Status update

IEA Wind 2200-22-MW Reference Offshore Wind Plants

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IEA Wind Task 55

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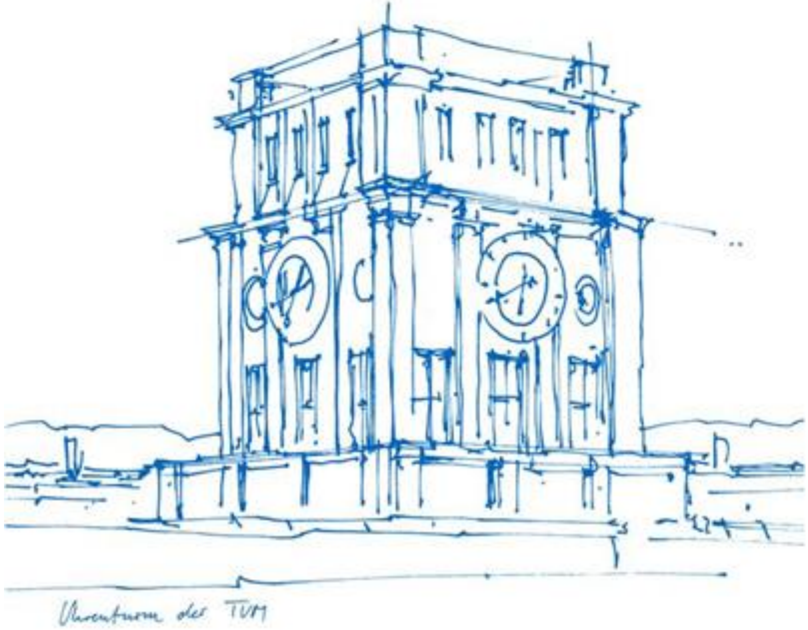
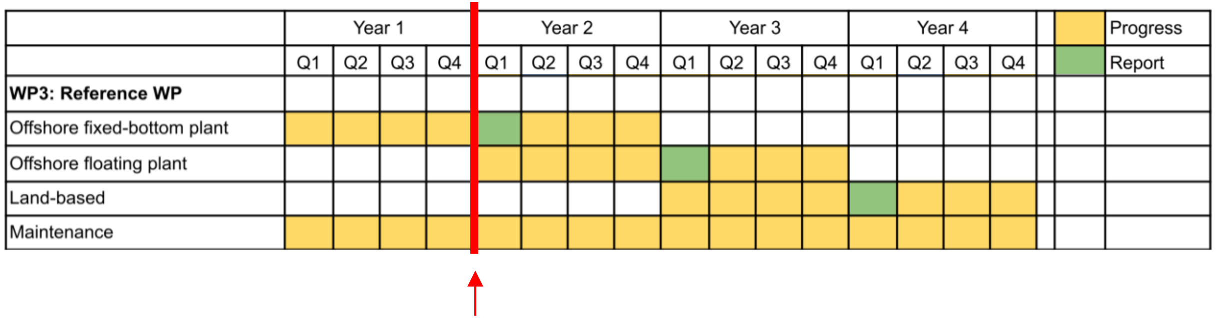


Introduction

- Work Package 3 of IEA Wind Task 55: Reference wind plants
- Objective: Design, release, and maintain new land-based and offshore reference wind plants
- Already published: IEA Wind 740-10-MW Reference Offshore Wind Plants[1] based on 10MW machines
- Current efforts: Next generation reference offshore wind plants using IEA 22-MW reference turbines
- Future plans:
    1. Floating reference offshore plants using IEA-22MW or IEA-15MW machines (collaboration with Task 49)
    2. Onshore reference plant using future IEA onshore turbine



Motivation

“Why do we need reference plants?”

- Benchmarks to evaluate innovations
- Popular when there is no access to real design + data
- Collaboration among / with industry to minimize use of intellectual property
- Great success for IEA reference turbines → next level: reference wind plants

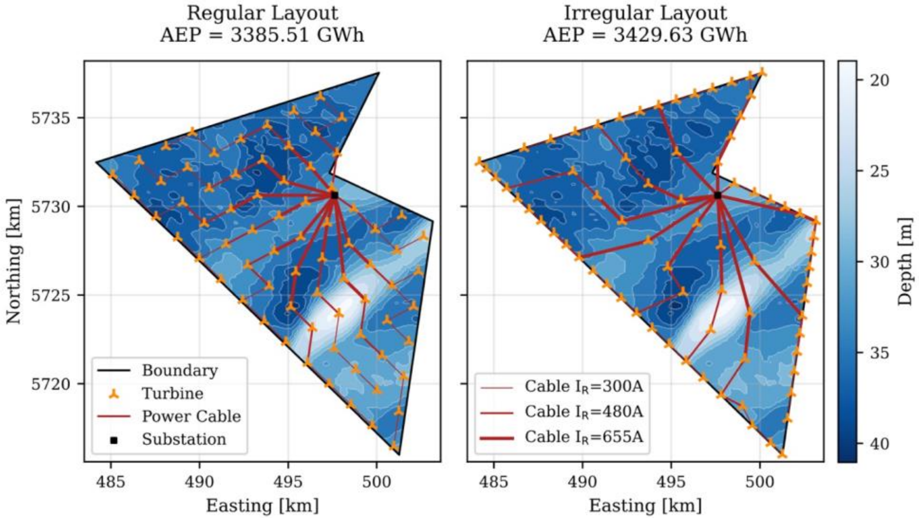
➔ Holistically defined and broadly applicable wind plants

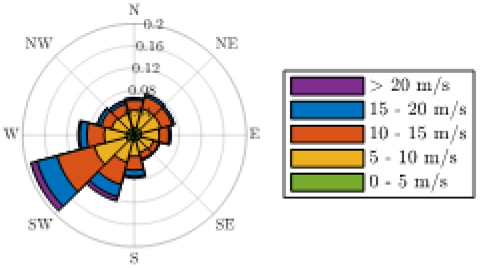
➔ Extensive and easily accessible information (windIO) on site characteristics, plant design, turbine definition, …

➔ Allowing for diversified and comprehensive studies with varying analysis and optimization objectives

IEA Wind 740-10-MW ROWPs

- Based on Borssele III & IV in Dutch-Belgian offshore cluster
- 74 x IEA-10MW turbines
- Optimization objective: maximum AEP
- Two reference layouts (regular / irregular)
- Plant data, optimization code, sample codes for Floris / Pywake publicly available on github
- NREL technical report[1] describing the reference plants in detail





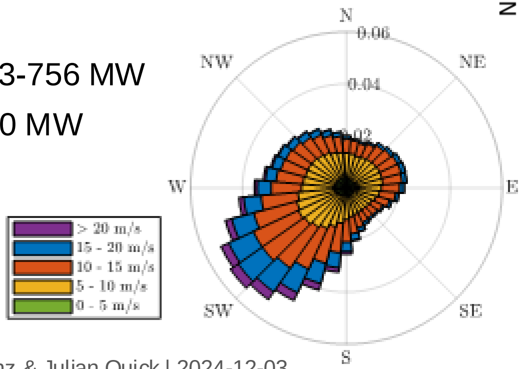
[1] Kainz S, J Quick, M Souza de Alencar, S Sanchez Perez Moreno, K Dykes, CJ Bay, MB. Zaaijer, P Bortolotti (2024): "The IEA Wind 740-10-MW Reference Offshore Wind Plants", IEA Wind TCP Task 55, NREL Technical Report

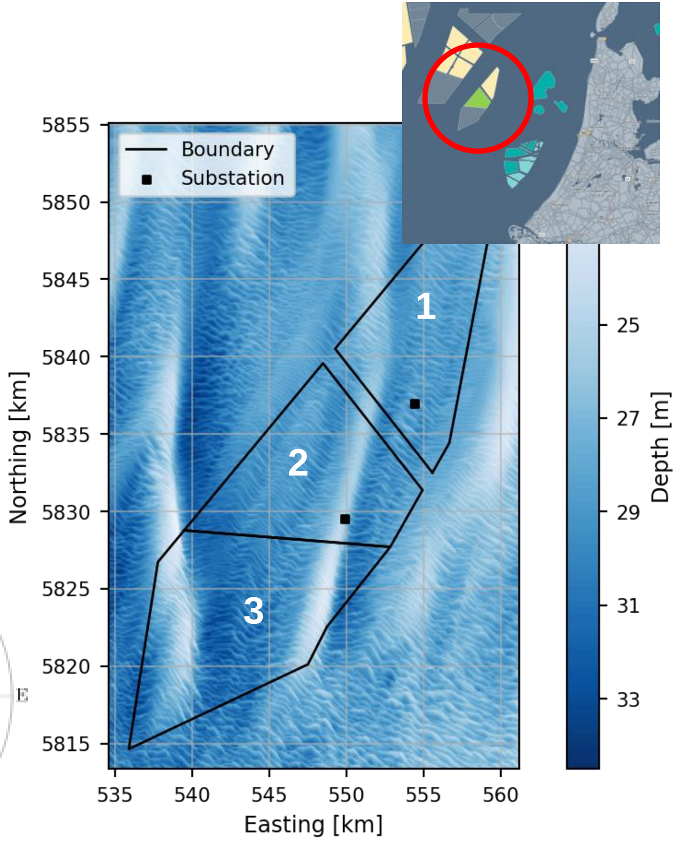
Ongoing work

The IEA 2200-22-MW Reference Offshore Wind Plants

Site description

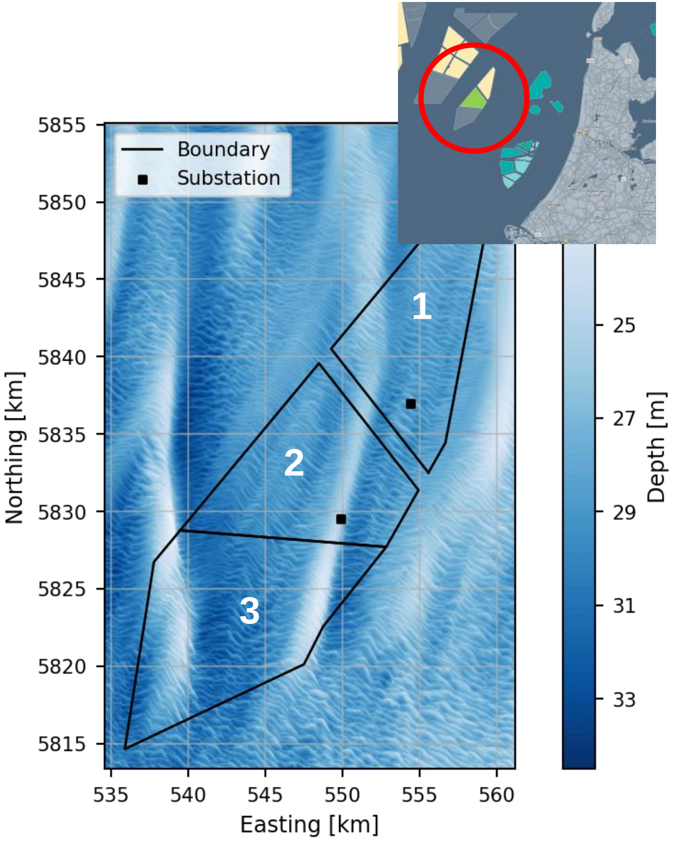
- Outcome of community survey / discussion in Task-55 meeting in Florence (May’24 before TORQUE)
- Hollandse Kust West (HKW) development zone
- 176km², 53 km from shore
- Abundant data publicly available through Dutch government (Coordinates, infrastructure plans, several lidar for wind, wave measurements, geophyiscal survey, archeological desk study, …)
- Consists of three sites, in total ~2.2GW (100 x IEA-22MW), two are sold and being developed:
    1. Ecowende (Shell & Eneco): 693-756 MW
    2. HKW VII (RWE subsidiary): 760 MW
    3. HKW VIII: 700 MW





Approach

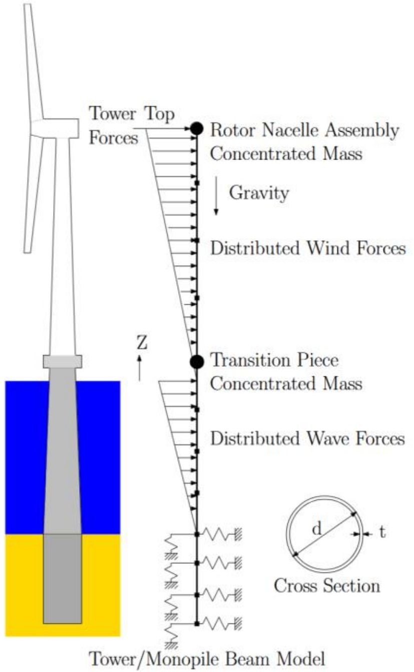
- Develop three sites concurrently while considering the others as neighboring wind farms
- Turbine type: monopile-based IEA 22-MW reference wind turbine
- Optimization objective: Levelized Cost of Energy (LCOE)
- Design variables: Turbine positions (x,y)
- Constraints: Boundaries and minimum turbine spacing (2D)
- Substation positions are fixed (Tennet)
- Optimization setup in TopFarm using SGD algorithm
- Initial layout: random positions within boundaries, will be updated with DTU's "Smart Start"
- Relevant data provided in windIO format
- Python script to load data and run optimization



Objective function (1/2)

Main impacts on LCOE when varying turbine positions:

1. **Wake effects**
   - ➔ Modeled through PyWake
   - ➔ Batankhah 2014 wake model, squared sum superposition, no TI dependance, rotor center effective wind speed
2. **Support structure**
   - ➔ DTU monopile mass surrogate model[2] to scale monopiles with varying bathymetry
   - ➔ Based on multiple monopile optimizations (objective: minimum mass) using WISDEM for different rotor types and different site conditions
3. **Array cabling**
   - ➔ new innovative DTU cabling optimization algorithm ("EDWIN")[3]
   - ➔ "Gap" parameter control solution time and accuracy



[2]Michael K. McWilliam et al 2022 J. Phys.: Conf. Ser. 2265 042048
[3]M Souza de Alencar, "interarray", https://github.com/mdealencar/interarray/

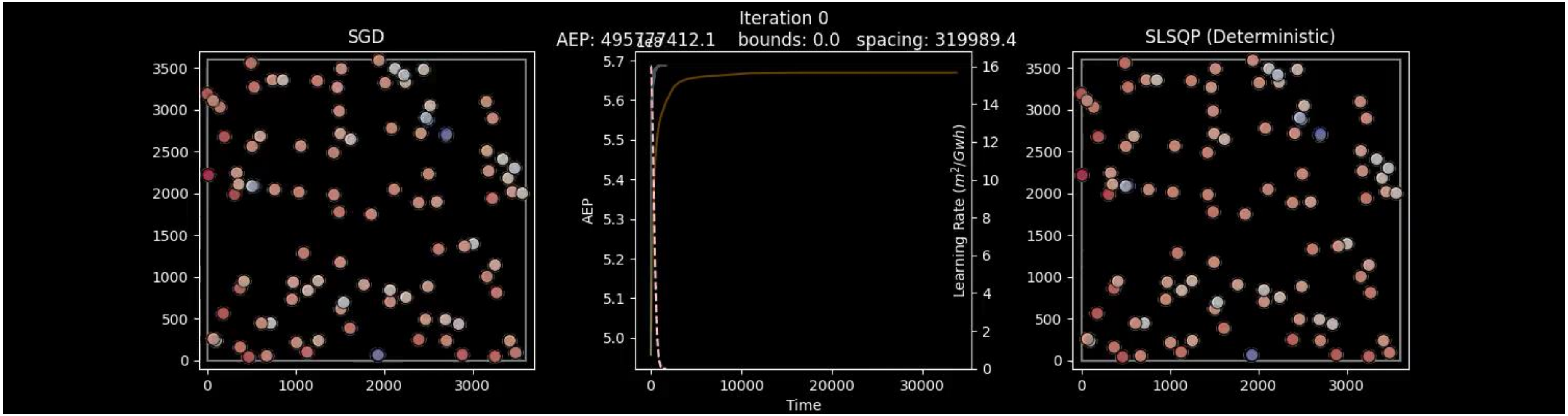
Objective function (2/2)

$$LCOE = \frac{(MPC + CC + CAPEX_{fix} + LP_d) \cdot CRF + OPEX_a}{AEP}$$

- **AEP** (annual energy production): modeled via PyWake
- **MPC** (monopile costs): mass output from surrogate model translated to cost using ORBIT[3] cost scaling function
- **CC** (cable costs): price per meter cable length (three cable types made available to optimizer)
- Baseline costs. Currently calculated with TUM in-house tool (DETECT), simplification planned. Potential check with industry?
  - **$CAPEX_{fix}$** – fixed investment costs (excl. monopile / array cabling)
  - **LP_d** – Liquidation proceeds at end-of-life (discounted to present value)
  - **$OPEX_a$** – annual O&M costs
- Neglected: taxes and financing
- **CRF** … Capital Recovery Factor = 1 / Annuity Factor

Optimization algorithm

- Optimization is performed using TOPFARM Stochastic Gradient Descent algorithm
- This randomly samples the gradient of the objective function while enforcing deterministic constraints



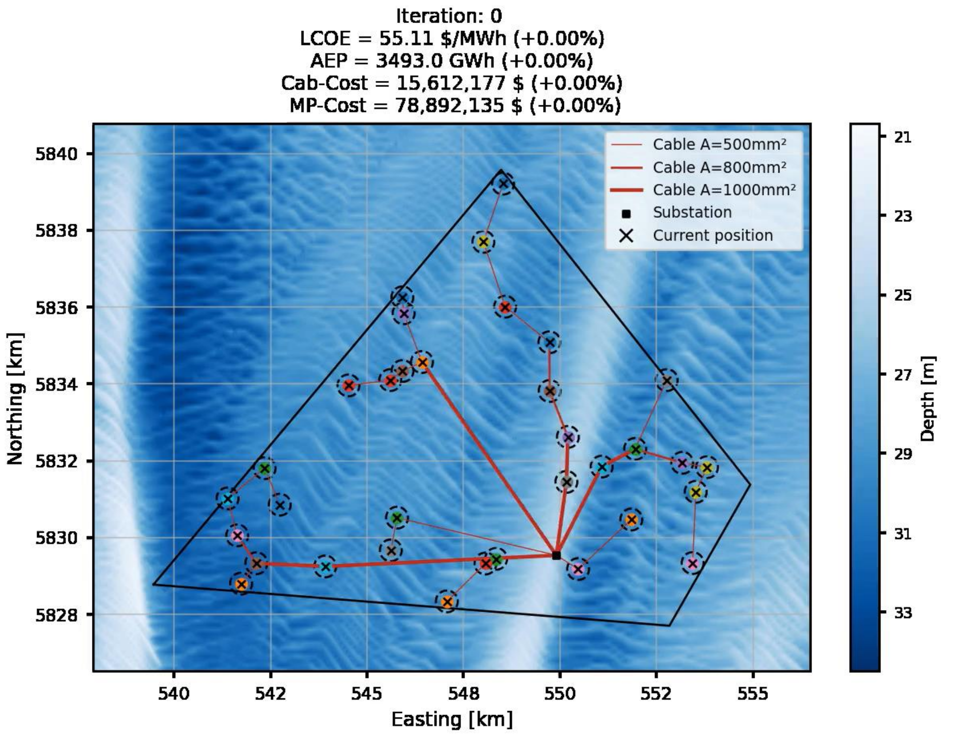
Gradients

- Applying the quotient rule to our objective function:

$$\partial LCOE = \frac{CRF \cdot (\partial MPC + \partial CC) \cdot AEP - ((CAPEX + LP + MPC + CC) * CRF + OPEX_a) \cdot \partial AEP}{AEP^2}$$

- Required for SGD optimizer (gradient-based algorithm)
- Validated with finite differences
- Monopile surrogate cost versus depth fit using polynomial
- Cable costs are determined as a linear mapping of turbine positions
- PyWake supports AEP gradients

Preliminary results



Next steps

- Define the three sites as inclusion zones
- Optimize all three sites at once
- Simplify fixed costs (literature-based instead of model-based)
- Further test and verify the setup. Particularly:
  - Monopile mass surrogate model: Tune with IEA-22MW reference monopile design? Model created with data for rated power up to 20MW → extrapolation to 22MW?
  - Examine the conservative "TurboPark" wake model
  - Co-operative versus competing layout (and controls?) designs

→ End January ‘25: Final plant layouts, draft of technical report

→ End February ‘25: Final version of report

→ March ‘25: Release report + repository

→ Potential follow-up journal paper using full potential of optimization setup

Discussion

- General thoughts about optimization approach?
- Is the monopile cost model realistic? Sand banks? Slope constraint?
- Should we rely on the conservative TurboPARK model? Is there a better way to capture these physics?
- Any other cost aspects to consider? Layout-specific O&M costs?
- Anything else to discuss?

Thank you!