# Exploring the Feasibility of Co-Located Marine Renewable Energy Systems: A Mooring System and Economic Analysis in the North Carolina Coast


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North Carolina Renewable Ocean Energy Program

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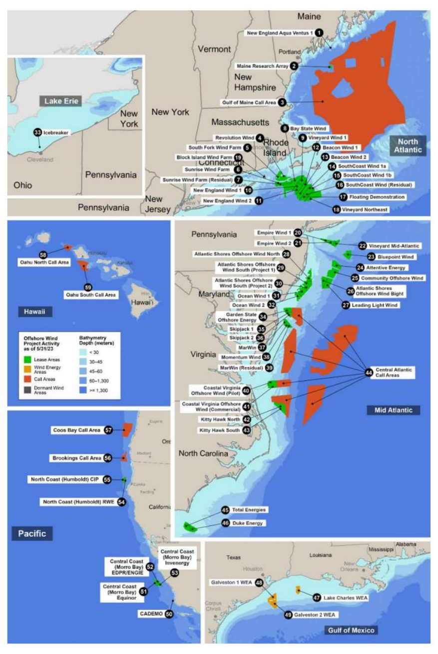
Co-locating wind turbines with wave energy converters like the Pelamis device allows the utilization of extra capacity in the transmission system by wave energy devices, increasing the total energy delivered to shore with little to no increase in the portfolio LCOE, especially with anticipated cost reductions for wave energy by 2050.

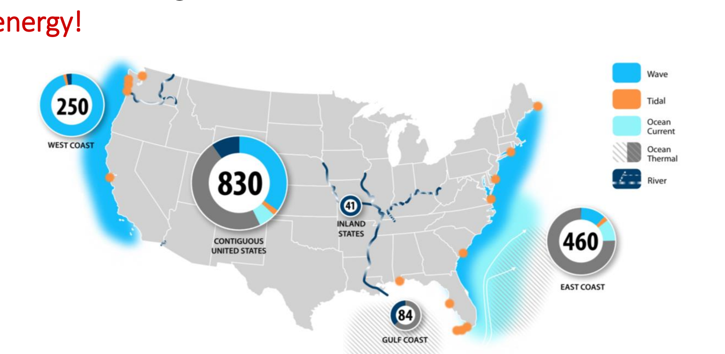

## INTRODUCTION

Locations of U.S. offshore wind energy pipeline activity and Call Areas (DOE, 2023)



Offshore Wind Market Report (DOE, 2023). Marine energy in the United States: An overview of opportunities (NREL, 2021).

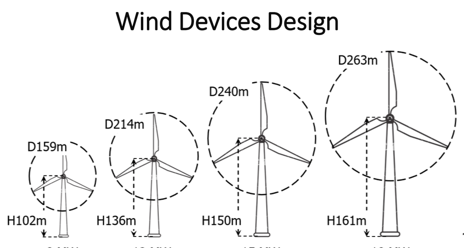
- The US currently has around 17GW of offshore wind power offtake agreements.
- States Planning Targets and Mandates: 63GW by 2040 and 112GW by 2050.
- In NC, Governor Cooper issued in 2021 the Executive Order No. 218 with targets for 2.8GW of offshore wind by 2030 and 8GW by 2040.
- NC has other considerable offshore resources like wave and ocean currents. **Can we take advantage of the future offshore wind energy infrastructure to integrate these other resources?** This work looks at wave energy!



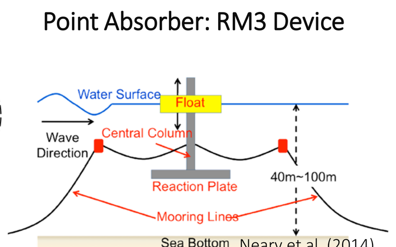

Technical power potential of US marine energy resources [TWh/year] (NREL, 2021)

## METHODS

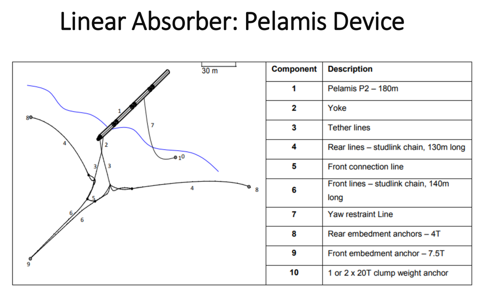
Wind Devices Design



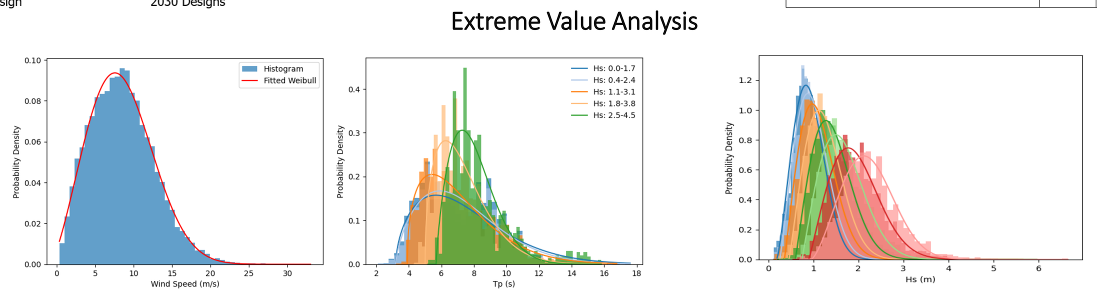

Point Absorber: RM3 Device




Linear Absorber: Pelamis Device



Extreme Value Analysis



Joint Probability Distribution

$$f_{U_w,H_s,T_p}(u,h,t) \approx f_{U_w}(u)\, f_{H_s|U_w}(h|u)\, f_{T_p|H_s}(t|h)$$

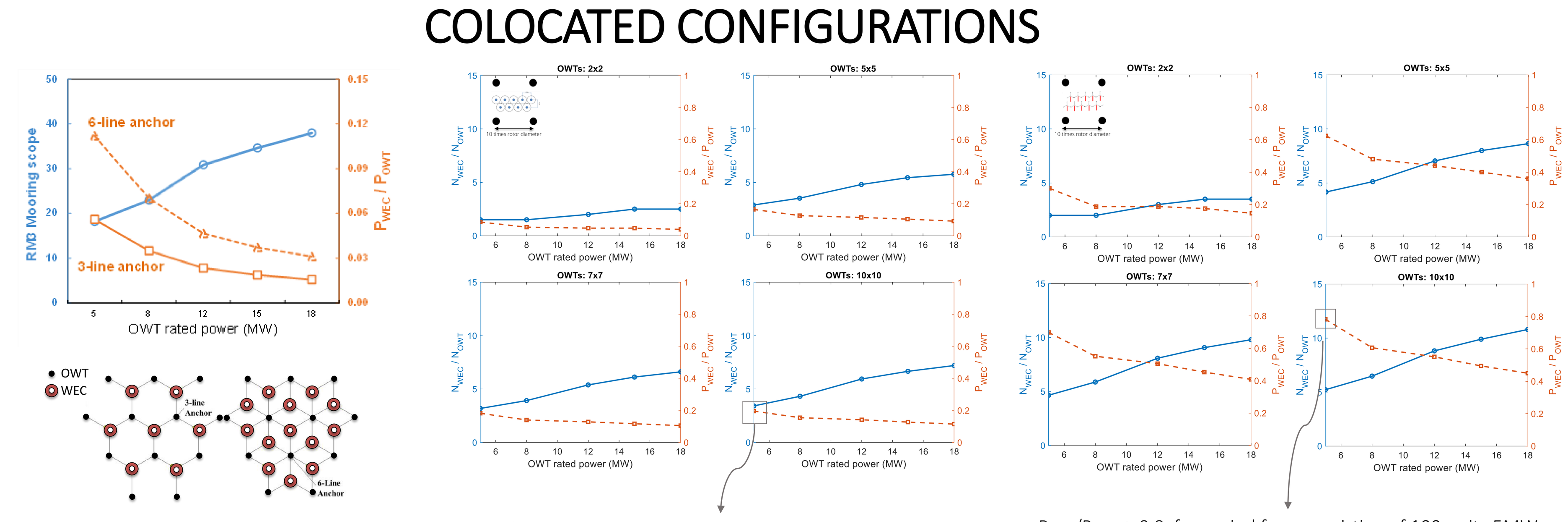
$$f_{U_w}, f_{H_s|U_w}, f_{T_p|H_s} \sim Weibull(\cdot)$$

Rosenblatt Transformation

$$\Phi(r) = 1 - \frac{1}{(365.25 * 24 * 100)} = 1 - \frac{1}{N_{100}}$$

## RESULTS

### COLOCATED CONFIGURATIONS



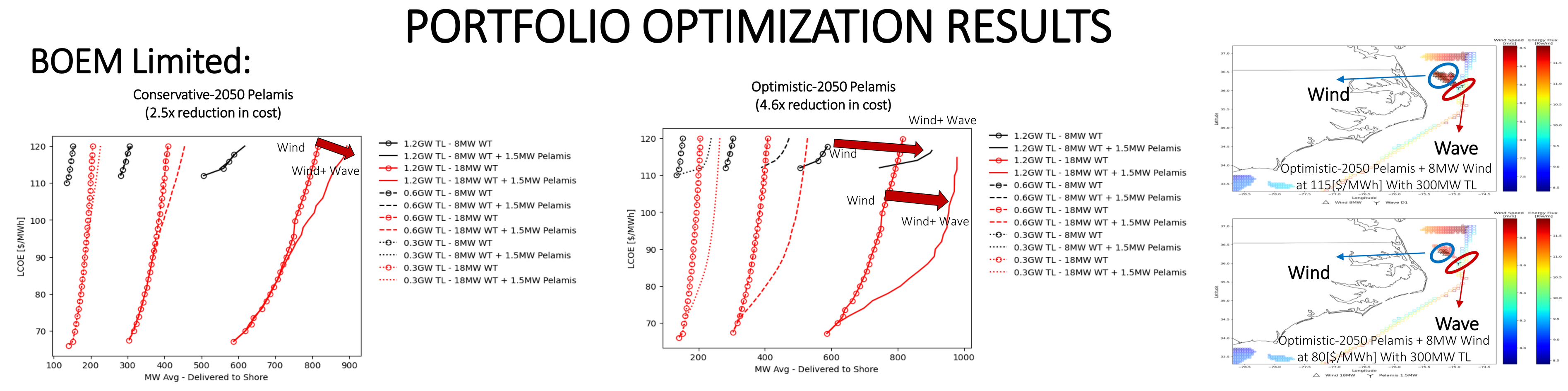

Layout of 3-line anchor and 6-line anchor systems.

$P_{WEC}/P_{OWT}$ ~ 0.2, for a wind farm consisting of 100-units 5MW OWTs and 350-units 286kW RM3 devices

$P_{WEC}/P_{OWT}$ ~ 0.8, for a wind farm consisting of 100-units 5MW OWTs and 500-units 750kW Pelamis devices

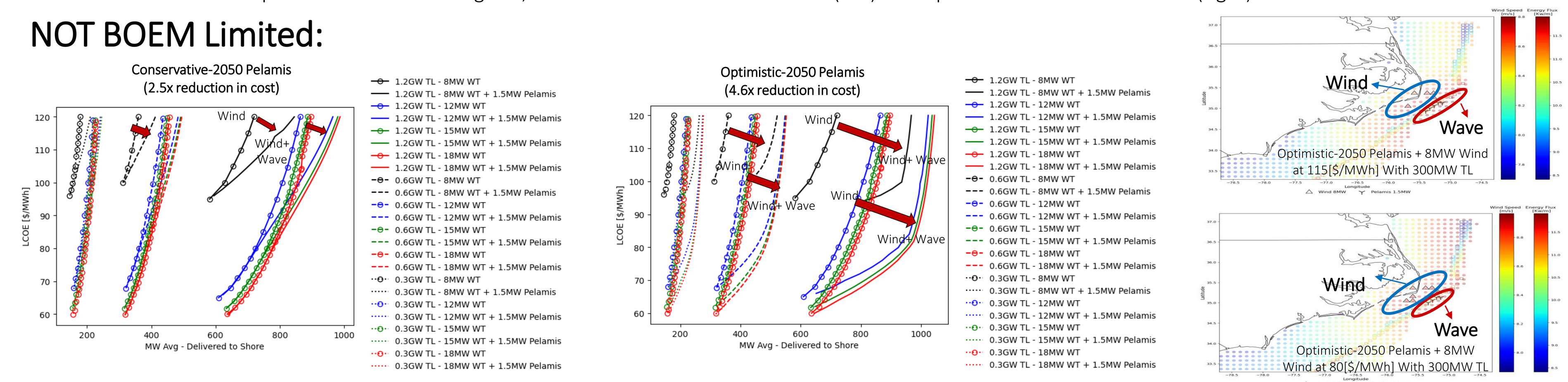
### PORTFOLIO OPTIMIZATION RESULTS

**BOEM Limited:**




Efficient frontier for the deployment of Pelamis turbines in colocation with wind technology using different transmission line capacities in the BOEM regions; Conservative-2050 Pelamis costs (left) and Optimistic-2050 Pelamis costs (right).

**NOT BOEM Limited:**




Efficient frontier for the deployment of Pelamis turbines in colocation with wind technology using different transmission line Capacities in the no-BOEM limited simulations; Conservative-2050 Pelamis Costs (left) and Optimistic-2050 Pelamis Costs (right).

## PORTFOLIO OPTIMIZATION

For a given budget ($\overline{LCOE}$), find me the solution that delivers the most electricity to the shore

**Solution:** Number of turbines at each viable site location (*y*), location of offshore substation (*v*)

Take into consideration:

- Curtailment
- Transmissions system cost
- Wind Energy Cost
- Wave Energy Cost
- Maximum Radius for Energy Collection systems

*Variables*

$y_i^{Wind}$: Number of wind turbines deployed at the site $i \in I_{Wind}$, $y_i^{Wind} \in Z^+$

$y_i^{Wave}$: Number of wave turbines deployed at the site $i \in I_{Wave}$, $y_i^{Wave} \in Z^+$

$v_i$: Binary variable responsible for controlling the center of the energy collection system for each energy technology, $v_i \in \{0,1\}$

Simplified Model Formulation

| | | | |
|---|---|---|---|
| Objective Function- Energy Maximization to Shore | $\underset{(y,v)}{Max} \sum_{t\in T}(EG_t^{Wind} + EG_t^{Wave} - \Delta_t)$ | | (1) |
| Budget Constraint | $\frac{TAC^{Wind} + TAC^{Wave} + TC}{8760\, \mathbb{E}_{t\in T}(EG_t^{Wind} + EG_t^{Wave} - \Delta_t)} \leq \overline{LCOE}$ | | (2) |
| Aggregating Costs | $TAC^{Wind} = \sum_{i\in I_{Wind}} AC_i^{Wind}\, y_i^{Wind}$ | | (3) |
| | $TAC^{Wind} = \sum_{i\in I_{Wave}} AC_i^{Wave}\, y_i^{Wave}$ | | (4) |
| | $TC = \sum_{i\in I_{Tr}} v_i\, TC_i$ | | (5) |
| Aggregating Energy Generation | $EG_t^{Wind} = \sum_{i\in I_{Wind}} EG_{i,t}^{Wind}\, y_i^{Wind}$ | $\forall t \in T$ | (6) |
| | $EG_t^{Wave} = \sum_{i\in I_{Wave}} EG_{i,t}^{Wave}\, y_i^{Wave}$ | $\forall t \in T$ | (7) |
| Curtailment Constraint | $EG_t^{Wind} + EG_t^{Wave} - \Delta_t \leq RP_{Tr}$ | $\forall t \in T$ | (8) |
| Maximum Number of Devices Per Site Location | $y_{i,d}^{Wind} \leq \overline{NT}_{i,d}^{Wind}$ … | $\forall i \in I_{Wind}$ | (9) |
| | $y_i^{Wave} \leq \overline{NT}_i^{Wave}$ … | $\forall i \in I_{Wave}$ | (10) |
| Maximum Radius for Energy Collection System | $\sum_{k\in OR_{v_i}^{Wind}} y_i^{Wind} + \sum_{k\in OR_{v_i}^{Wave}} y_i^{Wave} \leq (1-v_i)\,\overline{NT}$ | $\forall i \in I_{Tr}$ | (11) |
| | $\sum_{i\in I_{Tr}} v_i = 1$ | | (12) |

## CONCLUSIONS

- In shared anchoring configurations studied for the RM3 device with fixed-bottom wind turbines, it was found that mooring costs increase by 200% as the rated power of the wind turbines increases from 5MW to 18MW, due to the need for longer mooring lines.
- Analysis of the non-shared anchoring configuration revealed that Pelamis arrays have a higher installed capacity compared to RM3 devices in wind-wave farms, depending on the wind turbine's rated power and the number of turbines in the farm.
- A mathematical model capable of performing portfolio optimization for wind-wave integration was formalized, showing that wind-wave colocation, assuming conservative and optimistic WEC cost reductions from NREL, can be used as an alternative to deliver more energy to the shore, thereby making better use of the existing transmission system infrastructure.
- The Pelamis wave energy converter was identified as more feasible due to its lower LCOEs and higher capacity factors in North Carolina conditions.

## REFERENCES


- University of Edinburgh, "Matching Renewable Electricity Generation with Demand," Scottish Executive, 2006.
- NOAA, "NOAA WAVEWATCH III," [Online]. Available: https://polar.ncep.noaa.gov/waves.
- E. Baca, R. T. Philip, D. Greene and H. Battey, "Expert Elicitation for Wave Energy LCOE Futures," NREL, 2022.
- "The Farr Point Wave Farm Development: Request for Scoping Opinion," 2011.
- N. Jamaleddin, M. Gabr and R. Borden, "Shared Anchoring of Marine Renewable Energy Devices Utilizing Monopiles," in Geo-Congress 2024, Vancouver, 2024.
- V. S. Neary, M. Previsic, R. A. Jepsen, M. J. Lawson, Y.-H. Yu, A. E. Copping, A. A. Fontaine, K. C. Hallett and D. K. Murray, "Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies," SANDIA, 2014.
- NREL, "2022 Annual Technology Baseline (ATB) Cost and Performance Data for Electricity Generation Technologies -V3," 2022.



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