The drag effects of jacket piles and their implementation into regional-scale modelling would be an important topic of future study.

Additionally, the study demonstrates that mixed soil representations produce meaningfully different results from all sand simplifications and soil composition should not be overly simplified for regional scour assessments.

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Rethinking Drivability Assessment for Monopiles in Offshore Carbonate Soils Under Low-Noise Installation Methods

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Keywords: Monopile drivability, Low-noise monopile driving, Carbonate sands, Particle breakage

1. INTRODUCTION

Offshore wind construction including installing XL/XXL monopiles is expanding into complex geological features such as carbonate sediments (e.g. in Australia). At the same time, environmental regulations are pushing industry away from conventional impact hammering towards low-noise alternatives such as vibratory hammering, Gentle Driving of Piles (GDP), Blue Piling and Vibro-Jetting (Holeyman, 2002; Tsetas et al., 2023a; Konstadinou et al., 2023, WindEurope, 2026). While underwater noise reduction is the core aspect that these methods are typically assessed for, their drivability in problematic deposits remain poorly understood. Existing drivability models are basically calibrated in silica sands or clays under impact loading and do not account for particle breakage, destructuration or cyclic degradation (Watson et al., 2019). This paper briefly reviews how low-noise monopile installation methods may interact with carbonate sands and proposes an introduction to a qualitative framework for more reliable drivability assessments.

2. BACKGROUND

Carbonate sands are usually recognized by low particle strength and abrupt volumetric changes than by their sensitivity to stress path, stress rate, drainage condition and cumulative energy input. Carbonate sands are composed of weak, porous biogenic particles that show high initial friction angles, but crush rapidly under increased mean effective stress or repetitive shearing, leading to contractive behaviour, fines generation and progressive loss of dilatancy (Coop, 1990; Shahnazari & Rezvani, 2013; Wang and Zha, 2020). Laboratory studies show that particle breakage in carbonate sand is strongly governed by input energy, loading history and drainage condition. Drained or partially drained conditions produce significantly more breakage than undrained condition at the same total stress (Xiao et al., 2017; Wu et al., 2021; Zhu et al., 2022). Cyclic and dynamic tests reveal that breakage is dependent to both energy and strain rate, with hyperbolic or exponential relationships relating relative breakage (B_r) to cumulative input energy or strain rate (Liu et al., 2020; Wang & Zha, 2020; Xu et al., 2024). At the pile–soil interface, direct shear and constant-normal-stiffness tests show rapid degradation of shaft resistance due to particle corner breakage and smoothing of asperities (Peng et al., 2023; Feng et al., 2024; Wang et al., 2023). Field case histories in carbonate provinces confirm these mechanisms, reporting pile runs, abrupt increases in resistance at depth and lower shaft capacities than predicted by silica-calibrated methods (McCarel & Beard, 1984; Watson et al., 2019).

3. APPROACH

This review introduces a mechanistic approach that relates loading characteristics of low-noise monopile installation methods to the observed laboratory and field behaviour of problematic offshore soils. Instead of considering drivability as a function of static resistance profiles alone, installation is expressed in terms of stress magnitude, strain increment, strain rate, drainage regime and total energy input and examined how these govern particle breakage, destructuration and cyclic degradation.
First, impact hammering and Blue Piling are characterised by peak stress, pulse duration, stress rate and drainage condition within each hammer blow (Rausche and Hussein, 2009; Kourelis et al., 2022). These loading regimes are mapped onto monotonic, cyclic and high-rate element tests in carbonate sands, including triaxial, oedometer, ring shear, simple shear and Split Hopkinson Pressure Bar experiments

(Coop, 1990; Xiao et al., 2017; He et al., 2020; Xiao et al., 2019; Xu et al., 2024). This helps to infer that how short-duration, high-rate pulses promote localised breakage and toe densification while suppressing breakage under transiently undrained conditions.

Second, vibratory hammering and Gentle Driving of Piles can be interpreted through interface high-cycle and dynamic tests, which capture resonance, friction fatigue, liquefaction and torsional shear effects (Tsetas et al., 2023; Gómez et al., 2025). Their continuous, high-cycle loading is compared with undrained and partially drained cyclic triaxial and simple shear tests in calcareous sands, emphasising energy-controlled breakage and progressive loss of interface strength (Donohue et al., 2009; Wang & Zha, 2020; Liu et al., 2022; Peng et al., 2023).

Third, jet-assisted methods are evaluated by decomposing their response into an internal, fluidised soil and an external shaft zone subjected to VH-type loading (Zeilinger, 2009; de Brum Passini et al., 2017; Konstadinou et al., 2023; Cengiz et al., 2026).

Across these methods, we synthesize laboratory data, interface tests, physical models and field case histories in carbonate sands. This synthesis underpins a stress–rate–energy framework that explains why conventional drivability tools, which neglect breakage and cyclic degradation, may mispredict installation behaviour in problematic deposits and how these mechanisms might be adapted to account for evolving soil resistance and volumetric behaviour.

4. DISCUSSION

The comparative analysis shows that low-noise methods redistribute degradation mechanisms along the monopile in a transient way. Impact hammering and Blue Piling concentrate high stresses and strain increments near the toe, driving localised breakage and toe densification under partially drained conditions, and shifting load transfer towards end bearing in carbonate sands. Vibratory hammering and GDP, in contrast, use high-cycle high-frequency axial and torsional loading to accelerate friction fatigue and interface crushing. Although the undrained nature can somewhat supress particle breakage and the how the shaft resistance evolves through energy-controlled breakage. Vibro-jetting further decouples internal and external behaviour, improving drivability via internal plug fluidisation, however their effect in carbonate soil remains questionable. In all cases, the interaction between stress amplitude and cumulative energy input, altered by drainage and rate effects, proves more critical than peak stress alone and warrants further investigation for predicting drivability and post-installation performance in problematic soils.

5. CONCLUSIONS

Drivability of large-diameter monopiles in carbonate sands is governed by particle breakage characteristics induced by stress path, stress rate, drainage and cumulative energy, and how strength and critical state of soil may evolve during driving. Low-noise methods alter these variables in specific ways, redistributing rather than eliminating installation-induced degradation. Consequently, preliminary assumptions on how low-noise techniques may alter drivability or post-installation performance may need further investigation through laboratory or numerical modelling. Reliable assessment requires a stress–rate–energy framework that can consider particle breakage, destructuration and cyclic degradation, supported by laboratory tests and field data tailored to problematic deposits. Extending drivability models along these lines is essential for the safe certification and deployment of low-noise monopile installation methods in challenging offshore environments.

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Ecological Science as a Core Design Discipline: Integrating Nature Across the Lifecycle of Offshore Wind

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Keywords: Nature-inclusive infrastructure, decommissioning, ecosystem accounting, ecosystem enhancement, long term monitoring.

1. INTRODUCTION

"The challenge is no longer simply how to minimise environmental impacts. It is how ecological science can become a core technical input that improves project performance throughout the lifecycle of offshore wind developments".

As offshore wind farms become established components of Australia's marine environment, there is an opportunity to rethink how infrastructure is planned, designed, monitored and ultimately managed throughout its entire lifecycle. Rather than viewing biodiversity as a constraint to development, nature-inclusive infrastructure seeks to integrate ecological function into engineering design, creating opportunities to deliver renewable energy while supporting resilient marine ecosystems and healthy communities.

This shift requires moving beyond traditional project-based environmental assessment towards ecosystem-scale planning that recognises offshore infrastructure as a long-term structural component of marine ecosystems. Wind turbine foundations, scour protection and associated hard substrates introduce novel habitats into predominantly soft-sediment environments, initiating ecological succession that may continue for decades. The species and ecological communities that establish on these structures will influence biodiversity, fisheries productivity, ecosystem functioning and, ultimately, the environmental considerations surrounding future decommissioning decisions. Consequently, many of the most important environmental outcomes associated with offshore wind developments are determined well before the first turbine is installed.

This paper explores how ecological science can better inform offshore wind planning by considering the full infrastructure lifecycle—from project planning and environmental assessment through construction, operation, long-term monitoring and eventual decommissioning. Drawing on experience from offshore decommissioning, fisheries management and marine restoration in Gippsland, it argues that ecology should be considered alongside geotechnical engineering, hydrodynamics and structural engineering as a core technical discipline informing project design from the earliest stages of development. Rather than simply seeking to minimise environmental impacts, this approach identifies opportunities where environmental, engineering and commercial objectives align, reducing project risk, lowering whole-of-life costs, improving ecological resilience, and creating enduring partnerships with communities that support monitoring, stewardship and better long-term decision-making.

2. APPROACH

A central theme of the paper is the importance of selecting ecological assessment and management frameworks that operate at spatial and temporal scales relevant to ecosystem processes rather than individual infrastructure assets. Environmental Economic Accounting (SEEA Ecosystem Accounting) provides a framework for quantifying changes in ecosystem extent, condition and ecosystem services through time, enabling environmental outcomes to be considered alongside economic and engineering performance. Similarly, the IUCN Global Ecosystem Typology provides a consistent ecological classification system that supports ecosystem-scale planning, cumulative impact assessment and long-term monitoring across regional marine landscapes. Together, these frameworks provide an evidence base for integrating ecological values into infrastructure planning and evaluating environmental outcomes over multiple decades.

The presentation will also discuss the importance of designing environmental monitoring programs that extend beyond regulatory compliance. Conventional monitoring often focuses on demonstrating compliance during construction and the early operational phases of a project. However, ecological communities associated with offshore infrastructure continue to develop throughout the operational life of a wind farm. Understanding ecological succession, habitat development and changing ecosystem function requires long-term datasets that capture these trajectories over decades rather than years. Monitoring frameworks and lessons from the mature field of ecological restoration provide opportunities to leverage decades of practice to inform effective, long-term monitoring for windfarms.

These datasets will become increasingly important as Australia develops new environmental information standards and approaches to end-of-life infrastructure management. Monitoring efficiency is central to keeping costs low and programs viable over the lifecycle of the windfarm.

Long-term monitoring also provides an opportunity to build enduring relationships with local communities, Traditional Owners, commercial fishers, recreational users and citizen scientists. Rather than treating community engagement as a discrete project approval activity, ongoing partnerships can improve environmental knowledge, increase transparency and contribute valuable observations that strengthen ecological understanding. Building trusted monitoring partnerships throughout the life of a project also provides a stronger foundation for navigating future management decisions where environmental, social, cultural and economic values may intersect. These partnerships also create long-term social licence by involving communities in the production of ecological knowledge rather than simply communicating project outcomes.

An important component of nature-inclusive infrastructure is understanding which ecological communities are likely to develop on different forms of offshore infrastructure and how engineering design may influence these outcomes. Factors including substrate composition, surface complexity, orientation, hydrodynamic conditions and water depth all influence patterns of ecological colonisation. Integrating ecological knowledge into the design of foundations, scour protection systems and associated infrastructure presents opportunities to promote desirable habitat characteristics while maintaining engineering performance. Rather than allowing ecological communities to develop opportunistically, infrastructure can be designed to favour habitat characteristics and ecosystem functions aligned with project objectives.

As a practical case study, the paper provides an overview of Australia's first offshore seabed restoration and enhancement trials targeting mesophotic ecosystems. These restoration experiments are testing methods for restoring sponge-dominated benthic communities using engineered substrates and transplanted habitat-forming species within deep offshore environments. The project combines experimental ecology, habitat engineering, high-resolution seabed mapping, autonomous underwater vehicle monitoring and adaptive management to better understand the recovery and development of complex benthic communities. While undertaken in a restoration context, many of the ecological principles underpinning these trials—including substrate selection, habitat complexity, ecological succession, monitoring design and performance evaluation—are directly applicable to the planning and design of future offshore wind infrastructure.

3. CONCLUSIONS

The paper concludes by arguing that nature-inclusive offshore wind is not simply an environmental aspiration—it is a better way of delivering infrastructure. Integrating ecological science into planning, engineering design and long-term asset management has the potential to reduce project risk, improve environmental decision-making and lower whole-of-life costs associated with environmental approvals, monitoring, stakeholder engagement and, ultimately, decommissioning. Rather than treating nature inclusion as a discrete environmental or community engagement initiative, it should be considered a core business function that informs decisions across engineering, design, construction, legal, operations and asset management. Decisions made during concept design are typically the least expensive to change and often determine environmental, engineering and commercial outcomes for decades to come.

Central to this approach is identifying opportunities where environmental, engineering and commercial objectives align. Designing infrastructure that supports ecological function can generate benefits for biodiversity while also strengthening project resilience, building community confidence and reducing uncertainty over future environmental liabilities. These "win-win" and "triple-win" outcomes are likely to become increasingly important as offshore wind developments mature and expectations around nature-positive development continue to evolve.

Successfully embedding nature-inclusive offshore wind will therefore depend not only on advances in ecological science, but on positioning ecology alongside engineering and commercial disciplines from the earliest stages of project development. The greatest opportunity lies in making ecological science part of everyday project design and decision-making—not simply another environmental requirement.

Whole Life Risk-based Design for Subsea Cables - Where Early Design Decisions Can Provide Benefit

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Keywords: cables; Cable Protection System (CPS); risk-based design

1. INTRODUCTION

Understanding whole of life risks for subsea inter-array cables (IACs) and export cables can provide useful evidence to inform early design decisions for offshore wind farm (OWF) development. As prospective projects in the Gippsland Zone offshore of Victoria, Australia move from initial site characterisation surveys to FEED stage exploration of design solutions, it is important that these risks are considered. In this abstract we introduce the opportunities for risk-based design applied to optimisation of Cable Protection Systems (CPS). Particular focus is given to a risk-based integrity approach introduced in the British Standard 10009 [1].

2. RISK-BASED DEISGN FOR CABLES

OWFs are spatially distributed assets, connected internally via IACs and connected to shore via export cables. In contrast to oil & gas pipeline assets, OWF cables present little personnel safety risk in failure - noting much of the guidance for OWF cable on-bottom analysis has been adopted from the O&G industry, which has a significantly more hazardous safety profile [2].

Furthermore, the interconnected nature of OWF arrays means that the criticality in failure of different IACs and the export cables within the OWF differs greatly. This criticality variation is treated explicitly in the British Standard 10009 [1], where it is recognised that the failure of an IAC carrying the capacity of a single wind turbine generator (WTG) is far less consequential than the failure of an export cable carrying up to the full capacity of an OWFs. The offshore repair spread for both cables may be relatively similar, with similar vessel mobilisation costs etc., but the lost production cost is far greater for the export cable.

It is also crucial to recognise that the spatially distributed nature of the cable assets means the probability of failure under a given limit states is also likely to vary. Seabed, metocean, and bathymetric conditions varying across an OWF site, coupled with cable route directionality, can lead to higher probability of failure at some cable locations [3]. This can be the case even if a consistent design extreme condition return period is used.

In early project development, where some flexibility of design is still available, it is important to consider the above variation in failure consequence and probability to inform design decisions. This recognition of risk as consequence x probability can be leveraged to make optimised design decisions for cables, as shown in [3]. Section 3 provides an example of such an approach, where directionality of CPS approaches to WTGs and the offshore substation (OSS) are varied to test sensitivity of Ultimate and Fatigue Limit States (ULS & FLS) to design decisions.

3. CABLE LAYOUT – THE CONSEQUENCE OF EARLY-STAGE DECISIONS

Typically, OWF cable layout design happens at an early stage of a project driven by cost considerations (minimisation of length), broad technical considerations (avoidance of flagged ground risks) and environmental / planning considerations. This global layout is then matured to provide detail on micro-routing and structure interfaces.

It is at this juncture, where structure interfaces for cables are being detailed, that whole-life risks for cables can be influenced. Typical design for structure interfaces includes the short, exposed cable catenary between the structure and the seabed, termed the CPS, visualised in Figure 1.

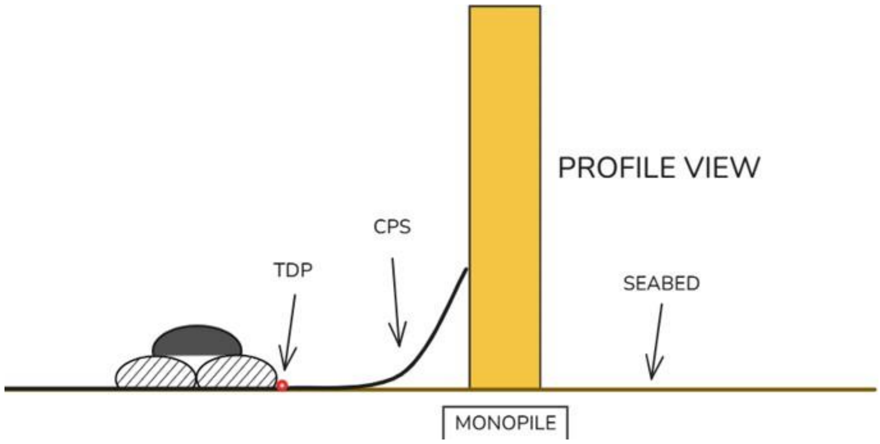

Figure 1 Schematic of WTG structure / cable interface, showing the exposed CPS between the monopile foundation and the touch-down point (TDP)

The CPS exposes a section of the cable (typically designed to be static) to environmental loading that may lead significant extreme and fatigue loads [4]. Industry practice has been to stabilise and protect the CPS using either a rock berm or rock bags.

However, the engineering requirements on stabilisation can vary significantly dependent on the orientation of the CPS relative to the prevailing metocean conditions. Flow amplification and disturbance at different points around structures may result in variation of design flow conditions by a factor of 2 between cables located at different orientations. The complexity of the flow field around the structures can also result in significant loading variation expected at the CPS and CPS stabilisation. Figure 2 presents results of Computational Fluid Dynamics (CFD) simulations of flow around a MP under reversing wave conditions.

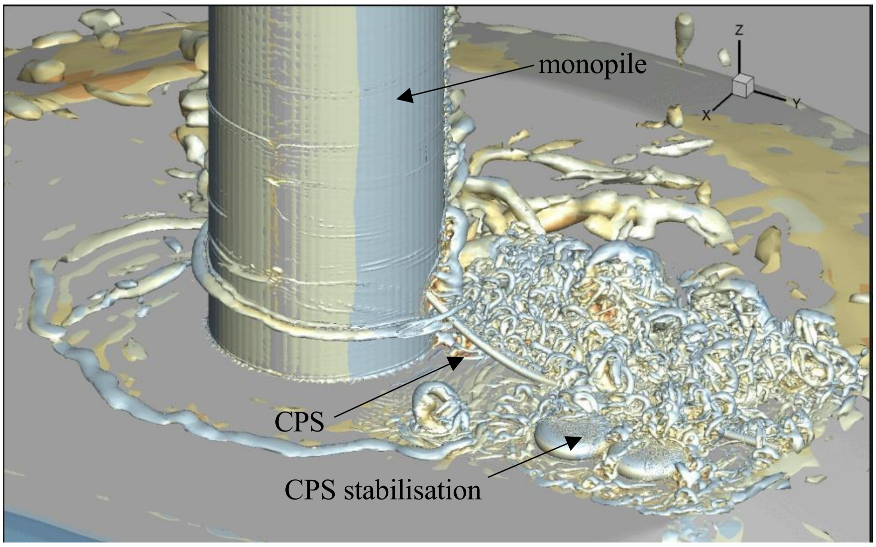

Figure 1 Visualisation of CFD simulation results under reversing wave flow conditions around a monopile foundation, with CPS and CPS stabilisation (rock bags) shown (courtesy Feifei Tong, Adelaide University)

4. PROJECT EXAMPLE – UK OWF CPS DESIGN

Early-stage design can account for such variation by considering simplified response models for ULS and FLS scenarios of the CPS to guide orientation selection. Table 1 presents a comparison of assessed cumulative fatigue damage of a CPS for an OWF in the UK, varying the orientation by 60 degrees. Whilst the absolute variation of cumulative fatigue damage is not expected to vary to this magnitude with full, detailed analysis, this simplified approach indicates a significant benefit of changing to orientation A + 60 degrees to reduce CPS exposure to FLS risk.

Table 1 Ratio of cumulative damage of CPS at bellmouth exit & touchdown point for varying orientation – Orientation A & Orientation A + 60 degrees

Location	Orientation A / Orientation A + 60 degrees
Bellmouth exit	$\sim 10^2$
Touchdown point	$\sim 10^3$

Furthermore, at the jacket founded OSS directional considerations were found to reduce the flow amplification factor required to be accounted for in design of rock bag or rock berm stabilisation of CPS by approximately half. This is a significant effect, as both IAC and export cables interface with the OSS. Understanding the variation of extreme load due to cable directionality can inform how IAC and export cables are designed to enter / exit the OSS. From a risk-based perspective, considering consequence of failure, it is likely to be preferred to orient the export cables in such a way to reduce probability of failure, whilst accepting that this might expose some IACs to a higher probability of failure.

5. CONCLUSIONS

Understanding variation of risk across an OWF at an early stage in project life can provide benefits in whole-life costs of cable infrastructure. The above project example demonstrates the need for early project life treatment of cable risks to optimise cable layout design. In particular, benefits of design variation in CPS orientation selection were observed for both the FLS considerations of the CPS at the WTGs and the secondary stabilisation ULS considerations at the CPS on the OSS.

With early-stage project data, these design decisions can be explored, providing an understanding of the risk to cable assets. Coupling the knowledge of probability of failure variation with an understanding of consequence of failure of different assets can drive design decisions that optimise reliability of more critical assets, whilst accepting that some assets in the OWF may be exposed to a higher level of risk. This is justified by understanding the risk (probability x consequence) is acceptable from a whole-life perspective.

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Structural Stability of Suction Bucket Foundations for Offshore Wind Turbines

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Keywords: Offshore wind; Suction bucket foundation; Buckling; Soil–structure interaction; FE analysis

1. INTRODUCTION

Australia is pursuing a significant expansion of renewable energy infrastructure, with offshore wind expected to play a major role in the transition toward a low-emission energy future. The successful deployment of offshore wind farms requires foundation systems that are economical, environmentally responsible, and suitable for Australian offshore conditions.

The project aims to develop an innovative offshore wind turbine installation system based on suction bucket foundations, enabling rapid deployment, reduced environmental impact, and lower installation costs. The broader vision is to facilitate the assembly of wind turbines onshore, utilise floating transportation systems, and minimise reliance on heavy lifting vessels during installation.

Among the key technical challenges associated with suction bucket foundations is the risk of structural instability during suction-assisted installation. Although suction installation offers substantial economic and environmental advantages, the pressure differential required to penetrate the foundation into the seabed can induce significant compressive stresses in the bucket skirt. If the applied suction exceeds the structural resistance of the foundation, shell buckling may occur, potentially leading to installation failure and substantial economic consequences.

2. BACKGROUND

Suction bucket foundations consist of large-diameter cylindrical steel shells that are installed by generating negative pressure within the bucket cavity. The resulting pressure differential produces a downward force that assists penetration into the seabed while reducing soil resistance around the skirt tip. This installation method eliminates many of the challenges associated with conventional pile driving, including noise generation, heavy equipment requirements, and lengthy installation operations.

Despite these advantages, several documented failures have demonstrated the vulnerability of suction buckets to buckling during installation [1]. Historical incidents have shown that excessive suction pressures can cause severe circumferential deformation of the bucket skirt, resulting in irreversible structural damage and unsuccessful installation [2].

The buckling resistance of suction bucket foundations is strongly influenced by geometric imperfections, material nonlinearity, installation depth, and the restraint provided by the surrounding soil [2–3]. Existing shell design approaches commonly assume simplified boundary conditions. In reality, however, the surrounding soil provides complex and nonlinear support conditions that vary with soil type, stiffness, strength, and embedment depth and cannot be adequately represented using idealised assumptions. Consequently, realistic representation of soil–structure interaction is required to obtain reliable estimates of buckling resistance [3–4].

Furthermore, Australian offshore regions are characterised by a wide range of seabed conditions, including dense sands, silty sands, soft marine sediments, and carbonate soils. These variations can significantly influence soil–structure interaction and consequently the buckling behaviour of suction bucket foundations. Therefore, Australian-specific assessment methodologies are required to support the safe and economical deployment of offshore wind infrastructure.

A comprehensive literature review has been conducted to evaluate current knowledge on suction bucket buckling during installation, including the effects of geometric imperfections, soil restraint, installation depth, and nonlinear structural response [2–7]. The review identified that, although previous studies have primarily focused on conventional suction bucket foundations, limited attention has been given to the buckling behaviour of compartmented suction bucket foundations, the optimisation of internal stiffening arrangements, and validation against field-scale installation data. This thesis aims to address these gaps.

3. APPROACH

This study investigates the structural stability of suction bucket foundations during installation through advanced finite element modelling. The numerical framework incorporates geometric and material nonlinearities together with geometric imperfections representative of fabrication-induced deviations.

The assessment procedure consists of an initial Linear Buckling Analysis (LBA) to identify potential instability modes, followed by Geometrically and Materially Nonlinear Analysis with Imperfections (GMNIA) to evaluate realistic buckling resistance and post-buckling behaviour. Soil–structure interaction is explicitly represented to capture the nonlinear restraint provided by the surrounding soil. The analyses investigate the influence of soil properties, installation depth, and imperfection amplitude on structural performance, providing a more realistic representation of boundary conditions than conventional shell design approaches.

The developed framework will be used to investigate the influence of Australian offshore soil conditions on the buckling behaviour and critical suction pressures of suction bucket foundations during installation. Subsequently, the framework will be extended to assess the buckling behaviour of compartmented suction bucket foundations incorporating alternative internal stiffener arrangements. Parametric studies involving different compartment layouts, stiffener geometries, and stiffener dimensions will be undertaken to identify structurally efficient configurations that maximise buckling resistance while minimising material usage and installation costs.

An example application of the proposed numerical framework is presented in Figure 1, which compares a documented suction bucket buckling failure with a preliminary finite element simulation developed in the present study. The similarity between the observed and simulated deformation patterns demonstrates the capability of the numerical framework to capture representative buckling mechanisms.

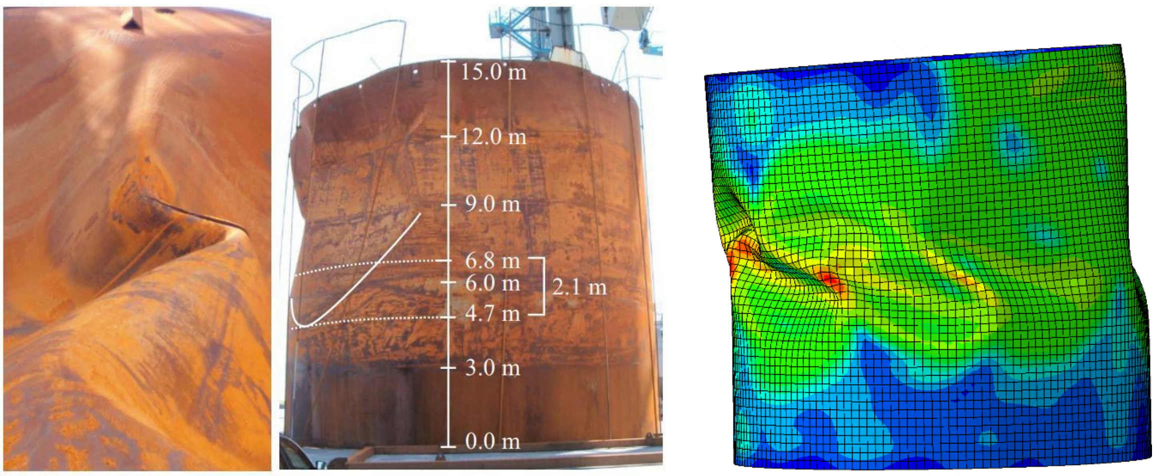

Figure 1. Comparison of a documented suction bucket buckling failure in Wilhelmshaven, Germany (Bakmar, 2009) (left), and a preliminary finite element simulation developed in this study (right).

4. DISCUSSION

The successful implementation of suction bucket technology depends on achieving a balance between the suction pressure required for penetration and the structural capacity of the foundation. Overly conservative designs increase fabrication costs, while inadequate consideration of buckling risks can compromise installation success.

The proposed research addresses this challenge by integrating realistic soil–structure interaction, geometric imperfections, and nonlinear structural response within a unified numerical framework. Furthermore, the planned investigation of the buckling behaviour of compartmented bucket configurations and stiffening systems provides an opportunity to optimise structural efficiency and reduce material consumption while maintaining adequate installation safety margins.

As part of the broader CRC-P project, a reduced-scale prototype is scheduled for fabrication and installation at an appropriate offshore location. The monitoring data obtained from this deployment will provide an important basis for validating the finite element modelling framework developed in this thesis and assessing its predictive capability under field conditions.

The outcomes are expected to contribute to improved design guidance for suction bucket foundations operating under Australian offshore conditions. Within the broader CRC-P project, the research provides a critical component of the integrated offshore wind installation system by addressing one of the primary structural risks associated with suction-assisted deployment.

5. CONCLUSIONS

This study represents one component of the broader CRC-P project, Holistic Economical Offshore Wind Turbine Solution for Australia. Within this wider program, the present work focuses on optimising the structural design of suction bucket foundations for Australian subsea soil conditions, with the aim of improving installation stability and overall foundation performance.

Suction bucket foundations offer significant advantages for offshore wind applications; however, buckling during suction-assisted installation remains a critical design challenge.

A finite element framework incorporating soil–structure interaction, geometric imperfections, material nonlinearity, and geometric nonlinearity is being developed in this research to assess installation stability under realistic conditions.

Future stages of the research will investigate the buckling behaviour of compartmented bucket foundations with alternative stiffening arrangements to identify structurally efficient solutions that maximise buckling resistance while minimising material usage.

The outcomes will contribute to safer, more economical, and more sustainable offshore wind foundation solutions for Australian offshore developments.

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The Effect of Virtual Camber Morphing on the Torque of Vertical Axis Wind Turbine Blades

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Keywords: Blade-Strut connection; Chord-to-radius ratio; Torque fluctuation; Vertical axis turbine; Virtual camber morphing; Wind turbine

1. INTRODUCTION

Offshore wind energy development is increasingly moving towards deeper waters, necessitating the deployment of floating wind turbine technologies (Robertson et al., 2025). Among the various turbine types, vertical-axis wind turbines (*VAWT*) have attracted considerable attention for offshore applications (Bianchini et al., 2026). The simplest *VAWT* configuration is the lift-based *H-Darrieus* turbine, which typically consists of two or three straight blades with a fixed chord length.

VAWT possess several characteristics that make them well suited for offshore floating installations (Shen et al., 2024). First, they can capture wind from all directions and therefore do not require a yaw mechanism. Second, the generator and drivetrain can be located near the base of the turbine, lowering the centre of gravity and facilitating transportation, installation, and maintenance. Third, the straight blades are relatively simple to manufacture compared with the twisted blades of horizontal-axis wind turbines. In addition, *VAWT* have been reported to generate weaker wakes and achieve higher power density within wind farms (Bianchini et al., 2026). Despite these advantages, *VAWT* generally exhibit lower aerodynamic efficiency than horizontal-axis wind turbines and are subject to significant torque fluctuations. These fluctuations arise from continuously varying angles of attack, changing relative velocities, and blade–vortex interactions during rotor rotation. Numerous conventional approaches that rely on complex blade geometries or active flow-control and actuation systems to improve self-starting performance—often at the expense of aerodynamic efficiency have been proposed to address these challenges (Abdolahifar & Zanj, 2025). Furthermore, because a significant portion of the rotor operates at relatively low elevations, *VAWT* are more susceptible to wind shear effects, which can further influence aerodynamic performance and structural loading.

The blades of an *H-Darrieus* turbine follow an orbital motion and consequently experience complex unsteady aerodynamics characterized by continuously varying angles of incidence and non-uniform pitching rates. This kinematics give rise to a phenomenon known as *virtual camber morphing* (Keisar et al., 2024; Keisar et al., 2020; Struber et al., 2026). Previous studies have shown that the aerodynamic loads acting on a virtually morphing symmetric aerofoil, including the normal force, tangential force, and pitching moment, differ significantly from those acting on an equivalent non-morphing aerofoil.

Unlike the afore-mentioned approaches, virtual camber morphing offers a passive alternative. By exploiting the inherent blade kinematics, this mechanism has been shown to enhance torque generation at low tip-speed ratios (Struber et al., 2026) and thus self-starting performance. Building on this concept, the present study investigates the potential for reducing torque fluctuations by exploiting virtual camber morphing through different blade–strut connection locations.

2. VIRTUAL CAMBER MORPHING

The blades of a vertical-axis wind turbine (*VAWT*) undergo circular orbital motion during operation, i.e. θ from 0 to 360°. Given, every point along the chord follows a trajectory with a different radius from the rotor centre, this results in variations in both the magnitude and the direction of the local tangential velocity. When combined with the freestream velocity, which acts predominantly in the horizontal direction, the effective angle of incidence varies along the chord. This phenomenon is illustrated in Figure 1 (left). As a result, a geometrically symmetric blade behaves aerodynamically as a cambered aerofoil, with the effective camber continuously changing throughout the rotor's cycle (Figure 1 right). This phenomenon is referred to as virtual camber morphing. In addition to this morphing behaviour, the blade also experiences surge and heave motions when viewed relative to the incoming flow. These motions arise from the continuously changing direction and magnitude of the relative velocity experienced by the blade along its circular trajectory (Figure 1 left).

The combination of virtual camber morphing, surge, and heave motions gives rise to highly complex unsteady aerodynamic behaviour. In particular, the rapidly varying angle of attack can trigger dynamic stall, characterised by the formation and convection of leading-edge and trailing-edge vortices. These vortical structures are subsequently shed into the wake and may interact with the blades during the downwind portion of the rotor's cycle, significantly influencing the aerodynamic loads, torque production, and overall turbine performance. Virtual camber morphing has been shown as potential way to improve self-star performance of *H-Darrieus* turbine. In this paper, the effect of virtual camber morphing on the reduction of torque fluctuation is investigated.

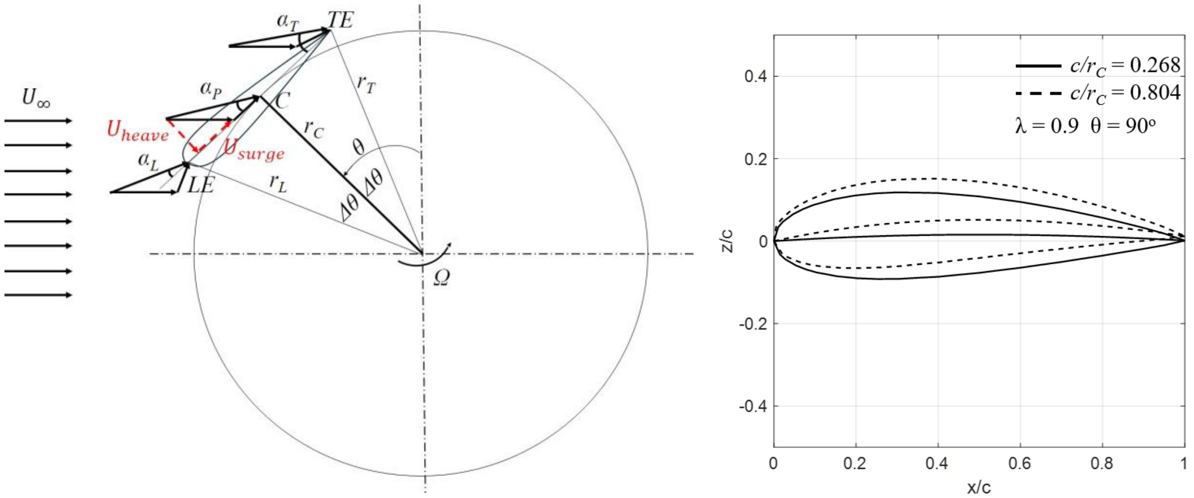

Figure 1 (Left) Relative velocity triangles illustrating the variation of the effective angle of attack along the blade chord showing surge and heave velocity vectors at the strut-blade connection. (Right) Virtual camber morphing exhibited by blades with different chord-to-radius ratios. The results shown correspond to a blade–strut connection located at the mid-chord position $x_c/c = 0.5$.

3. METHODOLOGY

CFD is used to investigate VAWT self-starting due to its ability to resolve unsteady flow and torque fluctuations (Fazlizan et al., 2025; Struber et al., 2026). Two-dimensional transient simulations were conducted using a pressure-based solver with a sliding-mesh approach, assuming incompressible flow. The *k–ω* SST-based SBES model was adopted to capture separation and vortex dynamics. A single blade of *VAWT* with a NACA0021 profile, a rotor radius of 0.25 m, and two chord-length configurations corresponding to chord-to-radius ratios (c/r_C) of 0.268 and 0.804 with three chordwise strut blade connection positions x_c/c = 0.25, 0.5, and 0.75, and *tip-speed-ratio (λ)* of 0.2 to 2 with 0.2 increment were investigated. Wind speeds $UU_\infty = 5$ m/s were considered, with Reynolds numbers ranging from ~2.2×10^4 to ~6.7×10^4 depending on *c* and *λ*. Second-order spatial discretization schemes for pressure and momentum, and a bound second-order implicit scheme for time advancement were used. Convergence was achieved with residuals below 10^{-5}.

4. RESULT SUMMARY & DISCUSSION

Computational Fluid Dynamics (*CFD*) simulations were conducted at $\lambda = 2$ for turbines with c/r_C of 0.268 and 0.804, and blade–strut connection locations (x_c/c) of 0.25, 0.50, and 0.75. Intra-cycle torque variations are presented in terms of torque coefficient, C_T against azimuthal angle, θ.

For lower c/r_C (0.268) blades (upper figure 2) plot shows the results show strong torque fluctuations associated with the passage of the three blades over a full cycle. The case with $x_c/c = 0.25$ exhibits the largest fluctuation amplitude, while the 0.5 and 0.75 configurations show comparatively similar but reduced variations. The intra-cycle averaged torque is also relatively low for this configuration. In contrast, the longer blade configuration the longer blades turbine with $c/r_C = 0.804$ shows significantly reduced torque fluctuations while producing higher overall torque compared to the shorter blade cases (lower figure 2). In particular, the $x_c/c = 0.50$ configuration exhibits the least torque variation and positive cycle-averaged torque.

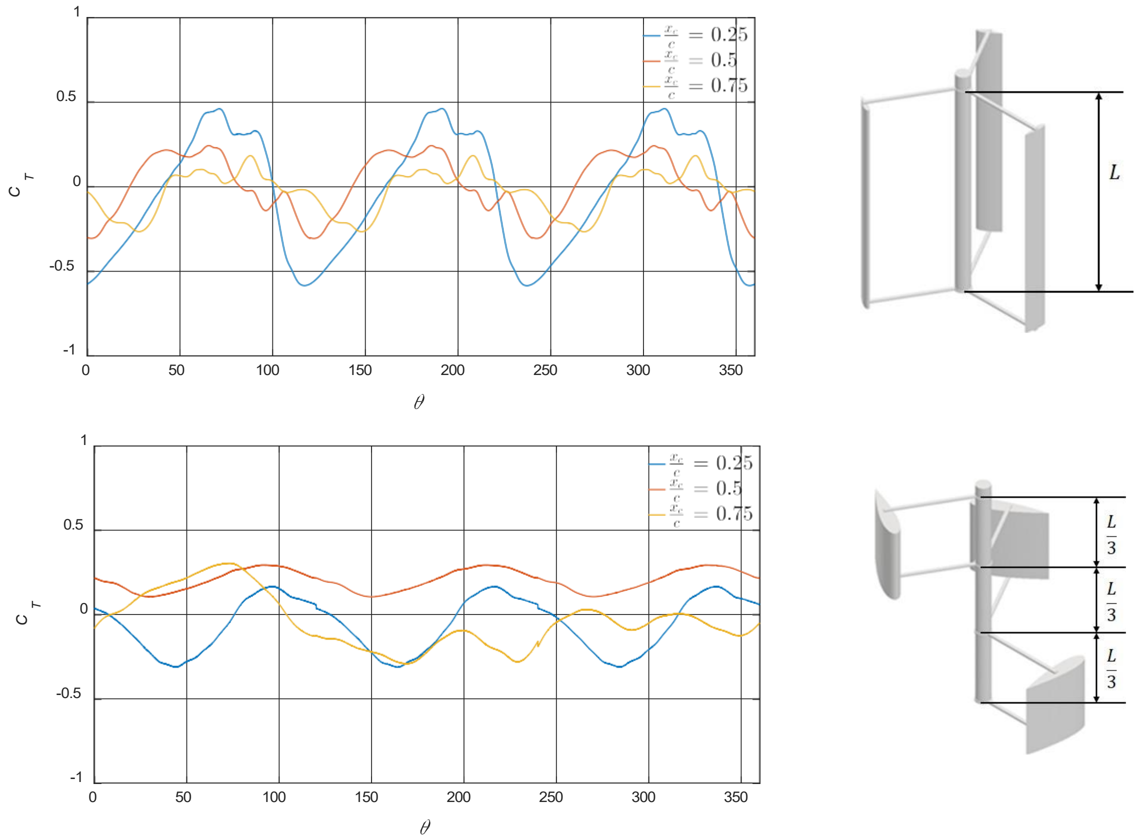

Figure 2 $C_T - \theta$ comparisons for c/r_C = 0.268 (upper figure) and 0.804 (lower figure). Note $C_T = \frac{T}{\frac{1}{2}\rho 2 r L U_\infty^2}$.

5. CONCLUSIONS

The paper demonstrates that both the blade–strut connection location, x_c/c and the chord-to-radius ratio, c/r_C can be used to exploit virtual camber morphing, providing a potential means of improving the performance of vertical-axis wind turbines. These findings suggest a promising design strategy for enhancing *VAWT* performance in floating offshore wind applications.

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UK Case Study: Driving Long-Term Commitment and Local Benefit Through Offshore Wind Clusters

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1. INTRODUCTION

The Humber region, on the East Coast of the UK, is a long-established industrial base, with oil refineries, chemical processing and steel manufacturing centred around an estuary and nationally and globally recognised ports. As the UK's highest carbon-emitting region, the Humber is now transitioning the industries that have long defined it while also welcoming and pioneering offshore wind.

The Humber's proximity to offshore wind farms and access to port infrastructure stimulated early investment in offshore wind projects in the mid-2000s. However, it was the sustained commitment of regional businesses, government stakeholders and the wider community network that anchored the industry in the region for the long term. Today, the Humber is home to eight operational offshore wind farms, including the world-record-breaking Hornsea 2, with a further four in development and two currently under construction.

Today, as the UK's largest and most established offshore wind cluster, the Humber is recognised globally as a blueprint for developing, constructing and operating offshore wind farms that deliver lasting social and economic benefits.

Fig. 1 Map of Humber offshore wind farms and status

2. THE HUMBER OFFSHORE WIND CLUSTER

The Humber Offshore Wind Cluster is one of seven nationally recognised offshore wind clusters in the UK spread across the coasts of Scotland, England, and Wales. Whilst all share a common desire to build their communities, each carry distinct propositions and are at varying levels of progress.

Fig.2 Map of UK Offshore Wind Clusters[1]

Although the Humber had been recognised as a centre of excellence for offshore wind and renewable engineering from the late 2000s into the mid-2010s, the cluster's early development and growth were largely informal and organic. During this period, committed local actors—including local government, developers and owners, supply chain businesses, and education providers—helped anchor several offshore wind farms, develop supporting infrastructure and build a skilled workforce, positioning the Humber early as an emerging offshore wind cluster.

Formal recognition of the Humber Offshore Wind Cluster came in early 2019 with the publication of the Offshore Wind Sector Deal, one of ten sector deals aligned with the UK Industrial Strategy. Agreed between government and industry, the ambitious deal aimed to strengthen the UK's leadership in offshore wind and maximise social and economic benefits through defined objectives and clear targets. It identified the Humber as one of eight offshore wind clusters and placed significant importance on the

[1] RenewableUK Offshore Wind Investment Guide p.7

role of clusters in 'places' where activity and investment are concentrated around ports and within coastal communities, often with established industrial ecosystems.

The Cluster's first formal meeting brought together 20 senior representatives from manufacturers, developers, policymakers, businesses, academic institutions, trade and membership organisations, and training providers. The group undertook a critical assessment of the cluster's strengths and opportunities, using the five themes set out in the Offshore Wind Sector Deal—place, ideas, infrastructure, people and business environment—alongside the attributes identified in the Offshore Wind Place (Clusters) Playbook, produced by the Offshore Wind Industry Council. The playbook synthesised key academic literature on industrial clusters, including work by Professor David B. Grant of the University of Hull, which identified 20 key attributes of an advanced offshore wind cluster.

Fig.3. Attributes of an advanced Offshore Wind Cluster[2]

Building on this work, the Humber Offshore Wind Cluster published the *Humber Offshore Wind Cluster Prospectus* in 2020. Co-created with, and owned by, key regional representatives, the prospectus serves as the region's plan for advancing the Humber Offshore Wind Cluster, maximising social and economic benefits, and supporting growth in line with national targets. The ongoing challenge is to ensure the cluster continues to deliver benefits for the region while contributing to strategic national priorities.

[2] The Humber Offshore Wind Cluster Prospectus p.14

Fig.4 Key actors and specialisms mapped[3]

Chaired by Orsted, the Humber Offshore Wind Cluster Network serves as both a convening body and a collective voice for the industry, while also driving delivery of the actions identified in the prospectus. To support this work, focused subgroups were established around the key themes of business environment, place, infrastructure, innovation and people, with specific actions assigned to each.

Since 2019, the Humber Offshore Wind Cluster has delivered and supported a range of business events, raised awareness of careers in offshore wind through community outreach, and led targeted interventions with schools, teachers, women and girls. It has also continued to raise the profile of the industry on the national and international stage, alongside many other initiatives that support the cluster's long-term growth and impact.

3. CONCLUSION

Offshore wind clusters continue to be recognised across the UK as a key vehicle for delivering national ambitions while ensuring regional benefit, growth and prosperity. The Humber Offshore Wind Cluster is testament to this, with collaboration and commitment embedded in its DNA, both formally and informally, over the past two decades. Founded on strong relationships, a shared location and a common interest in the future growth of the offshore wind sector, the Cluster is now formalised, nationally and internationally recognised, and organised to ensure that growth and benefit continue, opportunities are anchored, and investment is secured.

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Offshore Wind Sector Deal [now withdrawn] - 2019

[3] The Humber Offshore Wind Cluster Prospectus p.23

Environmental Monitoring of Offshore Wind Projects: A Whole Lifecycle Approach

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Keywords: Environmental monitoring, Offshore wind, Project lifecycle

1. INTRODUCTION

Offshore wind projects interface with a diversity of environments, with infrastructure spanning from offshore wind turbines in open ocean and coastal seas, through transmission cables along shoreline crossings and corridors on land.

Understanding the environment, from the ocean through the coast and land, is therefore critical to inform offshore wind projects through their lifecycle in terms of assessing and managing potential environmental and biodiversity impacts (Watson et al., 20205) as well as informing project planning and opportunities for nature inclusive design (Cosgrove, 2024).

This presentation looks at the needs for environmental monitoring through the whole project lifecycle. Examples of good practice on surveys of environmental sensitivities at different stages of projects, from local and international experience are presented, leading insight and recommendations for consideration in the development of the offshore wind industry in Australia.

2. BACKGROUND

The stages in an offshore wind project lifecycle can be broken down in various ways. For the purpose of this presentation we will consider:

- Feasibility
- Planning, Consenting & Design
- Pre-construction
- Construction
- Operations & Maintenance
- Decommissioning

Key environment components and sensitivities or receptors for offshore wind projects include: birdlife, marine mammals, fish, benthic and pelagic habitats, flora and fauna, as well as the physical ocean and coastal environments.

Developing a whole of environment understanding is critical to inform projects striving for best environmental, biodiversity and socioeconomic outcomes, while delivering project objectives. This requires environmental monitoring and ecosystem understanding at a regional scale beyond the immediate project area. The monitoring requirements and scope need to be considered in the context of each stage of the project lifecycle.

3. APPROACH

A set of examples and resources from international and local experience are presented.

Insights about environmental monitoring required at each stage of the project lifecycle for different environment components and sensitivities are derived from the examples presented.

Recommendations for environmental monitoring approach in the context of the developing offshore wind industry in Australia are discussed.

4. DISCUSSION

Environmental monitoring targeted by lifecycle stage, with consideration on strategic importance, is paramount to inform offshore wind project decisions. Some examples are presented on Table 1.

Table 1 Examples of environmental monitoring required throughout the lifecycle of offshore wind projects.

Project lifecycle stage	**Environmental monitoring – key examples**	**Commentary about strategic importance**
Feasibility	Site-specific metocean and geophysical surveys	Critical to understand the physical environment, quantifying the wind resource, climate and ground conditions to inform project feasibility and design
Planning, Consent and Design	Environmental baseline characterisation programme	Comprehensive monitoring, covering seasonal and interannual variability, to develop understanding of whole of environment/ecosystem and identify key sensitivity/receptors, potential impacts and management strategies
Pre-Construction	Localised, detailed benthic mapping	Necessary to inform final design and micro siting of main project components, e.g., location of turbine foundations, offshore substations and cable routes
Construction	Underwater noise monitoring and marine fauna observations	Required to manage potential impacts to sensitive receptors, e.g., marine mammals, during construction activities
Operations & Maintenance	Bird life monitoring	For projects where bird collision and displacement risks are identified, active monitoring throughout the O&M stage is required, to inform adaptive management
Decommissioning	Benthic and pelagic habitat sampling	To be analysed against baseline conditions as well as changes through the operational life of projects, with consideration of the regional environmental context, to inform key decision about fate of infrastructure, e.g., remove or leave in place foundations and cable scour protection

Key discussion points:

- The environment is more often a continuum of gradients than a set of discrete dimensions. This highlights the importance of monitoring local indicators as well as the regional context and global trends to identify cause-effect relationship, spatial and temporal scales of change (Turrell, 2026).
- Considering the above mentioned, as well as the context of evolving technologies of offshore wind and environmental monitoring (Kuo et al., 2022), key questions arise around: What are the gaps and priorities for environmental monitoring for the emerging offshore wind industry in Gippsland? More broadly in Australia? What about data management and accessibility?

5. CONCLUSIONS

In relation to environmental monitoring and management, there are many learnings from international experience of offshore wind, but also from other local offshore industries, covering the whole of project lifecycle. As the Australian offshore wind industry develops, it is imperative to leverage from those experiences to inform, design and implement environmental monitoring at each stage of project lifecycle.

For offshore wind project design to be nature inclusive, it must consider the whole of environment functioning. In turn this requires systematic, long-term environmental monitoring to develop a proper understanding of cause-effect relationships.

In order for environmental impact avoidance, mitigation, management and enhancement strategies & measures to be effective, these need to be informed by strategic environmental monitoring but also must remain adaptive as we learn more throughout the project (and industry) lifecycle, maintaining flexibility and leveraging from technology as it evolves.

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The Application of Underwater Acoustics for Offshore Wind: from Impact Assessment to Construction

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Keywords: passive acoustics; underwater noise; marine mammals; mitigation; monitoring

1. INTRODUCTION

Underwater acoustics plays an important role in all aspects of the execution of offshore wind projects. This talk will step out the role of underwater acoustics in baseline monitoring, Front End Engineering Design (FEED), the preparation of environmental impact assessments, real time mitigation, sound source verifications, and the long-term monitoring of effects and species responses. JASCO Applied Sciences (JASCO) has a unique perspective on the integration of passive underwater acoustics from a global set of offshore wind projects. This experience will be drawn on to present examples to inform the discussion about how the integration of passive underwater acoustics during project design can be optimised to assist project delivery.

2. DISCUSSION

Modelling and predictive studies are a key part of the FEED and environmental impact assessment (EIA) process, and the accurate representation of different pile designs, considering different seabed soil types, installation methodologies and noise attenuation systems can assist with key engineering and wind farm design decisions. The process that is taken during FEED and EIA can be cyclical. For example a pile run event during the construction of a wind farm in the USA, a sudden uncontrolled penetration that presents a serious construction and safety hazard, led to the consideration of the use of a combination of vibratory and impact pile driving. Despite many projects having already proceeded through the FEED and EIA process, the FEED and EIA processes revisited to account for the change in methodology. The complexity this added to the EIA process will be demonstrated and discussed.

The process and considerations for modelling to support an EIA will be discussed and will draw on examples from the recent regulatory submission by Southerly Ten for the Star of the South (SOTS) project (Koessler et al. 2025). This project has so far included over four rounds of detailed underwater acoustic modelling from 2020 to 2025 to predict the underwater noise emissions during wind farm construction. This has included noise generated from monopile and jacket pile installation using impact pile driving and vibro-piling installation methods as well as, associated construction vessel operations. The approach for SOTS has been iterative to refine project decisions, supported by refinements in modelling inputs and methods. The confidence of the modelling improved with a reduction in assumptions, due to refinement in increased confidence in the seabed soil types and the mitigation approaches to be applied, including three noise abatement systems (NAS), a double big bubble curtain (DBBC), hydro sound dampener (HSD) and modified hammer system (MHS) (PULSE). Examples of underwater acoustic modelling, including the integration of source models, full-waveform modelling, modelling particle motion and bubble curtain insertion at specific depths are provided.

Passive acoustic monitoring is recognised as a valuable approach for baseline surveys that is suitable for determining species presence, timing and relative acoustic abundance. The equipment used and the detection and validation methodology applied can have a considerable influence on the results of the study. It is essential to use robust approaches. There are innovative techniques now, being pioneered by JASCO, which apply directional sensing moorings to develop a SCAN, or 'spatial count of animal number' to count the number of directions that a species' calls arrive from over a short period of time. This information can be turned into heat maps showing the normalised density of automated detections for individual species (McPherson et al. 2026). Depending on the placement of moorings and the vocalising species, this approach can also allow for the tracking of individual animals as they move through the area, which can provide detail on habitat usage by fauna to inform the EIA.

In all projects in US Federal waters, federal regulatory approval for offshore wind construction permits have required Sound Field Verification (SFV) to confirm that the underwater sound levels remain at or below predictions of pile driving noise to evaluate the potential for physiological injury or behavioural disturbance of marina fauna (e.g. DoC and NOAA 2020, DoC and NOAA 2024). Similar requirements may be asked of Australian projects. JASCO has conducted SFV measurements for over 200 offshore wind foundation installations on the US Outer Continental Shelf (Küsel et al. 2024, Ozanich and Küsel 2025). There are two types of SFV required for US projects, Thorough and Abbreviated. During the initial stages of foundation installation, developers are required to conduct Thorough SFV (TSFV) to measure sound levels as a function of distance from the pile. Curve fitting techniques are applied to these data to derive an empirical regression curve, which defines the acoustic conditions at the time of installations. Empirical models help quantify how sound attenuates with range; they are used to validate or refine predictions made with more sophisticated models. Subsequently, acoustic recordings are collected at a single range (typically 750 m) during a monitoring phase known as Abbreviated SFV (ASFV). Using the previously derived empirical propagation models, these measurements are evaluated to confirm whether noise levels remain below predicted thresholds and to ensure that any required mitigation measures are appropriate.

Preliminary comparisons show good agreement between predictions and measurements during pile driving. Recordings collected across projects, seasons, pile characteristics, pile driving equipment, noise attenuation systems, and environments provide a unique opportunity to study noise from installation of large monopiles. This valuable dataset allows regulators and developers to make informed decisions to ensure the practicable management of impacts from offshore wind construction. A review of the measurements, findings, and implications will be presented. These will include: noise mitigation is effective at reducing distances to sound levels when deployed correctly and checked frequently; modelled predictions using accurate models provide a reliable basis for field measurements; TSFV are useful for providing a baseline of construction sound levels but may be sensitive to other secondary noise, whilst ASFV are useful to ensure sound reduction protocols continue to be used and are effective throughout the project.

Real-time passive acoustic monitoring is being increasingly employed to facilitate real time mitigation (ConocoPhillips 2024, Empire Wind 2024) . Particularly for cryptic species and in areas where visual observations are often hindered by poor weather, or where potential impact ranges far exceed that which can be monitored by visual observers. A recent Australian example includes the use of SLOCUM gliders equipped with hydrophones and a JASCO observer system to provide near real-time acoustic detections of baleen whales in proximity to operations, while US offshore wind projects (e.g. DoC and NOAA 2020, DoC and NOAA 2024) have involved deploying moorings to cover a 10 km radius monitoring zone for marine mammal mitigation.

Passive acoustic monitoring can be used as a tool to monitor the long-term effects of construction and operations on species, and to characterise the noise from the windfarms. For example, where good baseline information exists, post activity monitoring can be used to establish whether there have been any short- or long-term changes in species presence, densities or distributions. The US has required such long-term monitoring as part of permit conditions for marine mammals, and separately the Hywind projects provides a good example of characterising the noise from operational floating wind farms (Welch et al. 2025, Kriesell et al. 2026)

3. CONCLUSIONS

This presentation is a collation of the potential challenges and learnings from perspective underwater acoustics applied throughout construction life cycle of offshore wind farms. We draw on examples and experience during the last decade for a variety of globally distributed offshore wind farms, from concept to construction. We present the cyclical nature of FEED design and EIS implications from environmental baseline characterisation, analysis and predictions of underwater acoustic impacts, followed by the application of in-situ noise measurements during construction, for assessing compliance and mitigation performance. Specifically, highlighting where improvements in technology can lead to better and more robust outcomes. Looking to the future, we link the presented technologies and tools to the increasing potential development and expansion of offshore wind and how management and development can procced together in lock step.

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Refined Offshore Wind Farm Collision Risk for Albatrosses and Petrels

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Keywords: Albatross; Biologger; Collision; Procellariiform; Turbine

1. INTRODUCTION

Offshore wind farm risks to birds (e.g. collisions with turbine blades) are a well-established environmental concern (Perrow 2019) and remain a major research priority. However, most evidence on the environmental impacts of offshore wind farms has been derived from northern Europe, despite Australian seabird communities differing markedly in composition. Procellariiform seabirds, including albatrosses, petrels, shearwaters and storm-petrels, highlight this knowledge gap. They are especially prevalent in Australian waters yet remain poorly represented in marine research and offshore wind impact studies (Mott and Clarke 2018, Deakin et al. 2022; Reid et al. 2023). As Procellariiformes include both the world's most abundant seabird family (Procellariidae – the petrels and shearwaters) and its most threatened (Diomedeidae – the albatrosses), there is an urgent need to understand the potential risks posed by offshore wind farm development to these species in Australian waters.

Flight height is among the most influential inputs to collision risk models and collision risk is expected to be low where birds consistently fly below the rotor-swept zone (RSZ). To address this knowledge gap, we deployed biologging devices on Southern Ocean albatrosses and giant-petrels to quantify flight heights and develop species-specific flight height profiles for offshore wind collision risk assessment.

2. METHODS

This study formed part of the Australian Government's Renewables Environmental Research Initiative (RERI), which is supporting research to reduce environmental uncertainty associated with renewable energy development. Between September 2025 and March 2026, we deployed biologgers that recorded location, movement speed, GPS altitude and barometric pressure data. Biologgers were deployed on albatross and giant-petrel species which were captured at sea off south-eastern Australia or at breeding colonies on Albatross Island, Tas; Macquarie Island, Tas; Motu Maha/Auckland Islands, NZ; Motuhara/Forty Fours, NZ; Moutere Hauriri/Bounty Islands, NZ; Moutere Ihupuku/Campbell Island, NZ; Toru/Western Chain, NZ.

Flight heights were calculated from barometric pressure data using a bespoke algorithm for dynamic soaring species, such as the biologged albatrosses and giant-petrels (Miller et al. *in press*). The algorithm explicitly incorporates uncertainty arising from assumptions about wave height and whether birds skim the sea surface during lowest oscillations of dynamic soaring cycles by providing plausible bounds (lower and upper flight height scenarios), in addition to a central scenario. For each scenario, we present species-specific flight height profiles - heights expressed as the proportion of time spent in 1 m altitudinal bands, which are a common input for collision risk models. To calculate flight height profiles, we fitted a lognormal distribution to species-specific flight altitudes (Ross-Smith et al. 2016) and obtained a prediction of time spent per each metre altitude band via a 1000-iteration bootstrap, with logger identity as the bootstrap unit so that each logger contributed equally.

3. RESULTS

We analysed approximately 13 million flight-height observations collected by 136 biologgers deployed across 12 albatross species and both giant-petrel species. We demonstrate that Southern Ocean albatrosses and giant-petrels have generally low flight heights, with 63-82% of flight time spent below 10 m altitude and 87-97% of flight time spent below 20 m altitude (Figure 1). In altitudes above 30 m, which begin to overlap with the RSZ of modern offshore turbines, tracked birds spent 0.8-5.1% of their flight time, decreasing to 0.3-2.3% of flight time above 40 m altitude. Tracked birds generated flight height data day and night, and across a range of weather conditions and geographic regions. These findings suggest that collision exposure may be relatively low for many species under the range of conditions sampled.

However, while flight height distributions were strongly right-skewed, our results reveal that albatross and giant-petrel species routinely, albeit infrequently, attain maximum flight heights within or near RSZ altitudes. When combined with site-specific measures of abundance at proposed offshore wind farms, it is these data that will be central to formal risk assessment.

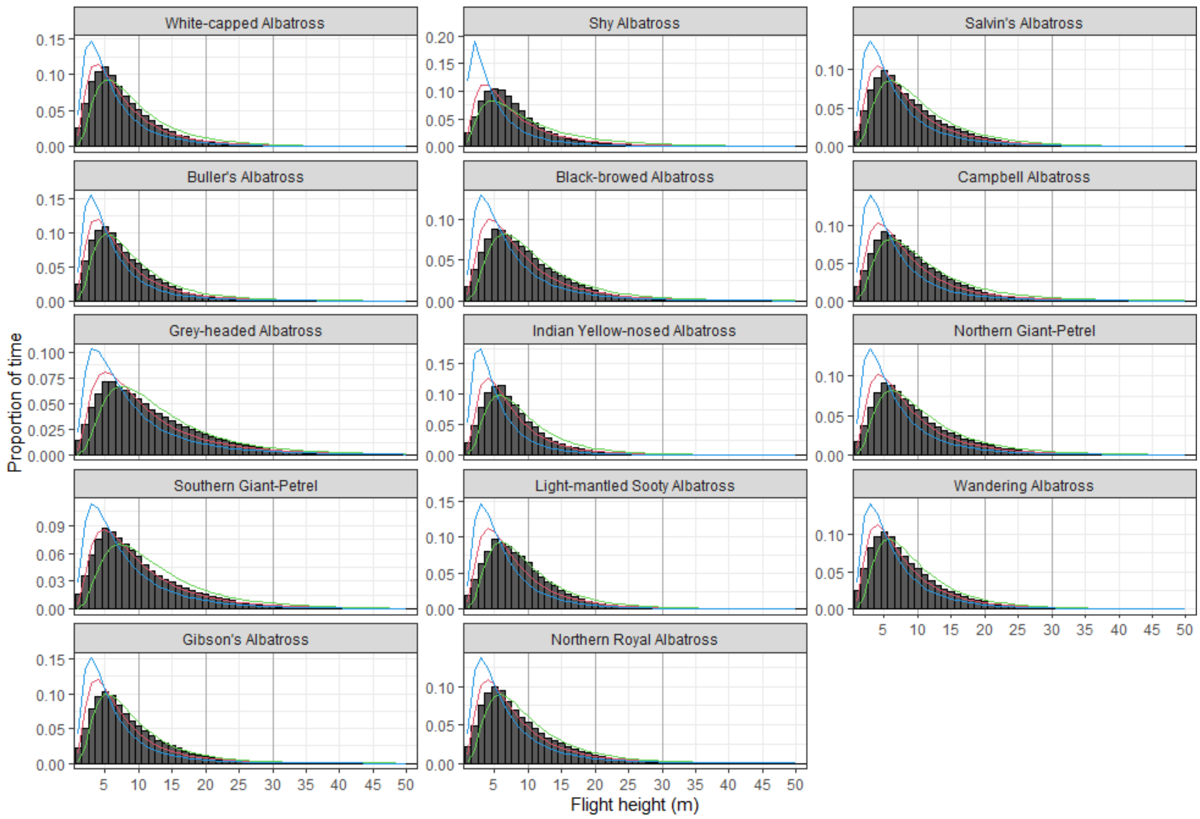

Figure 1 Distributions of flight height above sea level obtained from biologging during the period September 2025 – May 2026. aw flight-height distributions are shown with fitted lognormal curves under the lower scenario (blue), central scenario (red) and upper scenario (green).

4. DISCUSSION

A recent literature review (Miller et al. 2025) found that collision risk model parameters for Procellariiformes—including morphometrics, flight type, nocturnal activity and flight speed—were generally well represented, whereas flight height and avoidance rate remained major knowledge gaps. Mean flight height data were available for only 21 of 146 Procellariiformes and were generally based on sparse evidence, with each species represented by only one or two studies; avoidance rates remained unreported. These two parameters also have the greatest influence on estimated mortality in collision risk models (Masden et al. 2021), making them priority knowledge gaps for offshore wind farm impact assessment in the Southern Hemisphere.

By providing flight height data for 12 albatross and two giant-petrel species, this study substantially addresses one of these gaps for threatened EPBC Act-listed albatrosses and petrels (Commonwealth of Australia 2022). The resulting dataset provides the most comprehensive quantitative assessment of albatross flight height globally. While broadly consistent with flight heights estimated from field observations, these data provide the first quantitative, fine-resolution measurements across the 24-hour cycle, a range of weather conditions and diverse marine habitats. This substantially strengthens the evidence available for collision risk modelling. Given that modern offshore wind turbines are expected to have air gaps exceeding 30 m (the distance between the sea surface and the lower tip of the rotating blades), the flight heights reported here support previous suggestions that collision risk is likely to be relatively low for albatrosses and giant petrels (Reid et al. 2023; Miller et al. 2025).

The flight height results presented in this study are deliberately presented as broad summaries, over the 24-hr cycle, a range of weather conditions and marine habitats. This is designed to make them representative at the broadest level, thereby improving their generality despite individual birds typically contributing data over periods of only several months. However, it is noted that tracked birds ranged across the Southern Ocean and not all the marine conditions they experienced are comparable to those of Australian continental shelf regions that are suitable for traditional offshore wind farm development (<100 m depth). Further analyses will explore a subset of biologger flight heights from these regions, using windspeeds from these regions, on account of the anticipated positive relationship between wind speed and Procellariiform flight height (Ainley et al. 2015), to investigate more locally specific results. However, these analyses were beyond the scope of this study and future studies should be mindful of the potential value of interpreting a subset of the data against the cost of reduced sample size.

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Implementation of an Artificial Intelligence Supported Marine Mammal Acoustic Detection System During Installation of Offshore Wind Farms

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Keywords: marine protected species, marine mammal acoustic monitoring, marine environmental monitoring, impact mitigation

1. INTRODUCTION

To fulfill the acoustic monitoring permit requirements related to marine mammals during offshore wind farm construction in the U.S., Tetra Tech deployed acoustic buoys that processed data on board the buoy using Artificial Intelligence (AI) supported by detectors for seven types of marine mammal vocalizations. Data was transmitted in near real time to shore-based Passive Acoustic Monitoring (PAM) Operators using a satellite connection. Acoustic data from the deployed buoys on two different Atlantic wind farm areas for multiple years have been analyzed, and it has been confirmed that multiple species including Minke whales, Sei whales, Humpback whales and North Atlantic right whales (NARW) were detected in real time by the systems. Uniquely, there is also a large volume of visual monitoring and visual marine mammal detection data collected during the same period by Protected Species Observers (PSOs) stationed offshore to consider when evaluating the acoustic data collected. Many adaptations were made to the acoustic buoys throughout their deployment to improve data transmission, optimize energy consumption and increase operational efficiency. These lessons are directly translatable to supporting operations in Australia for offshore wind, as the species and environmental conditions are identical or similar and both countries employ similar strategies to mitigate potential impacts to marine protected species during offshore industry operations.

2. BACKGROUND

Installation of foundations within offshore wind farms involve the use of pile driving, during which the sound levels produced have the potential to impact marine protected species, like marine mammals, as determined by many environmental regulatory agencies globally. As a result of this determination, many agencies require visual and acoustic monitoring to be performed by PSOs to identify any animals in the area and then implement mitigation actions to reduce or eliminate the potential impacts when these operations are undertaken. One of the purposes of the monitoring conducted is to mitigate for potential impacts to species from sound exposure, where louder marine operations, like pile driving for installation of offshore wind turbines, are usually assessed as having the potential for impacts to animals inside larger zones and therefore requires implementation of monitoring methodologies capable of identifying those species of concern inside large offshore monitoring zones. Recent research has shown that incorporation of AI detection algorithms in PAM systems facilitates monitoring of large zones and real-time processing of extremely large acoustic datasets to maximize detection capabilities (Gervaise et al. 2021). Additionally, the AI provides enhanced capability to identify multiple species' cues simultaneously, which is critical for monitoring large ocean environments with multiple species of concern (Van Parijs et al. 2025).

3. APPROACH

Tetra Tech deployed a series of moored buoys throughout the Wind Development Area, each configured with a broadband hydrophone. This PAM system employs an AI neural network, developed by CHORUS and provided commercially by SenSeaFR with species-specific detectors, and the system alerts remotely located PAM Operators (PAMOs) to potential marine mammal vocalizations when encountered. The PAMOs analyzed the transmitted spectrograms and audio file and confirmed or rejected the detection. By reducing the overall data to be analyzed, relative to a traditional PAM system, the PAMO can manage and assess data from multiple systems without the data becoming unmanageable. This marked increase in efficiency via AI-powered data pre-screening substantially reduces the labor hours required to perform acoustic monitoring of large zones, and thus reduces overall costs associated with the environmental compliance scope for offshore construction.

A combination of buoys, from 4 to 7 units, were active during piling, recording continuously and transmitting potential detections to PAMOs. The active buoys were selected around each active piling site such that a 10-kilometer monitoring zone was achieved. Acoustic data from a broadband hydrophone was automatically processed onboard the buoy in real-time by seven AI supported classifier algorithms running through an AI neural network, where vocalizations from both Mysticete and delphinid species could be detected by the system. U.S. regulatory agencies required that a sufficient sized spectrogram and sufficient length wav files were provided to ensure that the Operator can identify the species and/or call type, but where the file size was also restricted to a size that is manageable for transmission without depleting the system's power to a degree that could jeopardize its ability to continuously operate.

The AI detection index threshold utilized varies between 0.6 and 1, where a low detection threshold leads to a high probability of detection (and a high probability of false alarm) and a high detection threshold leads to a low probability of false alarm (and a low probability of detection). Given that regulatory agencies were more concerned with the potential for real detections to be missed by the detectors, agencies required that low thresholds be set so that human PAMOs could review and confirm all potential detections, including ones with a high likelihood of being false (0.6 to 0.7 for whale calls and 0.7 to 0.8 for delphinid calls). Post-hoc data review was performed to examine the rate of false detections forwarded by the AI detectors for each species to support refinement of threshold settings for future projects.

Acoustic monitoring was performed by remote, shore-based PAMOs who were approved to support the projects based upon their training and acoustic monitoring experience in both the region in which operations were undertaken and in detecting the species of concern found in that region. Regulatory agencies stipulated the number of PAMO required to monitor each system based upon an evaluation of the anticipated volume and complexity of the data that they would review.

The buoys were recording and analyzing acoustic data continuously and during periods absent of marine mammal vocalizations, the buoys sent system health data that confirmed system function every 20 minutes. During periods of possible and active vocalizations, the system also transmitted detection data to the remote PAM operator every 5 minutes

Analysis of Acoustic Detection Events of Marine Mammals:

Detection events included in the analysis were those that occurred when both visual monitoring was undertaken by PSOs and acoustic monitoring was being undertaken by PAMOs. Detection events were defined as a series of observation cues such as whistles, clicks, burst pulses that occur continuously within a defined period of time without interruption and can be grouped together as one event. Detection events were analyzed via calculation of the Spearman Correlation Coefficient to assess the relationship between acoustic and visual detections across species using the spearmanr() function from the scipy.stats package for Python. Detections were aggregated by species or species group, and ranks were assigned to each modality (visual and acoustic) using the rank() function from the pandas package. Rank differences were then calculated to evaluate the relative effectiveness of each detection modality by species.

4. DISCUSSION

Although comprehensive legislation governing protected marine species has existed in many countries for many years, there is often a lack of technical guidance that addresses the execution of many of the field requirements that must be implemented for protected species monitoring and mitigation. These gaps frequently result in misalignment between regulatory agencies and offshore wind developers and their subcontractors with respect to how compliance can best be achieved. One example that has the potential to impact installation operations from both a schedule and cost perspective concerns the lack of parameters that must be used to determine the acoustic monitoring range of a particular system, where most peer-reviewed publications do not assess or report the detection range of the passive acoustic monitoring equipment used in the study. This is exacerbated by the fact that in an ocean environment detection range varies based on region and even daily and hourly conditions at the site and thus, is not constant. Further, there are currently no guidelines that specify what, if any, validation of modeled or predicated detection ranges of systems must be undertaken using field measurements. Successful implementation of a comprehensive protected species monitoring and mitigation program requires that government regulators establish clear parameters for these important components of an acoustic detection system in advance and thus allow developers and technology providers to build the most robust environmental compliance structure to support the project's needs.

5. RESULTS

PAM buoys operated for over 400 days and for over 18,000 hours of acoustic monitoring. Four mysticete species, Humpback whales, Sei whales, NARWs and Minke whales were detected on the deployed PAM systems during active monitoring. Over 1700 detection events of both mysticete and delphinid species were recorded during operation. All species of mysticete that were detected visually over the course of all active monitoring periods were also detected acoustically on the PAM system. Calculation of the Spearman Correlation Coefficient across all six species/species groups indicated there was no statistically significant relationship (ρ [rho] = -0.045; p =0.932) between visual or acoustic detections across species. Review of rank differences, however, showed important species-specific differences in relative effectiveness of detection modality. Delphinids were the most frequently detected species and were detectable by both acoustic and visual methods. Sei whales displayed a strong bias towards acoustic detection and had the strongest positive rank differential. Humpback whales also showed a moderate bias for acoustic detection to visual, though less notable than Sei whales. North Atlantic right whales and Minke whales both displayed higher visual detectability, possibly due to acoustic crypsis near offshore wind projects or increased time spent at the surface facilitating visual detection.

6. CONCLUSIONS

Incorporation of AI detectors into the PAM protocols for offshore wind construction has allowed for the processing of massive quantities of acoustic data in real-time. Approval of the PAM systems and AI detectors required extensive consultation with environmental regulators to fully explore the functionality and limitations of the systems and led to many last-minute requests for adjustment to the operational parameters of the systems. The provision of specific and clearly defined requirements for PAM system capabilities and any associated modeling and/or equipment validation by environmental regulators is critical to enable developers to better understand the associated costs and to make well informed evaluations of the technical capabilities of their potential supply chain. In addition, to ensure that the supply chain can support the growth of an offshore wind industry in Australia, it is important for regulatory agencies to be aware of the capabilities and limitations of the technology that will be essential to support all phases of development and operations.

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Design Optimization of Floating Offshore Wind Foundations Considering Detailed Manufacturing Costs

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Keywords: floating offshore wind turbines; semi-submersible foundation; capital cost optimisation; structural design; manufacturing cost

1. INTRODUCTION

Australia's offshore wind sector is growing quickly, with several zones already declared along the coast, including the Illawarra area off New South Wales [1]. As development moves into deeper water, fixed foundations lose their economic advantage beyond roughly 50 meters, and floating platforms become the only practical option [2]. Among available platform types, semi-submersibles are well suited to Australian conditions [2,3]. They can be assembled onshore, towed to site, and offer good stability without the complexity of tension-leg systems. Their main commercial barrier, however, remains capital cost, and reducing that cost through better structural design has become one of the most active areas of research in the field [4,5]. Most published optimization work uses total steel mass as a proxy for project cost [4,5]. This is a reasonable starting point, but it leaves out the fabrication side entirely. Welding, cutting, plate forming, and surface treatment together represent a large share of what these platforms cost to build. This research addresses that gap by developing an optimization framework that works with real fabrication cost from the start.

2. BACKGROUND

The literature on semi-submersible optimization is now quite large, covering platform motion, structural mass, material cost, and mooring response. Around 83% of published studies treat cost as the primary objective [5], which reflects where the commercial pressure on the industry currently sits. The consistent limitation across most of this work, however, is that cost is equated to steel mass. For welded steel structures, manufacturing processes alone can represent around 30% of total build cost, while welding and plate forming together can account for close to half of all fabrication expenses [6,7]. There is also a consistent scope problem that runs across most published studies. The outer platform geometry is typically what gets optimized, while internal components like stiffeners, bulkheads, and internal framing are left out entirely [8–10]. These elements affect both structural performance and fabrication complexity in ways that external geometry alone does not capture.

3. APPROACH

The reference platform is the UMaine VolturnUS-S, a four-column steel semi-submersible developed to support the IEA 15-MW wind turbine [11]. The target site is the Illawarra offshore wind zone in the Pacific Ocean off the New South Wales coast [1], formally declared in June 2024. The site lies at approximately 200 meters water depth, which places it firmly in the range where floating foundations are required.

The optimization problem minimizes total cost C, which consists of two components, formulated as:

$$C = K_m + K_f \qquad (1)$$

where K_m is the material cost based on steel volume and density, and K_f is the fabrication cost calculated from the time required for each manufacturing operation, such as welding, cutting, and plate forming. Decision variables cover column diameters, heights, wall thicknesses, pontoon dimensions, internal stiffener sizes and spacings, and ballast heights. Constraints cover global stability requirements including metacentric height, natural periods, and heeling angle, alongside Ultimate Limit State (ULS) buckling checks in accordance with DNV standards. Evaluating all these constraints across thousands of candidate designs requires automated geometry generation. A parametric model serves exactly this purpose, linking design variables directly to platform geometry and eliminating the need for manual remodeling at each iteration. For each configuration, it computes components weights, total mass, center of mass, total mass moment of inertia tensor, alongside weld lengths at structural connections, and surface areas for coating, feeding these directly into K_f. The hydrodynamic panel mesh is generated automatically for each design variant as well.

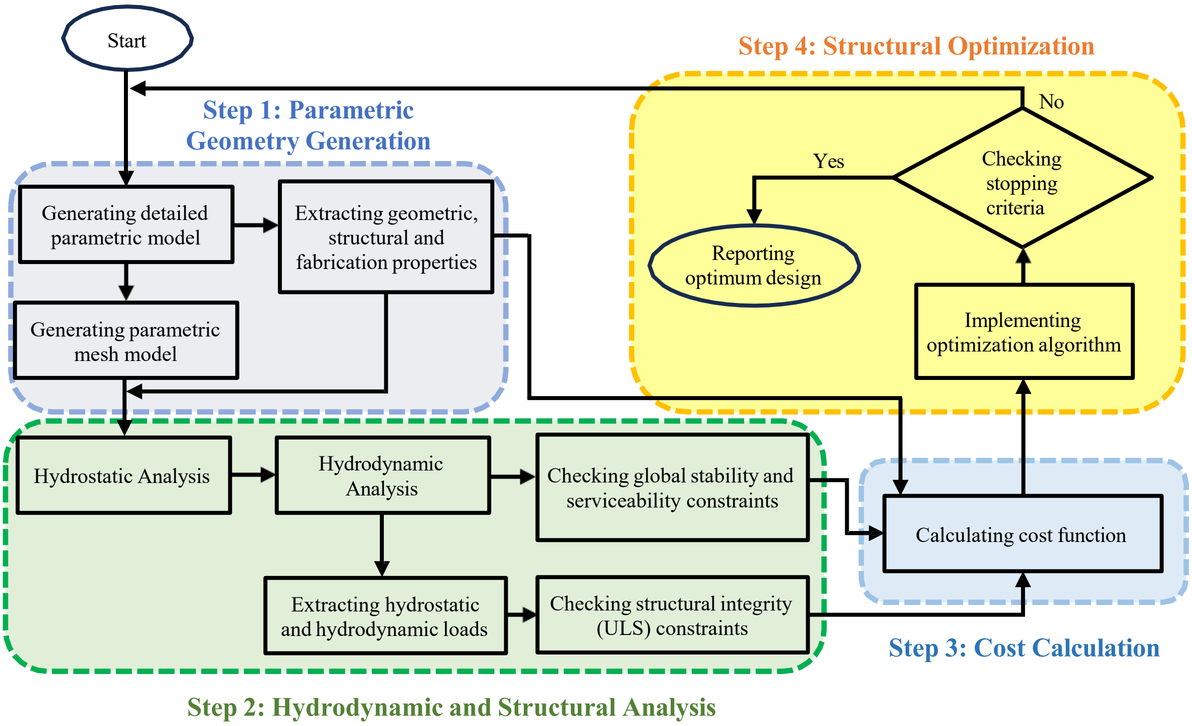

Figure 1. Design optimization flowchart

The framework additionally incorporates a Life Cycle Assessment of the manufacturing stage, aiming to identify which fabrication processes drive embodied carbon and whether cost-efficient designs are also environmentally favorable.

4. DISCUSSION

The parametric model has been developed and validated against the established UMaine VolturnUS-S reference case. Figure 2 shows heave RAO from the parametric model plotted alongside the reference results. Close agreement across the full frequency range confirms that the model produces accurate hydrodynamic predictions and is ready to be integrated into the optimization loop.

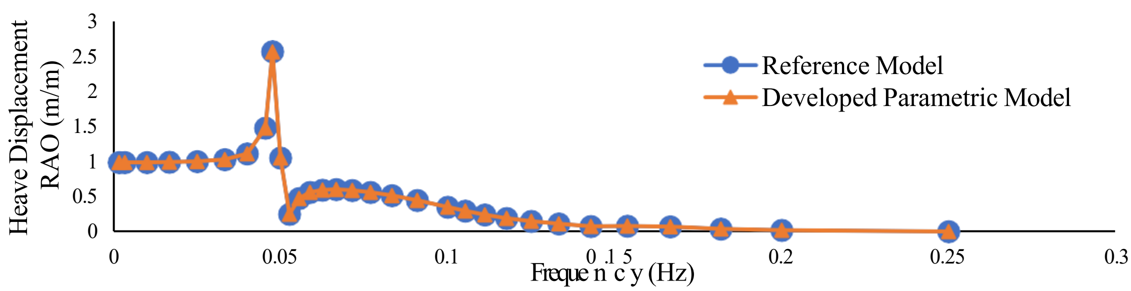

Figure 2. Heave Displacement RAO comparison between parametric model and reference

A mesh sensitivity study was also conducted across five representative platform configurations to ensure that the panel mesh remains appropriate throughout the optimization process. Results confirm that hydrodynamic analysis outputs are consistent and reliable across the full parametric geometry range. With the modelling and validation phases complete, the framework is now being applied to optimization runs for the Illawarra site, with full results to follow through peer-reviewed publication.

5. CONCLUSIONS

Getting floating offshore wind to work commercially in Australia requires cheaper foundations. That means optimizing for what a platform costs to build, not just for how much steel it contains. Most existing research stops short of this by using mass as a cost proxy, missing the fabrication expenses that drive a large share of the real project cost. This research delivers an optimization framework that integrates material and manufacturing cost from the start, built around a validated parametric model of the reference platform. An integrated Life Cycle Assessment further ensures that designs optimized for cost are also evaluated for their environmental footprint. The work is ongoing, and detailed results will follow through peer-reviewed journals. For the Australian offshore wind sector, this framework represents a practical step toward cost-competitive floating foundation design.

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The Power of Partnerships: How Collaboration Can Solve the Energy Transition's Biggest Challenges

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Keywords: energy transition, collaboration

1. INTRODUCTION

The energy transition is one of our greatest collective challenges, but it also presents unprecedented opportunity for innovation. Coal-fired power stations in Victoria are becoming increasingly unreliable and closing over the next 10 years.

To replace coal and meet the growing demand for electricity, VicGrid must oversee the construction of hundreds of kilometers of new and upgraded transmission lines, and connect large volumes of renewable generation and storage capacity, at a scale and speed never before seen.

With transmission investment increasing globally and nationally, competition for skilled workers, equipment and capital is intensifying, while increasingly complex projects are placing greater pressure on supply chains, procurement models and delivery capability. At the same time, the consequences of delay are becoming increasingly significant. For every year major transmission infrastructure is deferred or delayed, the cost to consumers will climb, while the confidence for renewable energy developers to invest diminishes.

These challenges cannot be solved by governments, network businesses or industry acting independently. They require a fundamentally different approach. This keynote will highlight some of the known challenges, and pose the question: How we can partnerships unlock innovation?

2. MAIN BODY

There are four key opportunities for partnership.

The **first partnership** needed is between **governments and industry**. Today's environment is markedly different to how large-scale infrastructure has been previously delivered. Contractors face unprecedented demand across multiple sectors, labour shortages continue to constrain capacity, and increasing uncertainty is changing how markets price and manage risk.

Successfully delivering transmission infrastructure at the pace required will depend on creating greater certainty across the delivery pipeline, developing commercial models that allocate risk more appropriately, engaging earlier with delivery partners and providing the confidence needed for industry to invest in workforce capability, equipment and local manufacturing.

The **second partnership** opportunity is between **VicGrid, industry and Australia's research sector**. Many of the challenges facing the energy transition do not yet have established solutions. Artificial intelligence, digital engineering, advanced analytics, automation and new construction methodologies all present opportunities to improve productivity, enhance safety and reduce delivery timeframes. Similarly, innovations in materials, logistics, environmental management and infrastructure design have the potential to significantly reduce costs while improving environmental and community outcomes.

Australia's universities and research institutions represent an underutilised strategic capability in accelerating the energy transition. Bringing together engineers, economists, environmental scientists, software developers, social researchers and industry practitioners offers the opportunity to develop practical solutions that improve infrastructure delivery while creating new intellectual property, advanced capability and future export opportunities.

The **third partnership** is across the **infrastructure system** itself. Transmission projects can no longer be viewed as individual developments competing for the same finite resources. VicGrid is working to ensure project sequencing, workforce development, manufacturing capacity, procurement, logistics and supply chains increasingly affect projects across jurisdictions and sectors. A more coordinated national approach provides opportunities to reduce bottlenecks, strengthen Australian capability and create the certainty needed for businesses to invest for the long term.

Finally, successful delivery depends on **partnerships with communities**. The energy transition cannot succeed without public confidence and social licence. Communities expect to be engaged early, treated with respect and have genuine opportunities to influence decisions that affect them. They also expect to see tangible benefits flowing from major infrastructure investment.

One of the reasons VicGrid was established was to place community engagement at the heart of planning. By integrating technical planning with meaningful engagement from the outset, infrastructure can be designed not only to meet engineering requirements but also to better reflect community values, local knowledge and regional priorities.

3. CONCLUSIONS

Ultimately, the energy transition is not simply about replacing one source of electricity with another. It is about transforming the way governments, industry, researchers and communities work together to solve increasingly complex problems. Australia already possesses many of the ingredients required for success: world-class renewable energy resources, significant investment, leading technical expertise and an outstanding research sector. The opportunity now is to connect those strengths more effectively through partnerships that encourage innovation, share knowledge, build capability and solve problems collectively rather than independently.

Advancing Australia's Offshore Wind Future: Blue Economy Research, Collaboration and Demonstration

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Keywords: Floating Offshore Wind; Feasibility Study

1. INTRODUCTION

The TASDEMO project is a feasibility study focused on deploying Saitec Offshores SATH (Swinging Around Twin Hull) floating offshore wind turbine technology in Australian waters. Delivered through collaboration between the Blue Economy Cooperative Research Centre, Saitec Offshore, the Australian Maritime College, University of Tasmania and BMT, this initiative aims to assess both the technical and economic viability of deploying this innovative platform, laying the groundwork for future large-scale floating wind developments in Australia [1]. The project focuses on identifying suitable sites for SATH turbines in Australian waters, estimating annual energy potential, and assessing grid connection options to find optimal site locations. The project also examines transport, installation, commissioning, operations, maintenance, regulatory frameworks, and funding strategies to gain a clear overview of future commercialisation pathways at research and full commercial scale.

Figure 1 Saitec Offshores SATH (Swinging Around Twin Hull) technology 2 MW turbine deployed at the Biscay Marine Energy Platform (BIMEP) off Bilbao, Spain [2].

Future monitoring opportunities are also under investigation, including platform use as an environmental research station, enabling biodiversity studies and assessment of potential interactions, with a particular focus on potential impacts on birds and marine mammals.

Through these interlinked studies, the TASDEMO study will demonstrate the entire process lifecycle of developing a floating offshore wind project in Australia. By showcasing this end-to-end process, the project aims to significantly reduce risks and uncertainties associated with future development.

2. APPROACH

This project assesses the feasibility of deploying floating offshore wind in Australian waters through six distinct but interlinked Work Packages (WP). These covers Transportation and Installation (T&I), site selection and energy generation, Operations and Maintenance (O&M), environmental approvals, funding, stakeholder engagement, and commercial scaling opportunities, creating a roadmap for future offshore wind development in Australia. The six work packages are outlined below:

2.1 WP 1: Device Transportation and Installation

Work package 1 seeks to evaluate the feasibility of transporting the 2 MW DemoSATH unit from Spain to Australia and reassembling it. Key activities assessed include the complete project lifecycle, covering decommissioning in Spain, towing, mooring and commissioning in Australian waters, followed by decommissioning, with comprehensive cost estimates for all stages. The scope also covers port suitability assessment and local supply chain analysis.

2.2 WP 2: Site Selection, Energy & Installation Study

This study evaluates site characterisation and installation planning for identified Australian sites. This includes site selection assessment using multicriteria decision making techniques, energy production and revenue estimates, potential towing and mooring design, supply chain assessment, electrical grid connection studies, and commissioning procedures. All tasks involved technical evaluations and cost estimates.

2.3 WP 3: Operation and Maintenance

This work package develops an Australian-based O&M strategy based on DemoSATH's field performance at BIMEP, Spain. It includes updating preventive and corrective plans, examining local contractor suppliers, preparing cost estimates, and revising remote monitoring procedures.

2.4 WP 4: Environmental, permitting & licensing

Work package 4 is currently identifying all permitting, licensing, and environmental requirements for deploying SATH technologies in Australian waters. It includes consolidating Environmental Impact Assessment obligations, engaging with regulators, assessing Environment Protection and Biodiversity Conservation Act 1999 and Offshore Electricity Infrastructure Act 2021 (OEI) applicability, reviewing National Offshore Petroleum Titles Administrator / National Offshore Petroleum Safety and Environmental Management Authority regulations, defining approval pathways, and preparing a timetable for submissions, ensuring compliance with relevant identified Commonwealth and State regulatory frameworks.

2.5 WP 5: Funding opportunities and stakeholder management

This work package component seeks to identify funding opportunities from local and international sources and assess requirements for successful approval. It also involves developing a stakeholder engagement strategy to promote early involvement and support for floating offshore wind technology in Australia.

2.6 WP 6: Technical Feasibility for Large-Scale Deployment

Work package 6 is assessing the technical feasibility of constructing 8–15 MW commercial-scale SATH floating turbines at an Australian port and deploying them in an OEI-declared offshore wind zone. It includes port capability analysis, site selection, grid connection, and marine operations. Additionally, it will analyse requirements and timelines for securing a research and development license.

3. RESULTS AND DISCUSSION

Preliminary results demonstrate significant progress across all work packages. Transportation and installation strategies for SATH technologies are under active assessment and refinement. Site selection and energy yield analyses have been completed for all OEI zones, as well as state and Commonwealth waters. Operations and maintenance strategies are being adapted from Spanish experience to suit local conditions. Environmental permitting pathways are being mapped, while funding frameworks and stakeholder engagement strategies are in development. In addition, feasibility studies for port infrastructure and research licensing have commenced to enable future deployments.

4. CONCLUSION

A comprehensive feasibility study is critical to unlocking Australia's floating offshore wind potential. The work package outputs outlined in this work will guide strategic investment, enable domestic manufacturing, foster innovation, and accelerate commercialisation, creating a clear pathway for large-scale offshore wind development in Australian waters. This project is also a key step in demonstrating SATH technology for offshore wind in Australia, strengthening industry and research collaboration, accelerating growth and supporting Australia's clean energy transition.

ACKNOWLEDGEMENTS

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What Does It Mean To Be a Good Host? Preparedness of the Yarram Community for Offshore Wind

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Keywords: social impact; community benefit; regional transition, place-based; offshore wind

1. INTRODUCTION

The Australian Federal Government has set a target to reduce domestic greenhouse gas emissions to 62-70% below 2005 levels by 2035[1]. The Victorian State Government has made an even more ambitious pledge of 80% reduction by 2030 and Net Zero by 2045[2]. To achieve this, radical action has commenced, including cessation of native timber harvesting, decommissioning of offshore oil and gas and replacement of coal-fired energy generation with renewable electricity from solar farms and offshore wind, as well as significant shifts in agricultural production methods. Each of these changes has had a disproportionate impact on the communities of Gippsland, in Victoria's southeast, which has been designated a REZ (renewable energy zone)[3].

Establishing an offshore wind operation can have benefits and adverse impacts to a community. Adverse impacts include disruptions on livelihoods, competition with access to housing and services, reduced aesthetic views or sense of place in the community, and potential conflict in community between those who accept and oppose offshore wind[4]. Benefits, on the other hand, are provided through community benefit sharing schemes implemented by offshore wind operators and economic opportunities through job creation and an increase in demand for services[5]. However, obtaining the potential benefits depends on whether communities are ready to host the offshore wind industry.

Here we present a case study, working with the community of Yarram and district, to understand their level of understanding of and preparedness for this new industry. It is a 'pulse check' on their sense of wellbeing and what it means to live in a prosperous Yarram. We undertake a mixed-methods approach incorporating a survey and focus groups to elicit both quantitative and qualitative responses from a broad participant base. The outcomes will help inform priorities for investment and track change over time, focusing on the areas most important to the community. This research moves beyond social acceptance to positioning community in the centre of decision-making for their region, during transition.

2. BACKGROUND

Nestled between the Gondwanan rainforest of the Tarra Valley and the Ninety Mile Beach facing the mighty Southern Ocean, the community of Yarram and district is home to a population of around 5000 people[6]. This is the Traditional lands of the Brataualung people of the Gunaikurnai nation, whose Sea Country once formed a land bridge to Tasmania. Historically home to thriving timber, dairy and fishing industries, with offshore oil and gas nearby, the region is soon to be the home of Australia's first offshore wind developments. The shallow continental shelf, strong westerly winds, low population density and proximity to extensive transmission infrastructure make this a premium location for the new industry.

The initial proposal for offshore wind in the region was in 2017, through the Star of the South development. In 2024, feasibility licenses were issued to twelve proponents within the Gippsland REZ, over an area of 15,000 km^2, with the potential power generation of up to 25GW[3]. The first auction for an initial 2GW generation goes live in August 2026.

A feasibility assessment undertaken by Wellington Shire Council highlighted the requirements to facilitate the growth of the industry, including supply-chain, jobs and skills, housing infrastructure and community readiness[7]. Key gaps identified included: a supply chain supporting ongoing operational and maintenance requirements, in-direct businesses and services to support the growing workforce and provision of a diversity of housing[5]. The report estimates around 7500 jobs during construction and 1300 ongoing jobs in Wellington Shire, throughout the realization of the industry[7].

As one of the larger townships in the region, and already home to one of the prospective proponents since 2020, Yarram is earmarked to be a key service-town for the development of the industry. As well as understanding 'readiness' from a workforce and infrastructure perspective, it is necessary to also understand community preparedness, to facilitate a smoother transition. Beyond social license and acceptance, community preparedness includes what people value in their communities and how this can be maintained or enhanced through the new industry, as well as understanding what they fear to lose. This can assist in both how the town presents itself as a 'good host', as well as enabling community members to potentially see how they may benefit from or contribute to the development. This may be either directly through employment or service provision, or through community benefit sharing schemes, generated from the projects.

3. APPROACH

A survey instrument, co-designed with the Yarram Wind Transition Working Group, was distributed in hardcopy via mail to over 2000 residences within the 3971 postcode – representing Yarram and district. The survey includes questions regarding people's perceptions of their community; current economic condition of the region and future potential; infrastructure and facilities, amenities and services; as well as their understanding of the offshore wind proposals and the opportunities – either through employment or benefit sharing, it may provide for the Yarram region.

Complementing the survey, listening posts were set up at key locations in the Yarram township. These were both to draw awareness to the survey, to encourage participation, as well as answer any questions and capture qualitative feedback. Following data collection, findings were shared with workshops comprising local community members. Workshop participants were recruited from survey participants who indicated that they would like to be invited to the workshop. The workshops to validated the initial results of the survey and sought feedback from participants on the following questions:

1. What is needed to prepare communities for the offshore wind industry? What's most important?
2. Who should be involved to prepare communities? How can they be involved?
3. How can we support stakeholders to collaborate to help prepare communities?

4. CONCLUSIONS

This social benchmarking and impact study aims to develop a set of social indicators unique to the region that will guide the requirements that will need to be met for Yarram and district to effectively host the future development of the offshore wind industry. Developing this understanding can contribute to the preparation and implementation of community engagement strategies for the government and offshore wind operators, design of local policies and governance mechanisms, and prepare the community for the offshore wind industry. The study, which we hope will be longitudinal, will explore current and future hopes and concerns of the community, and support community-led decision making.

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Assessing the Performance of a 15 MW Wind Turbine under Site-specific Conditions for the Bunbury Offshore Wind Zone

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Keywords: *Offshore wind turbine*; *Site conditions; OpenFAST, Jacket Support Structure, Structural response.*

1. INTRODUCTION

Due to the nascent stage of the Australian offshore wind industry, there is very little published research specifically focussing on offshore wind energy in this country. This research addresses this gap by assessing the structural response and energy output of a 15 MW offshore wind turbine simulated as deployed in the Bunbury wind zone, off the southwest coast of Western Australia.

Australia has six declared offshore wind zones, of which the Bunbury zone in the southwest of WA was the area selected for this study. The Zone is made up of two parts, with 3 feasibility licenses just recently approved [1]. The Bunbury declared areas and selected turbine site have been illustrated in Figure 1.

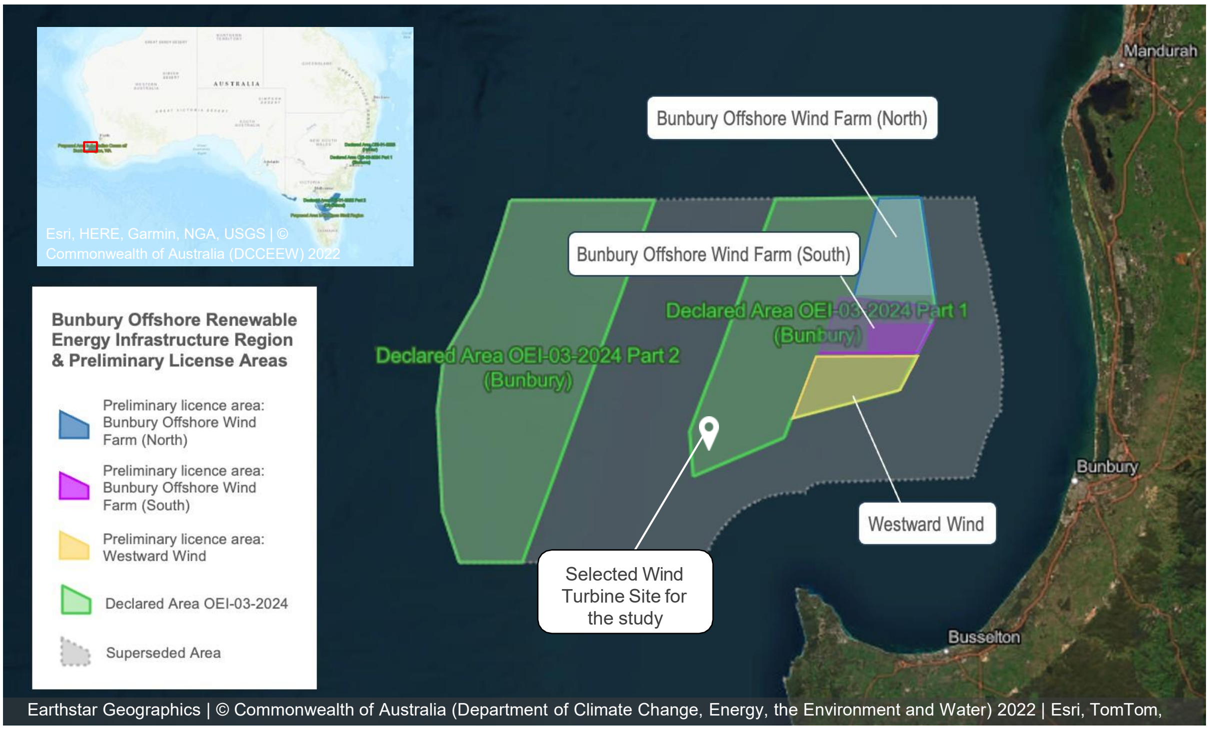

Figure 1 Bunbury offshore wind zone and preliminary license areas. (Declared Area OEI-03-2024 for Offshore Renewable Energy Infrastructure Regions). Source: Adapted from DCCEEW.gov.au [2].

2. APPROACH

A six-step methodology was developed. The first step involved a comprehensive literature review to identify knowledge gaps, define research objectives, and establish methods for characterizing site conditions, selecting foundation type, turbine location, and site-specific parameters. The second step involved setting up and verifying an OpenFAST numerical model [3], a widely used simulation tool in the offshore wind industry for calculating the coupled aero-servo-hydro and structural dynamics. In the third step, the model was customized for Bunbury's offshore conditions (see figure 2). Step four consisted of simulations to determine natural frequency, evaluate jacket orientation relative to wind-wave direction, assess structural response in terms of ultimate strength and fatigue load analyses using relevant IEC design load cases (DLC) [4], as well as an assessments of power performance and annual energy production. Step five, a sensitivity analysis was then conducted with varying soil stiffness and extreme metocean conditions. Finally, simulation results were benchmarked, interpreted, and synthesized to identify key insights and recommendations.

3. DISCUSSION

The Bunbury offshore wind zone environmental conditions were characterised and a wind turbine site for the study selected at the southern end of the inner zone (figure 1) in 50 meters of water (average for the zone) [5]. Metocean conditions were summarised for the site [6] [7] [8], as shown in table 1.

Table 1 Summary of Bunbury Site Metocean Data

Mean wind speed at hub height V_{hub} (m/s)	50-year return period mean wind speed V_{50yr} (m/s)	Mean wind direction (deg)	Mean significant wave height Hs (m)	50-year return period significant wave height Hs_{50yr} (m)	Mean peak wave period Tp (s)	Mean wave direction (deg)
9.3	30.2	176	2.79	9.85	10.9	236

Geotechnical conditions were predicted to be challenging with variably cemented carbonate and an area SW of a major fault-line possibly having a shallow granite-like basement [9] [10] [11]. The selected turbine site lay on an ancient calcarenite shoreline [9] (Tamala limestone), providing a very stiff mudline spring soil-structure-interaction (SSI) [12]. A three-leg jacket substructure was chosen for its suitability to the expected geotechnical conditions, it's cost-effectiveness [13] [14] [15], and potential compatibility with the site wind–wave misalignment [16] [17].

Results confirm that the first natural frequency of the tower avoids resonance with both wind/wave excitation and blade/rotor frequencies. Initial simulations identified the 3-legged jacket had lower structural responses when oriented with one leg pointing into the incoming waves. Ultimate strength utilisation ratios were below 60% across all components, indicating substantial reserve capacity. Fatigue assessment confirmed that all critical elements exceeded the 20-year design life, with the blade root identified as the most critical (≈33 years life, UR 61%) and the jacket mudline the least (≈267 years life, UR 22%). Annual energy production was estimated to be 66.7 GWh with a capacity factor of 51%. Sensitivity studies highlighted the importance of soil stiffness, where reduced stiffness lowered tower

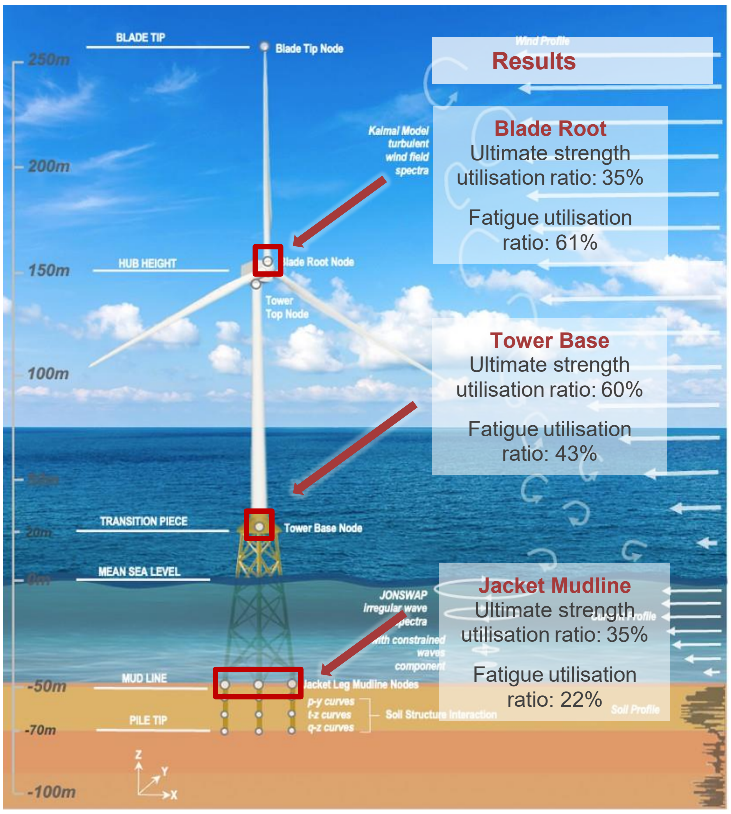

Figure 2 Bunbury three-leg jacket 15 MW OWT model [17].

natural frequency by 8.2% and significantly increased fatigue. Under extreme 500-year metocean conditions with reduced soil stiffness, jacket mudline utilisation ratio (85%) approached its ultimate strength capacity. The full results are available at [17].

4. CONCLUSIONS

Based on a subset of DLCs simulations, this study demonstrates that a 15 MW offshore wind turbine can operate safely and efficiently under Bunbury conditions, with ample ultimate strength and fatigue capacity. Key findings:

- jacket orientation is important in reducing mudline loads
- softer soil stiffness increases fatigue
- the turbine can survive extreme weather events

This study provides a strong technical foundation for future Bunbury offshore wind development and further wind farm–scale studies.

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The Last Spin: European Lessons for Offshore Wind Decommissioning and Implications for Australia

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Keywords: Offshore Wind Farms, Decommissioning, Circular Economy, Best Practice, Australia,

1. INTRODUCTION

Offshore wind (OW) energy is central to global decarbonization and green hydrogen production, with a deployed generation capacity of 92 GW in 2025 (GOWA, 2025) and technical potential of 120 TW ((IEA, 2024, p. 45). This capacity could help decarbonize electricity systems and hard-to-abate sectors such as steel, fertilizers, shipping, and aviation (González et al., 2025). As a late entrant to both OW and offshore decommissioning, and with a technical potential of 27.369 TW (Goodman, 2022), Australia is uniquely positioned to apply international lessons and embed circular economy (CE) principles from the outset, while building its expertise across a decommissioning sector projected to require US$40.5 billion in expenditure by 2060 (Milne, 2021; Wild & Warrier, 2024). As OW infrastructure reaches the end of its operational life, Europe is confronting a growing decommissioning challenge (Gaborieau et al., 2026; Stravens, 2025). In 2024, Europe retired approximately 1.3 GW of wind capacity, with a further 22 GW expected to reach EOL by 2030 (Fields, 2025). Although around 90% of a turbine's mass can be recycled (Clean Energy Council, 2023), composite blades and other difficult-to-recover materials remain challenging (Parlov & das Neves, 2025). Furthermore, early decommissioning projects in Denmark, Sweden, Germany, and the Netherlands have revealed significant technical, environmental, regulatory, and financial challenges (Vetters et al., 2024). At the same time, these projects have not only demonstrated opportunities for material recovery, repowering, life extension, and site repurposing (Díaz & Guedes Soares, 2020; Stravens, 2025), but a growing debate on whether complete removal should remain the default approach or if selected assets can be retained to support biodiversity, research, aquaculture, and other marine uses(Australian Government, 2021; Parlov & das Neves, 2025).

This abstract explores international best practices in OW decommissioning and CE initiatives, with a particular focus on lessons emerging from Europe and the United Kingdom. By examining regulatory frameworks, decommissioning experiences, repowering strategies, and material recovery innovations, the study identifies pathways that can help Australia embed CE principles into OW planning, design, operation, and end-of-life (EOL) management from the beginning.

2. APPROACH

This report builds on the *Illawarra Clean Energy Roadmap (2025)*, which identified strong interest in offshore wind (OW) development but limited consideration of circular economy (CE) principles during project planning and design. Stakeholders highlighted uncertainty around end-of-life (EOL) management, decommissioning responsibilities, and opportunities for material recovery.

Given Australia's emerging OW sector and limited experience with large-scale decommissioning, this study adopts an international perspective, focusing primarily on Europe. Using a comprehensive desktop review of academic literature, government policies, industry reports, and developer publications, the study examines best practices across the offshore wind lifecycle. Attention is given to decommissioning, repowering, asset life extension, material recovery, recycling, site repurposing, financial assurance mechanisms, and regulatory frameworks.

Case studies from the UK, Denmark, Germany, and the Netherlands, provide insights into emerging approaches and lessons for Australia. While the study is limited by its reliance on secondary sources, it offers a valuable evidence base to support the integration of CE principles into Australia's first generation of offshore wind projects.

3. DISCUSSION

The most widely cited CE strategy in OW is the extension of asset life beyond the conventional 25-year design horizon through maintenance, refurbishment, repowering, and life-extension initiatives. Unlike fossil fuel extraction infrastructure, which frequently becomes obsolete once oil or gas reserves are exhausted, OW infrastructure operates within a renewable and continuously replenished resource base. Consequently, while individual turbines and associated assets may reach the end of their technical life, the sites themselves typically retain long-term value. Advances in turbine technology, installation methods, and resource assessment have further increased the viability of repowering older wind farms and optimizing site productivity, making asset life extension and infrastructure renewal key pathways for enhancing circularity and resource efficiency in the sector.

3.1 Repurposing

Most OW decommissioning literature applies a CE lens through three primary EOL pathways**:** life extension**,** repowering, and full or partial decommissioning (Gaborieau et al., 2026). These approaches are also reflected in emerging Australian OW policy and regulatory frameworks (Clean Energy Council, 2023). However, recent research has identified repurposing as a fourth pathway, particularly where full removal may generate greater environmental or economic costs than retaining selected infrastructure. (Stravens, 2025). Repurposed sites may support marine research, aquaculture, artificial reefs, biodiversity enhancement, or tourism activities (Stravens, 2025). While such opportunities align with CE objectives, international frameworks including UNCLOS, the London Convention, and the London Protocol distinguish beneficial repurposing from the dumping or abandonment of offshore structures (Australian Government, 2021; Parlov & das Neves, 2025). Furthermore, the London Protocol provides that proposals to retain infrastructure must be supported by robust environmental assessments demonstrating that benefits outweigh ecological risks and that higher-order waste management options, including reuse and recycling, have been considered (Parlov & das Neves, 2025). While these agreements do not explicitly promote CE principles, they provide sufficient flexibility to support sustainable decommissioning and offer valuable guidance for Australia as it develops EOL policies for its emerging OW sector.

3.2 Decommissioning Governance and Circular Economy Uncertainty

Despite growing attention from governments, regulators, developers, and industry, significant uncertainty remains around OW decommissioning governance and the integration of CE principles into EOL planning. In Australia, the *Offshore Electricity Infrastructure Act* (2021) assigns decommissioning responsibility to developers and license holders. However, practical implementation remains uncertain due to unpredictable future technologies, costs, regulatory requirements, and environmental conditions (Momentum, 2018; Parlov & das Neves, 2025). In the UK, the government acts as the decommissioner of last resort, retaining ultimate responsibility should developers fail to meet their obligations; consequently, developers are required to provide financial securities to protect taxpayers from future liabilities (Directorate, 2025; Jurrius & van Hoof, 2024). European and UK experience further shows that challenges extend beyond financing to include regulatory interpretation, environmental priorities, and stakeholder expectations (Directorate, 2025). Ongoing debate over what constitutes 'full decommissioning' complicates the assessment of CE pathways such as life extension, repowering, repurposing, and partial decommissioning (Gaborieau et al., 2026; Parlov & das Neves, 2025; Vetters et al., 2024). These lessons highlight the need for Australia to embed CE principles into offshore wind planning, permitting, and financing from the outset. The challenge is not if OWF will be decommissioned, but how this can be achieved in a sustainable, transparent, and economically efficient manner.

3.3 Repowering and Material Recovery

Repowering involves replacing ageing turbines with more efficient technologies while retaining selected foundations, substations, cables, or transmission assets (Fields, 2025; Topham & McMillan, 2017; Topham et al., 2019). Given the continuing demand for renewable energy, repowering existing OW sites offers a means of increasing energy output and delaying decommissioning while minimizing the environmental impacts associated with developing new sites within the marine estate (Momentum, 2018). The Bockstigen OWF in Sweden demonstrates this potential: upgraded using refurbished turbine components while retaining existing foundations and towers, the project doubled energy production and extended operational life by at least 15 years (Momentum, 2018).

Beyond repowering, material recovery and reuse offer substantial opportunities to retain value from decommissioned assets. Across Europe, retired turbine blades are being repurposed into bridges, playground equipment, noise barriers, shelters, and other infrastructure (Fields, 2025). At the same time, companies such as Iberdrola, Vestas, Ørsted, and Siemens Gamesa are advancing recycling technologies that recover composite materials for use in construction, automotive, aerospace, and other industries (Adedipe & Shafiee, 2021) . These developments demonstrate how OW decommissioning can evolve from a waste management challenge into a source of ongoing economic and environmental value.

3.4 Non-Price Criteria

As OW industries mature, governments are increasingly using procurement and auction processes to promote sustainability beyond price alone. Across Europe, non-price criteria now encourage biodiversity enhancement, circularity, resource efficiency, innovation, and community benefits, with several countries introducing requirements for recyclable turbine components, material recovery, ecological monitoring, and sustainable decommissioning (Stravens, 2025; WindEurope, 2022). This shift reflects a growing recognition that EOL management should be integrated throughout the OW lifecycle rather than treated as a future liability. While current frameworks primarily focus on construction and operation, interest is growing in repowering, life extension, reuse, recycling, and ecological value retention (Stravens, 2025). For Australia, which is establishing its OW industry, this presents an opportunity to embed CE principles from the outset through project approvals and license conditions, reducing future environmental and financial risks while supporting more sustainable OW development.

4. CONCLUSION

Europe's experience demonstrates that OW decommissioning should be embedded into project planning, design, financing, and regulation from the outset rather than treated as a future EOL obligation. As early offshore wind projects reach retirement, there is growing recognition that flexible approaches, can deliver better environmental and economic outcomes than complete removal in all cases. For Australia, which is only beginning large-scale OW development, this presents a unique opportunity to learn from Europe's successes and challenges. By incorporating CE principles, clear regulatory pathways, robust financial assurance mechanisms, and EOL planning into early project approvals, Australia can minimise future liabilities while maximising resource recovery, biodiversity outcomes, and long-term value. Taking this proactive approach will help establish a more resilient, adaptive, and circular OW industry from the outset.

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Holistic Economical Offshore Wind Turbine Solution for Australia

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Keywords: Bucket foundation system; offshore wind; prefabricated structure; marine transportation; installation methodology

1. INTRODUCTION

Offshore wind is globally recognised as a transformative solution for delivering clean, affordable energy while stimulating economic growth. However, Australia continues to lag in its implementation due to a combination of technological challenges, regulatory hurdles, and environmental considerations. Traditional offshore wind turbine installation methods rely heavily on large-scale machinery and heavy-lift vessels, contributing to higher costs and longer assembly times compared to onshore alternatives.

This presentation introduces a pioneering Australian project funded by the Department of Industry, Science and Resources (DISR), which is developing an end-to-end solution for offshore wind turbine deployment using suction bucket foundation technology. The project aims to design, fabricate, transport, install, and eventually decommission wind turbines without the need for heavy-lift vessels, drastically improving efficiency and reducing environmental and economic impact. The system is being tailored to suit Australian waters and geotechnical conditions, setting a precedent for scalable deployment across the region.

The objectives of this presentation are: (1) to introduce the project, its goals, and the research and industry teams involved; (2) to invite collaboration from summit participants and stakeholders who may contribute expertise and/or resources; and (3) to provide an update on the project's progress and future milestones.

2. BACKGROUND

Wind energy is an increasingly reliable source of renewable power; in 2025, a record-breaking 165GW of the total global capacity was added to the grid marking a 40% year-on-year increase from 2024, including 9.2 GW of offshore wind (GWEC 2026). Globally, wind energy deployment is surging, led by China's record-breaking commissioning of over 120 GW in 2025 (GWEC 2026). Wind also plays a pivotal role in Australia, where renewable energy supplied 42.7% of total electricity generation in 2025, with wind contributing 15.7% the highest percentage among the electricity generation produced by renewable energy (CEA2026). However, in 2025 Australia's large-scale onshore wind sector showed a mixed picture: 1.4 GW of new wind capacity was completed, a 67% year-on-year increase, but financial commitments to onshore wind fell to 0.9 GW, 59% below 2024 levels, while capital costs rose by a further 6% (CEA2026). To overcome these onshore limitations, attention is shifting offshore; Australia possesses 2,233 GW of technically accessible offshore wind resource which, if utilized effectively, could easily fulfill national electricity demand while enhancing energy diversification and affordability (Blue Economy 2021). Australia is lagging in offshore wind compared to the other countries, but its leadership in the offshore oil and gas sector offers potential for increased involvement. The Offshore Electricity Infrastructure Act 2021 established a legislative framework for offshore wind energy in Australia, with the licensing regime already in full swing. The Australian Government identified six regions with significant offshore wind potential, with Victoria planning to build a 9 GW offshore wind farm in Gippsland by 2040 and New South Wales proposing 24.5 GW in the Hunter. However, progress has been uneven, with delays to Victoria's auction process until August 2026 and only incremental progress on offshore projects in Western Australia (CEA2026).

Building on recent advances in offshore wind foundation technologies and integrated installation concepts, this project adopts a holistic approach to the design, fabrication, transportation, and installation of offshore wind turbine systems. The proposed methodology involves the onshore assembly of the bucket foundation, tower, and turbine into a single integrated unit, enabling floating transportation to site and installation without the need for conventional heavy-lift vessels or installation barges. By significantly reducing offshore construction activities and associated maritime logistics, the proposed approach has the potential to lower installation costs, improve operational flexibility under varying weather and sea conditions, and enhance the economic viability of offshore wind energy developments in Aust

3. APPROACH

Key activities included the development of low-carbon, sustainable, high-performance concrete composite materials for wind turbine systems' foundation structure, utilising upcycled mining, oil, and gas infrastructure for strength, serviceability, and durability.

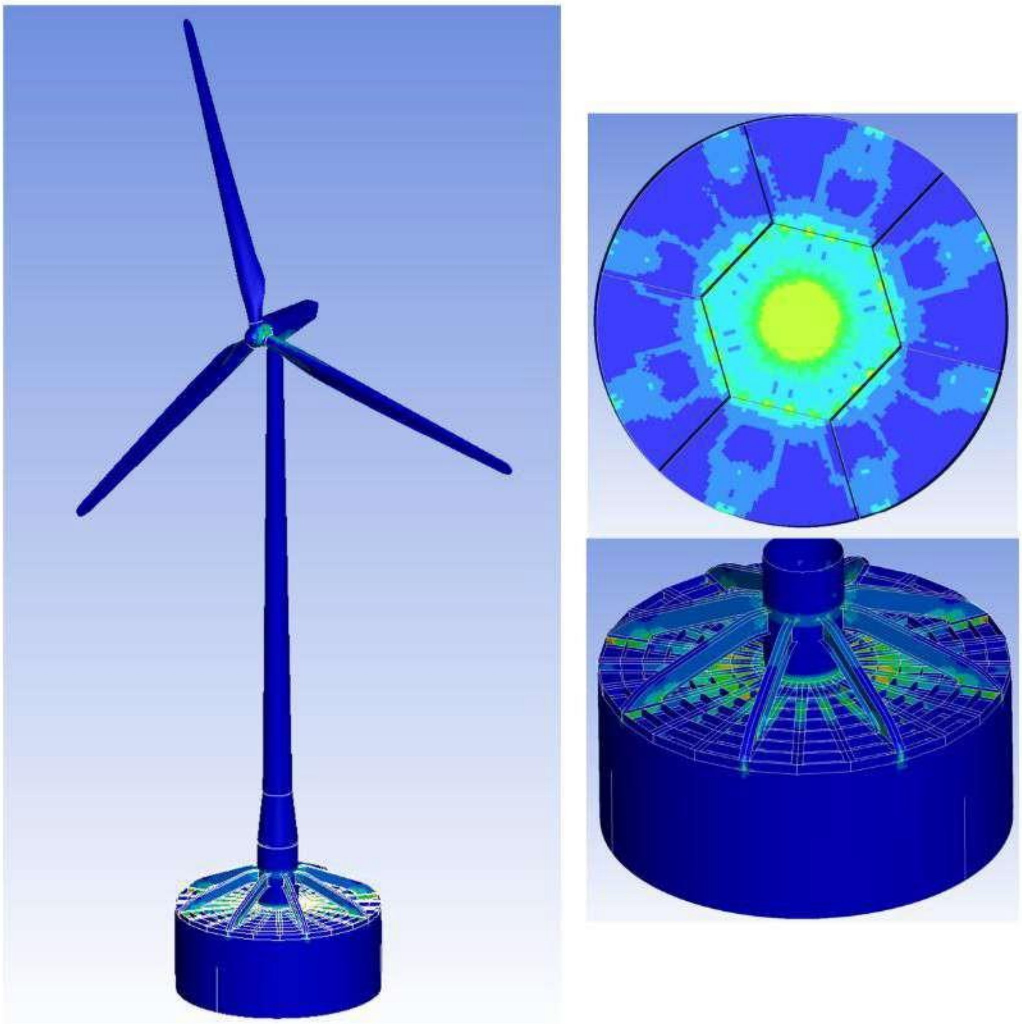

Figure 1 – Preliminary FEM for the conceptual bucket foundation design, highlighting the localized structural behavior of the internal stiffeners and base slab assembly.

The project yearns to develop a composite bucket foundation, optimising its stability, transition structure, and base for sub-sea conditions in Australia. Then, cost-effective manufacturing, prefabrication, and assembly processes will be developed for a wind turbine system (WTS) at a port-based advanced manufacturing precinct utilising robotics and automation to minimise occupational health and safety risks. Various components of the system under consideration are depicted in Figure 1. A method for manufacturing, transporting, installing, and decommissioning a WTS, minimising maritime operations and enhancing adaptability to Australian conditions will be developed.

4. Project Development Stages and Research Framework

The Next Harbour project investigates the use of advanced concrete composites incorporating upcycled offshore materials for large-scale offshore wind foundation applications, with a particular focus on suction bucket foundation systems. The research is structured into four interconnected work packages (WPs) that progress from material selection to commercial deployment.

WP1: Material Assessment and Foundation Concept Development. Steel and concrete were evaluated as the primary structural materials for offshore wind foundations, considering mechanical performance, durability, fabrication, and lifecycle implications in aggressive marine environments. Material requirements were mapped against fixed-bottom and floating foundation typologies, identifying suction bucket foundations as a promising application for concrete-intensive and hybrid solutions. Attention was given to installation requirements, soil–structure interaction, skirt buckling resistance, fatigue performance, and long-term durability.

WP2: Upcycling Pathways for Decommissioned Infrastructure. Potential material streams from decommissioned offshore oil and gas and mining assets were assessed. While direct structural reuse of offshore steel was found to face significant regulatory and certification barriers, a scalable alternative was identified through conversion of recovered steel into recycled steel fibres. This approach retains the value of high-quality structural steel while enabling its incorporation into advanced concrete composites.

WP3: Development and Validation of Fibre-Reinforced Concrete Composites. Laboratory testing was undertaken to characterise concrete mixes containing upcycled steel fibres. Mechanical, fatigue, toughness, corrosion, and durability demonstrated that steel fibre reinforced concrete (SFRC) can achieve performance levels suitable for offshore exposure conditions. Mix optimisation focused on meeting the durability and serviceability demands of suction bucket foundations while reducing embodied carbon and maintenance requirements.

WP4: Manufacturing and Deployment Feasibility. Preliminary studies examined industrial-scale production pathways, including precast manufacturing concepts for bucket foundation components and engagement with industry partners. Regulatory compliance, certification requirements, and pathways toward commercial adoption within the Australian offshore wind sector were also evaluated. Collectively, the results indicate that SFRC bucket foundations incorporating upcycled steel fibres represent a viable pathway toward more durable, lower-carbon offshore wind infrastructure.

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Not Just for and Against: A Multidisciplinary Approach to Unpacking the Complexity of Stakeholders' Attitudes to Offshore Wind Developments

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Keywords: offshore wind; stakeholder engagement; social licence; ethics; community perspectives

1. INTRODUCTION

This presentation discusses recently published research that brings together expertise from social science, social marketing, governance, and moral philosophy to better understand community responses to offshore wind development. The work addresses a persistent challenge in offshore wind development: stakeholder attitudes are frequently portrayed as simple binaries of support or opposition, despite being shaped by complex combinations of values, identities, ethical commitments, experiences, and relationships to place.

The work responds to growing recognition that many offshore wind conflicts are not information problems that can be resolved through better communication alone. Instead, they reflect genuine ethical diversity and different ways of understanding what constitutes a fair, legitimate, and desirable energy future. As Australia expands offshore renewable energy development, understanding these diverse perspectives is critical for achieving social licence and moving beyond polarised debate.

2. BACKGROUND

Offshore wind development sits at the intersection of climate action, environmental stewardship, cultural heritage, coastal livelihoods, and community identity. Traditional engagement approaches frequently assume that resistance stems from a lack of information. However, evidence from Australian offshore wind debates suggests that stakeholders evaluate developments through different moral and cultural lenses that cannot be reconciled through factual information alone.

This research demonstrates the value of an interdisciplinary approach. Social scientists contributed insights into place attachment, community identity, and governance; marketing researchers applied audience segmentation, framing theory, and social listening methodologies; and moral philosophers provided ethical pluralism as a framework for understanding diverse forms of moral reasoning. Together, these perspectives enabled a richer understanding of stakeholder positions and pathways for engagement.

3. APPROACH

The study combined large-scale social listening and discourse analysis with ethical analysis and participatory community engagement. First, a social listening analysis examined more than 4,000 social media posts and approximately 3,000 public submissions relating to offshore wind development in Australia. Discourse analysis methods using cognitive bias frameworks and Systemic Functional Linguistics were employed to identify recurring themes, concerns and narratives. This analysis produced eight stakeholder personas:

- Community Guardian
- Environmental Sceptic
- Eco-Advocate
- Pragmatic Optimist
- Economic Realist

- Energy Visionary
- Ocean Enthusiast
- Cultural Steward

Each persona reflected distinctive ethical priorities, communication styles, and approaches to evidence and decision-making.

Second, community workshops were conducted in the Illawarra region to test the personas and explore their usefulness as engagement tools. Participants used role-playing exercises to examine offshore wind benefit-sharing schemes and identify areas of agreement across differing perspectives.

4. DISCUSSION

The research found that stakeholder positions cannot be accurately understood through simple support-opposition classifications. Instead, attitudes emerge from multiple ethical orientations including consequentialist concerns about climate change and economic outcomes, place-based and biocultural commitments, care ethics, and social justice perspectives. Importantly, the workshop activities demonstrated that participants could identify significant areas of common ground despite substantial differences in values and priorities. Shared interests included:

- Transparent and independent governance.
- Fair distribution of benefits.
- Protection of marine environments.
- Support for local communities and livelihoods.
- Meaningful community participation in decision-making.

A key contribution of the research was demonstrating that stakeholder positions are underpinned by different ethical frameworks rather than simply different opinions. The combination of social marketing and moral philosophy proved particularly valuable. Marketing concepts helped identify audience segments, communication styles, and engagement opportunities, while ethical analysis explained why particular frames resonated with different groups. This interdisciplinary lens revealed that meaningful engagement requires more than tailoring messages; it requires recognising distinct moral perspectives as legitimate and creating processes capable of navigating ethical plurality.

5. CONCLUSIONS

This research demonstrates how interdisciplinary collaboration can generate new insights into offshore wind stakeholder engagement. By integrating social science, social marketing, and moral philosophy, the project moved beyond binary framings of support and opposition to reveal the ethical complexity underpinning community responses to offshore wind development.

For offshore wind developers, regulators and policymakers, the findings suggest that engagement processes should recognise ethical diversity, support multiple forms of knowledge, and create opportunities for meaningful dialogue. Such approaches may strengthen social licence and contribute to more inclusive and effective marine governance.

The findings suggest that effective offshore wind engagement should focus not only on information provision but also on ethical literacy, procedural fairness, and recognition of diverse value systems. This approach offers a practical framework for improving stakeholder engagement, strengthening social licence, and supporting more inclusive offshore renewable energy governance.

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Mapping the Stakeholder Landscape of Gippsland Offshore Wind Development

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Keywords: offshore wind; stakeholder mapping; Gippsland; social acceptance; Traditional Owners; just transition; social licence to operate

1. INTRODUCTION AND REGIONAL CONTEXT

Australia's first declared offshore wind zone gazette off the Gippsland coast of Victoria in December 2022 encompasses approximately 15,000 km² of Bass Strait with an estimated 10 GW development potential (DCCEEW, 2022). Governed by the Offshore Electricity Infrastructure Act 2021 and Victoria's legislated targets of 2 GW by 2032, 4 GW by 2035, and 9 GW by 2040 (DEECA, 2023), Gippsland is simultaneously Australia's most advanced offshore wind region and a site of pronounced social complexity. As of mid-2026, nine of twelve feasibility licenses remained active, with Star of the South the most advanced project, having lodged its Environment Effects Statement in December 2025.

The Gippsland region (population 313,600) has an older demographic profile, an economy anchored in food and fiber, tourism, and coal energy. The Latrobe Valley is among Victoria's most disadvantaged sub-regions on SEIFA indices, and Gunaikurnai Traditional Owners hold Native Title over the Sea Country within and adjacent to the declared zone. This convergence of economic transition, demographic vulnerability, and First Nations rights makes stakeholder diversity both high and consequential for project viability. This paper systematically maps eleven principal stakeholder groups relevant to Gippsland offshore wind development, synthesising peer-reviewed evidence on their interests and concerns to inform developer engagement, policy design, and future research.

2. METHODOLOGY

This paper employs a systematic narrative review methodology to map the stakeholder landscape relevant to offshore wind development in Gippsland, following the approach established by Rand and Hoen (2017) for synthesising wind energy acceptance research. Peer-reviewed literature was identified through searches of Scopus, Web of Science, and the Consensus academic database using terms including 'offshore wind', 'social license to operate', 'stakeholder engagement', 'community acceptance', 'just transition', 'First Nations renewable energy', and 'marine spatial planning'. Searches were supplemented by authoritative grey literature including Australian Government regulatory instruments, Victorian Government policy statements, ABS Census data (2021), and Star of the South Environment Effects Statement documentation. Sources were assessed for credibility, relevance to the Gippsland context, and methodological rigour, with peer-reviewed Australian evidence prioritised over international comparators where available, consistent with contextually grounded approaches to social acceptance research (Wüstenhagen et al., 2007; Devine-Wright et al., 2020). Findings were synthesised thematically around eleven stakeholder groups identified a priori from the regional literature.

3. STAKEHOLDER MAPPING

Traditional Owners (Gunaikurnai) comprising five clans holding Native Title (determined 2010) and a Recognition and Settlement Agreement under the Traditional Owner Settlement Act 2010 (Vic) represent the most rights-bearing stakeholder group. O'Neill et al. (2021) identify Free, Prior and Informed Consent (FPIC) as the critical framework for renewable energy development on the

Indigenous estate in Australia, while Quail et al. (2025) find that absent FPIC in regulatory frameworks is the primary barrier to First Nations benefit realisation.

Lakes Entrance hosts Victoria's largest **Commercial and recreational fishing** fleet, contributing an estimated $200 million annually to the local economy. Szostek et al. (2025) demonstrate through structured survey research in the UK that the majority of commercial fishers across all vessel sizes and gear types feel their grounds and livelihoods are directly threatened by offshore wind development, while Stelzenmüller et al. (2022) quantify that bottom contacting gear targeting flatfish and crustaceans faces the greatest displacement risk directly relevant to Bass Strait trawl fisheries. Recreational fishers present a distinct but related profile: Smythe et al. (2021) find that anglers experience both enhanced catch from artificial-reef effects and concerns about exclusion-zone access and crowding, warranting differentiated engagement from the commercial sector.

Devine-Wright et al. (2020) demonstrate that acceptance of the same offshore wind project varies significantly by proximity and place attachment by **local residents and tourism operators**. The 'place-technology fit' effect with Fleming et al. (2022) conceptualising the 'engaged minority versus quiet majority' dynamic characteristic of coastal communities where organised opponents are more visible but not necessarily more numerous than general supporters. These dynamics are manifest in Gippsland, where project documentation records marked resistance among Woodside Beach coastal residents. Tourism operators add a distinct economic dimension: Oh et al. (2022) demonstrate that offshore wind farms affect coastal tourism behaviours including site substitution, while Rand et al. (2017) identify visual and amenity impacts as among the strongest drivers of wind energy opposition acute concerns for the Gippsland Lakes (Ramsar-listed), Ninety Mile Beach, and Wilsons Promontory visitor economy. **Agricultural and farming communities (landholders)** are principally affected by the terrestrial transmission corridor, with most land access agreements along some projects reached at time of Environment Effects Statement lodgement. Hübner et al. (2023) find that perceived economic effects and land impacts are among the five most significant predictors of local wind energy acceptance, underscoring the need for transparent easement and compensation frameworks.

Environmental and conservation organisations are characterised by internal tension. Vuichard et al. (2022) find in a large cross-country study (n = 2,003) that ecological impact is the most important attribute shaping wind energy acceptance, and Spencer-Cotton et al. (2024) show that Australians with the strongest ocean-conservation values are measurably less likely to support offshore wind. Key concerns in Gippsland include the Burrunan dolphin, the Orange-bellied Parrot (OBP) migration corridor which shaped the western boundary of the declared zone and the Ramsar-listed Gippsland Lakes. Boussarie et al. (2023) demonstrate that equitable marine spatial planning representing conservation values is technically achievable without disproportionate cost to offshore wind development.

Local businesses, industry, and local government is another important group. The Committee for Gippsland have identified more than 380 supply-chain opportunities, though local businesses cite economic leakage risk and the absence of legislated local content requirements. Harrahill and Douglas (2019), identify targeted regional economic diversification not energy employment alone as the primary determinant of sustained community benefit. One Gippsland's six constituent councils play a dual role as regional advocates and infrastructure planners. Leiren et al. (2020) identify local governance capacity and policy framework coherence as key determinants of community-level acceptance outcomes. Considering **Renewable energy advocates, unions, and community action groups,** the Gippsland Climate Change Network (GCCN) and Committee for Gippsland co-chair the Gippsland Offshore Wind Alliance (GOWA), advocating for offshore wind as central to regional renewal. Sovacool et al. (2019) identify wage and skills mismatches as recurring injustices in low-carbon transitions, validating union concerns about renewable job equivalency. Rand et al. (2017) caution that treating opposition as something to overcome prevents meaningful engagement and worsens conflict a finding that applies across all organised community advocacy in the Gippsland context.

4. CONCLUSION

Gippsland's stakeholder landscape is characterised by high diversity and partially competing interests: eleven distinct groups from Gunaikurnai Traditional Owners and commercial fishers to just-transition advocates and organised opposition each bring specific rights, concerns, and evidentiary needs to the engagement process. The weight of international evidence on social licence to operate consistently demonstrates that broad in-principle support for offshore wind coexists with deep, locally-grounded concern, and that the trajectory of acceptance is determined less by the technology itself than by the quality of procedural engagement, the credibility of benefit distribution, and genuine co-design with the most directly affected groups. Ensuring that social licence is built on trust and equity rather than thin, economically weighted acceptance is foundational to the long-term viability of Gippsland's offshore wind future.

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A Free-surface Based Model for Predicting Wave Loads on Monopiles in Australian Long-wave Conditions

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Keywords: nonlinear wave loads; offshore wind monopiles; wave-structure interaction; T-FNV;

1. INTRODUCTION

Monopiles are bottom-fixed steel tubular foundations driven into the seabed and are widely used to support offshore wind turbines (OWTs) owing to their structural simplicity and cost-effectiveness. In the UK, where the offshore wind industry is considerably more mature than in Australia, monopiles supported approximately 83% of installed OWTs by the end of 2024 [1]. As Australia's offshore wind industry emerges, monopiles are being considered for the first generation of Australian offshore wind projects, particularly at sites with water depths below 40 m. Foundations are a major cost driver in offshore wind projects, representing approximately 14% of total CAPEX and constituting the third-largest cost component after the turbine and installation costs [2]. Therefore, **accurate estimation of wave-induced loading on the foundation** is critical for achieving safe, and economically feasible monopile design.

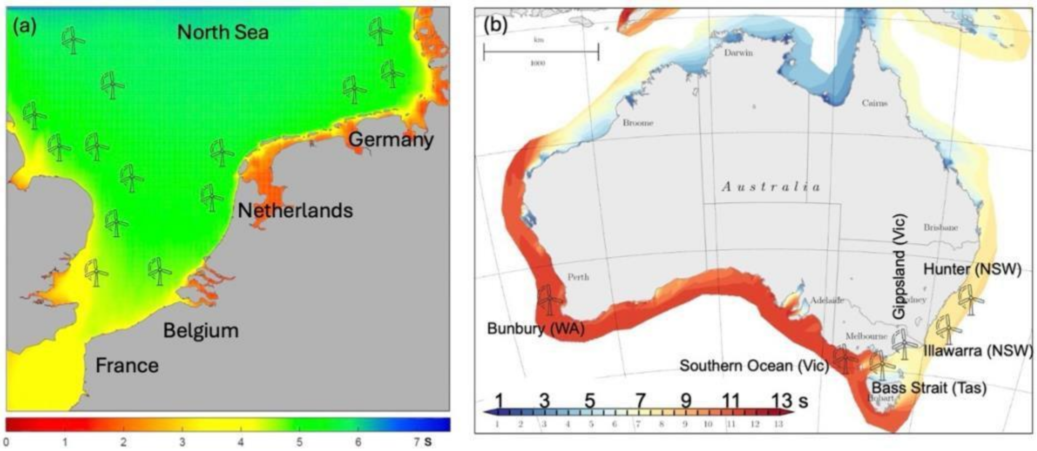

Figure 1: Annual mean wave energy period T_e in the North Sea (a) and Australia (b) [3, 4, 5].

While some declared offshore wind zones, including Hunter and Illawarra, are in relatively deep waters where alternative concepts (e.g., floating foundations) may be required, several prospective development regions, such as Gippsland and Bunbury, are in shallower water favorable for monopile-supported OWTs. These regions are characterized by substantially longer wave periods than those typically encountered in the North Sea. As illustrated in figure 1, wave energy periods are typically around 6 s in the North Sea, whereas **Australian offshore environments are dominated by long-period Southern Ocean swells**, with wave energy periods of approximately 13 s along the exposed south-west and southern coasts and around 8 s in more sheltered south-east coasts. As wavelength scales approximately with the square of wave period ($L \propto T^2$), longer period waves are associated with significantly larger wavelengths, which results in a wave environment that differs markedly from that of the North Sea. This distinction has important implications for the wave loading on monopiles.

2. EXPERIMENTS

Physical experiments were conducted at 1:50 scale in the Coastal and Offshore Research Laboratory (CORL) at The University of Western Australia (UWA). The experimental model was a circular cylinder of 160 mm diameter, representing a contemporary 8 m diameter monopile at full scale. The model was instrumented with two piezoelectric triaxial load cells to measure the hydrodynamic forces exerted on the structure. The water depth was 0.6 m in the lab, corresponding to a prototype water depth of 30 m. A piston wavemaker was used to create NewWave-type focused wave groups, which represent realistic time histories of large waves in a given sea state [6, 7]. Wave conditions with full-scale peak periods of 8, 11, 14, and 16 s were tested over a range of wave amplitudes. Figure 2 shows the wave–monopile interaction observed during testing.

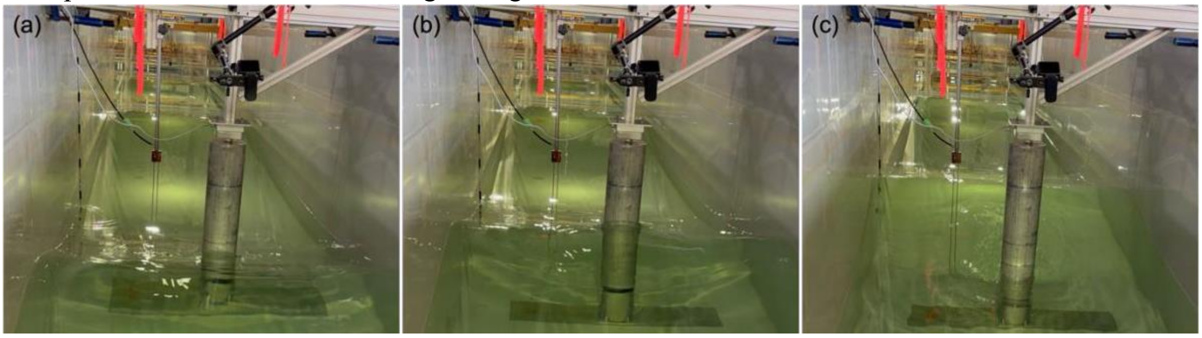

Figure 2: Experiment set-up showing wave-monopile interaction (a) Wave crest approaching the cylinder, (b) wave run-up on the cylinder, (c) wave propagating past the cylinder.

3. RESULTS

Figure 3 illustrates the contribution of nonlinear loading to the total horizontal wave force acting on the monopile. Figure 3 (a) represents a wave period typical of the North Sea, whereas figure 3 (b) is representative of the longer period wave conditions in Australia. Under the North Sea condition, nonlinear loading contributes approximately 17% of the peak total force. In contrast, the nonlinear contribution increases to approximately 53% under Australian conditions. **This substantial increase arises from the longer wavelengths associated with Australian wave climates**. The results suggest that **the wave loading regimes differ substantially** and that design approaches developed for North Sea conditions may not be directly applicable to Australian offshore wind projects. **Nonlinear effects should be carefully considered in the monopile design.**

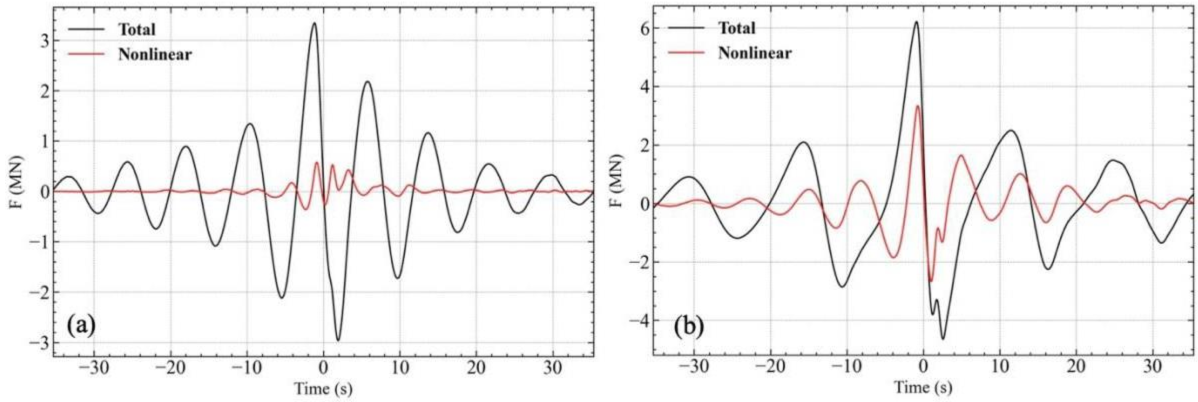

Figure 3: Total horizontal wave force and nonlinear force contribution for near-breaking focused wave groups. Results are shown for peak periods of $T_p = 8$ s (a) and $T_p = 14$ s (b), with maximum wave amplitudes of 4.6 and 8.4 m, respectively. Both cases represent the near-largest wave amplitudes that could be tested without wave breaking. Here, $T_p \approx 1.1T_e$.

In a long wavelength regime, the hydrodynamic force acting on a slender structure is commonly estimated by integrating sectional forces along its length. The semi-empirical Morison equation remains the industry-standard approach for predicting wave loads on cylindrical structures [8, 9]. This formulation represents the total load as the sum of a linear inertia component, proportional to fluid particle acceleration, and a nonlinear drag component, proportional to the square of fluid particle velocity. The inertia term provides a useful first-order estimate but does not capture the nonlinearity. Furthermore, implementation of the Morison equation requires detailed wave kinematics throughout the water column, which are often difficult to obtain in practice. To address these limitations, **a fully nonlinear force prediction model, T-FNV**, is proposed [10]. The model **requires only free-surface elevation as input** while providing **accurate predictions of wave-induced loads on compact cylinders**.

Figure 4 compares the experimentally measured total force with T-FNV model prediction and the linear inertia component of the Morison equation for the same wave conditions shown in figure 3. Under the North Sea condition, the linear Morison inertia component provides a reasonable approximation of the total load, as shown in figure 4 (a). In contrast, under the representative Australian long wavelength conditions, figure 4 (b) shows that the linear model is insufficient, underpredicting the total force. The nonlinear T-FNV model captures the measured load with better accuracy.

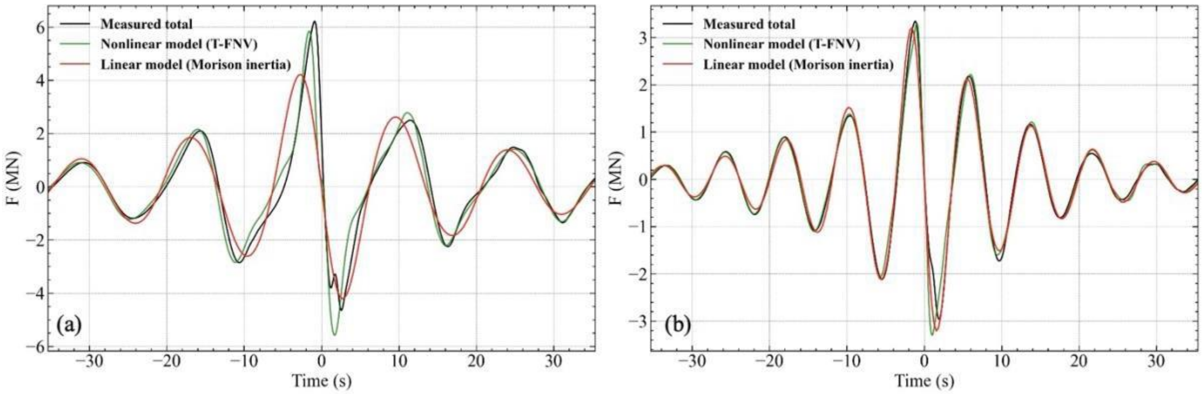

Figure 4: Comparison between the experimentally measured total force, the nonlinear T-FNV model prediction, and the Morison linear inertia load. Wave conditions are identical to in figure 3.

In summary, these preliminary results indicate that **nonlinear loading becomes increasingly important in Australia's long-wavelength wave climate** and suggest that the **T-FNV model provides a practical and more accurate alternative** to conventional linear approach for wave load prediction. Note that although the mean conditions in Australia are more nonlinear, the extremes are milder than many European sites. These new methods should allow designers to account for these differences.

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A Reduced-Order Modelling Framework for Tower and Platform Flexibility in a 15 MW Semi-Submersible Floating Wind Turbine

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Keywords: floating offshore wind turbine; structural flexibility; reduced-order modelling; semi-submersible platform; coupled dynamics.

1. INTRODUCTION

Turbine upscaling is an important cost-reduction pathway for floating offshore wind turbines (FOWTs), but it cannot be treated as simple geometric enlargement. Floating wind scaling studies show that rotor thrust, rotor-nacelle assembly mass, overturning moment, hub height and semi-submersible restoring requirements scale differently and must be considered simultaneously [1,2]. Large turbines tend to use longer blades, taller towers and larger support structures without proportional increases in sectional or member stiffness. This can lower structural natural frequencies and increase the risk of interaction with wave, rotor-excitation and controller-relevant frequency ranges.

In this study, structural flexibility denotes elastic deformation of the tower or floating support structure, including deformation of columns, pontoons, braces or tower-support regions, rather than 6-degree-of-freedom (DOF) rigid-body platform motion. Recent studies have shown that floater-member deformation can change the tower-base boundary condition and shift tower-related frequencies, which may move these modes closer to wave and rotor-excitation ranges and increase the risk of amplified nacelle motion, tower-base loading or coupled system response [3–5], as shown in Figure 1.

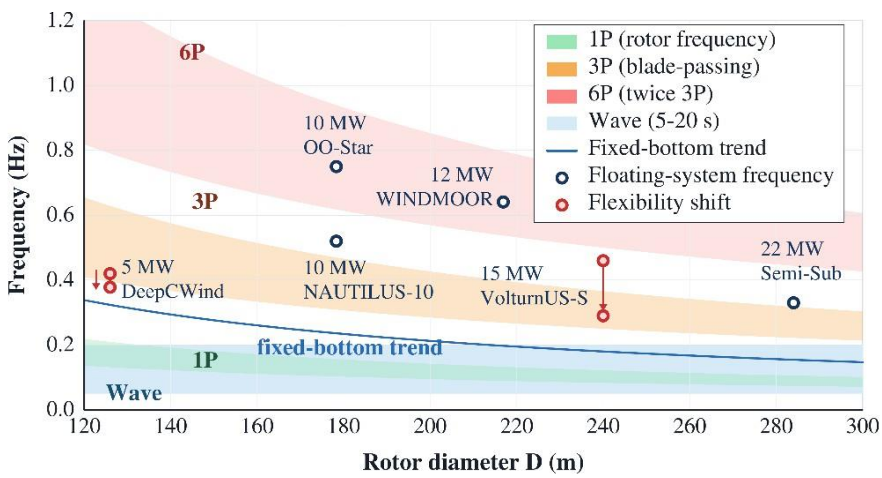

Figure 1 Frequency-separation map for representative FOWTs, showing tower-related frequencies relative to wave and rotor-excitation ranges. Downward arrows indicate reductions in tower modal frequency when support-structure flexibility is included. Reconstructed from published data [1,3,5,6].

Existing studies have shown that tower or floater flexibility can modify coupled dynamic responses across different turbine sizes, platform concepts and flexible components. However, it remains unclear whether these response changes are mainly governed by stiffness, damping, mass distribution or frequency relationships. This study addresses this gap by developing a reduced-order model to examine how flexibility-related parameters influence the response, without relying solely on fully coupled simulations. The aim is to identify the most influential parameters and develop preliminary criteria for deciding when structural flexibility should be explicitly represented.

2. METHODOLOGY

A 4-DOF reduced-order model is developed based on the free-body and kinematic idealisation shown in Figure 2. The model extends previous reduced-order floater–tower coupling studies [7,8] by separately representing platform surge, platform pitch, tower fore-aft elastic bending and deformation-induced tower-base rotation. These coordinates correspond to rigid-body platform motion, tower flexibility and floater-member deformation. The generalised coordinate vector is as follows:

$$\mathbf{q}=\begin{bmatrix} x_p & \theta_p & \eta_t & \psi_s \end{bmatrix}^T , \tag{1}$$

where x_p is platform surge, θ_p is platform pitch, η_t is the first tower fore-aft generalised displacement, and ψ_s is the effective tower-base rotation caused by floater-member deformation. The coupled equations of motion are written as follows:

$$\mathbf{M}\ddot{\mathbf{q}}+\mathbf{C}\dot{\mathbf{q}}+\mathbf{K}\mathbf{q}=\mathbf{F}(t) , \tag{2}$$

where **M**, **C** and **K** include the dominant inertia, damping and stiffness contributions from platform motion, hydrodynamics, moorings, tower bending, rotor-nacelle assembly inertia and floater-flexibility-induced tower-base rotation. The force vector **F(*t*)** represents external aerodynamic, hydrodynamic and mooring loads transmitted through the simplified load path.

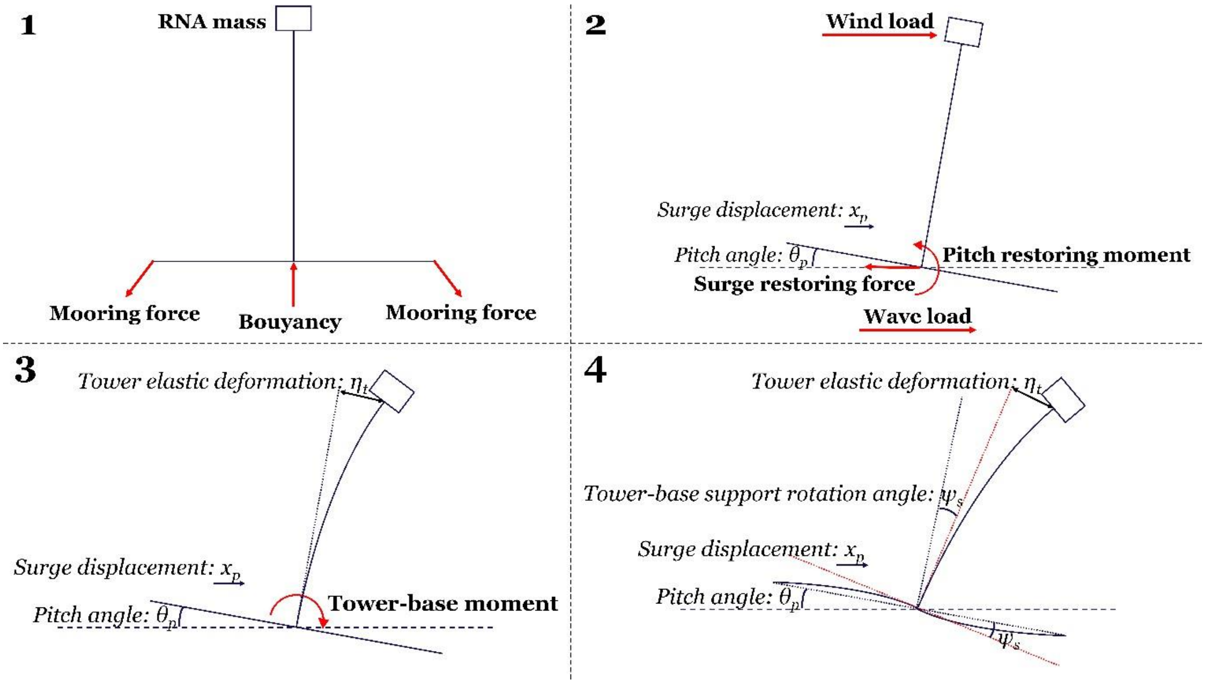

Figure 2 Free-body and kinematic idealisation of the 4-DOF model, including platform surge x_p, platform pitch θ_p, tower elastic deformation η_t, and tower-base support rotation ψ_s.

The model is used to derive indicators for inertia, stiffness, damping and frequency separation. These indicators describe the relative roles of tower/RNA inertia, platform pitch inertia, tower bending stiffness, effective tower-base rotational stiffness, hydrodynamic damping and structural damping. The framework is developed progressively: a 2-DOF rigid-platform surge-pitch model is first validated against OpenFAST free-decay simulations, before tower fore-aft deformation and floater-flexibility-induced tower-base rotation are added to form the 4-DOF model.

3. PRELIMINARY VALIDATION AND DISCUSSION

As a first implementation step, a 2-DOF rigid-platform surge-pitch reduced-order model (ROM) has been developed for the IEA 15 MW turbine with the UMaine VolturnUS-S semi-submersible platform [9]. The model parameters are extracted from the corresponding OpenFAST, HydroDyn and WAMIT input files, including platform mass, hydrodynamic added mass, hydrostatic restoring, mooring stiffness and damping, radiation damping and nonlinear quadratic viscous damping. The subsystem is compared with OpenFAST free-decay simulations to establish a rigid-platform baseline before tower fore-aft deformation and floater-flexibility-induced tower-base rotation are introduced.

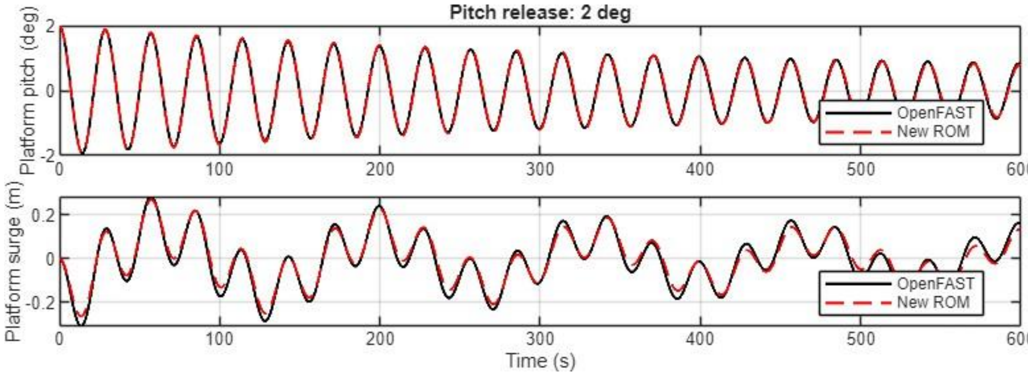

Figure 3 Free-decay comparison between OpenFAST and 2-DOF ROM under a 2° initial pitch release.

Preliminary validation shows that the 2-DOF ROM captures the dominant surge-pitch decay behaviour, as shown in Figure 3. The coupled response is sensitive to the off-diagonal added-mass term linking surge force and pitch acceleration. Direct use of the WAMIT-based coupling coefficient does not give the closest time-domain agreement, while an equivalent calibrated coefficient improves the free-decay match. This supports the use of the ROM as an interpretive screening tool rather than a replacement for fully coupled simulation.

4. CONCLUSIONS

In this project, a reduced-order modelling framework is developed for interpreting tower and platform flexibility effects in a 15 MW semi-submersible FOWT. The proposed 4-DOF formulation separates rigid-body platform motion, tower fore-aft deformation and floater-flexibility-induced tower-base rotation. OpenFAST free-decay comparisons show that the 2-DOF ROM captures the dominant surge-pitch decay response, but is sensitive to cross-coupled hydrodynamic coefficients. The next step is to extend the validated subsystem to include structural flexibility before high-fidelity simulations.

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