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FLOAWER FLOAting Wind Energy netwoRk

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement N° 860879.

Cost modelling for offshore wind farms using dynamic cost functions and engineering wake models

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DeepWind Conference 2023 – 19.01.2023

Motivation & Project background

- Excellent wind conditions at deep offshore areas (50-200m): high wind speeds, less turbulence, less shear
- Huge potential for Europe to achieve renewable energy goals
- Floating substructure costs are less sensitive to sea depth compared to fixed-bottom
- FWTs become feasible at sea depth >50m

Goal: to make FWT competitive in energy market

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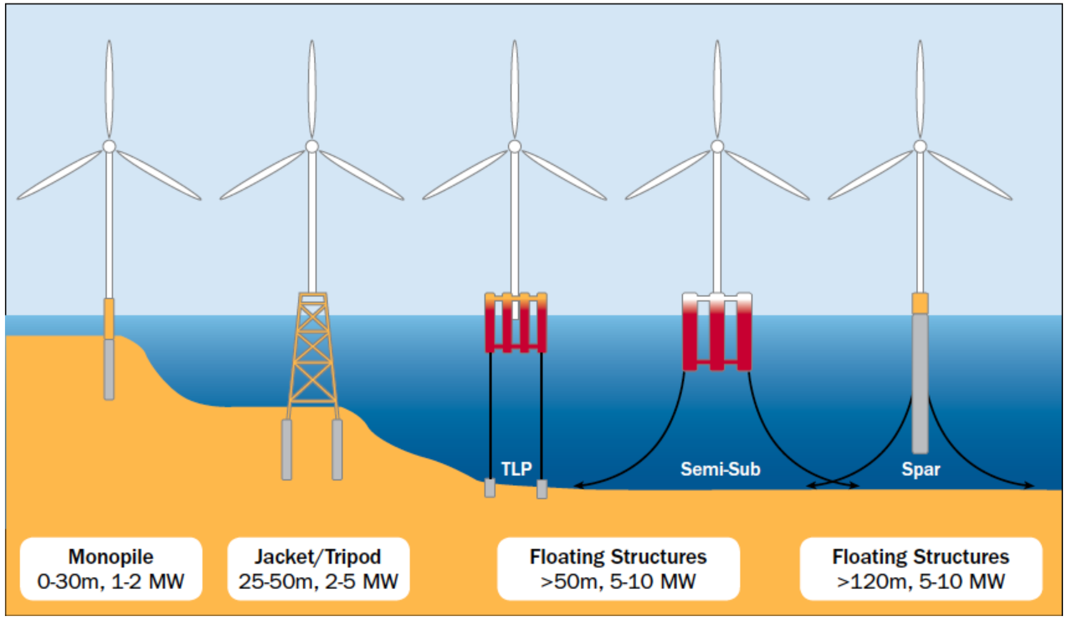
Work packages:

- Wind resource assessment
- Advanced floater analysis
- Dynamics of wind turbine
- **System design to reduce LCOE**



Adapted from Arapogianni et al. 2013

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Introduction

- Need to assist turbine design optimization at *farm level*, driving the design with wind farm LCoE

- Onshore wind farm layout depends on terrain orography, whereas offshore environment offers a more flexible room for layout optimization.

Michelle Lewis
(retrieved through http://www.electrek.co)

Matthias Ibeler
(retrieved through https://www.offshore-stiftung.de/en/alpha-ventus)

- Opportunity to design site-specific wind turbine systems

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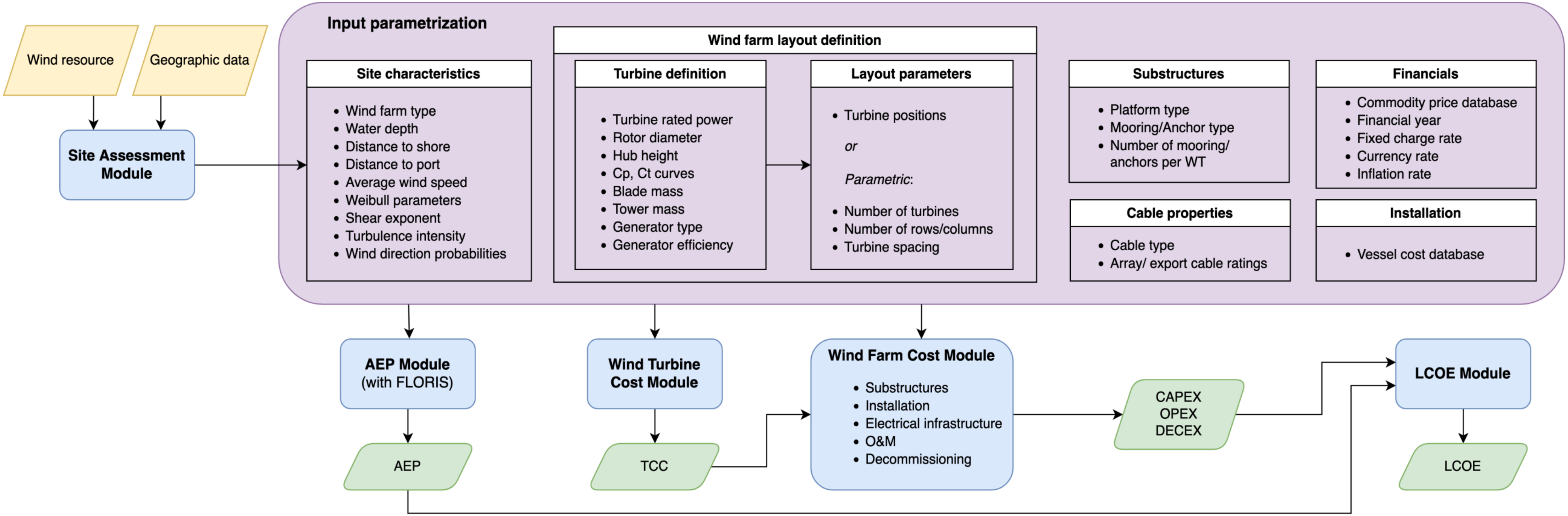
Wind farm cost model overview

Fully automated MATLAB tool ***COSMO-WF*** (COSt Model for Wind Farms)



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Dynamic cost functions 1

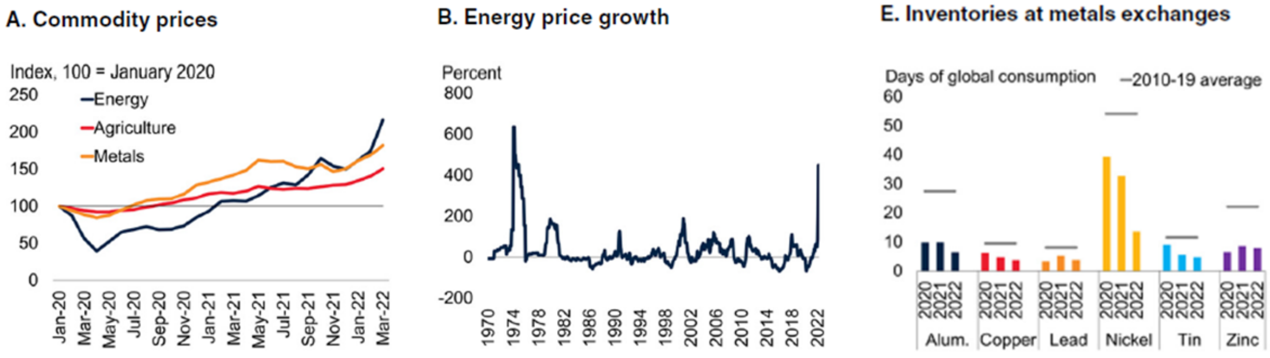
Progression away from "static costs":

- High level, €/kW
- Fixed at time of publication
- Do not change with market conditions
- Applies to total CAPEX, OPEX or component level costs

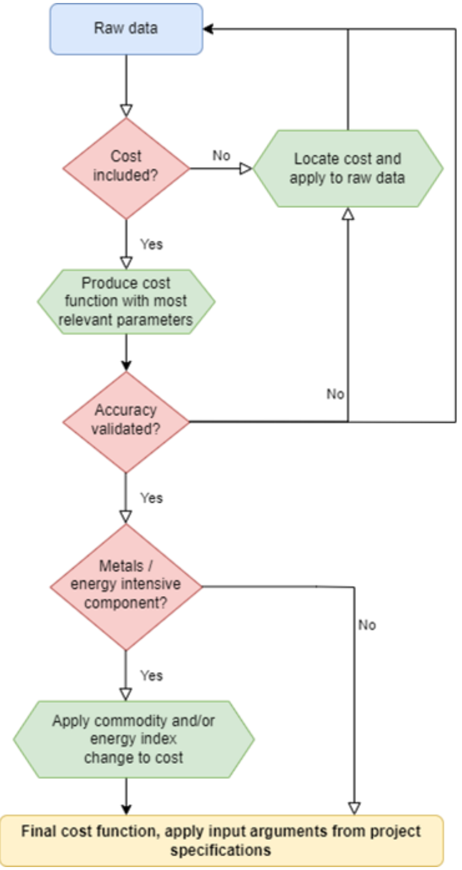
$$cost_{component} = Power_{farm(kW)} \cdot cost_{€/kW}$$

Dynamic cost functions

- Component-specific
- Market adjustable
- Range of possible inputs (MW, diameter, mass, loads)
- Value defined by original cost year and year of project financial close



[1] World Bank Commodity Markets Outlook April 2022



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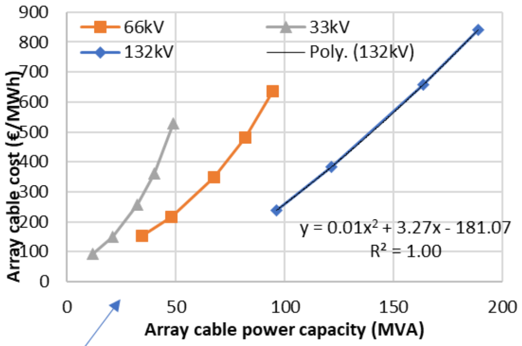
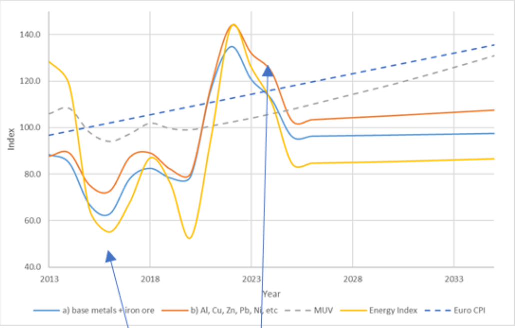
Dynamic cost functions 2

kV	a_air	Power_MVA
0.69	135	0.16
0.69	288	0.34
0.69	405	0.48
0.69	564	0.67
0.69	699	0.84
3.3	135	0.77
3.3	240	1.37
3.3	380	2.17



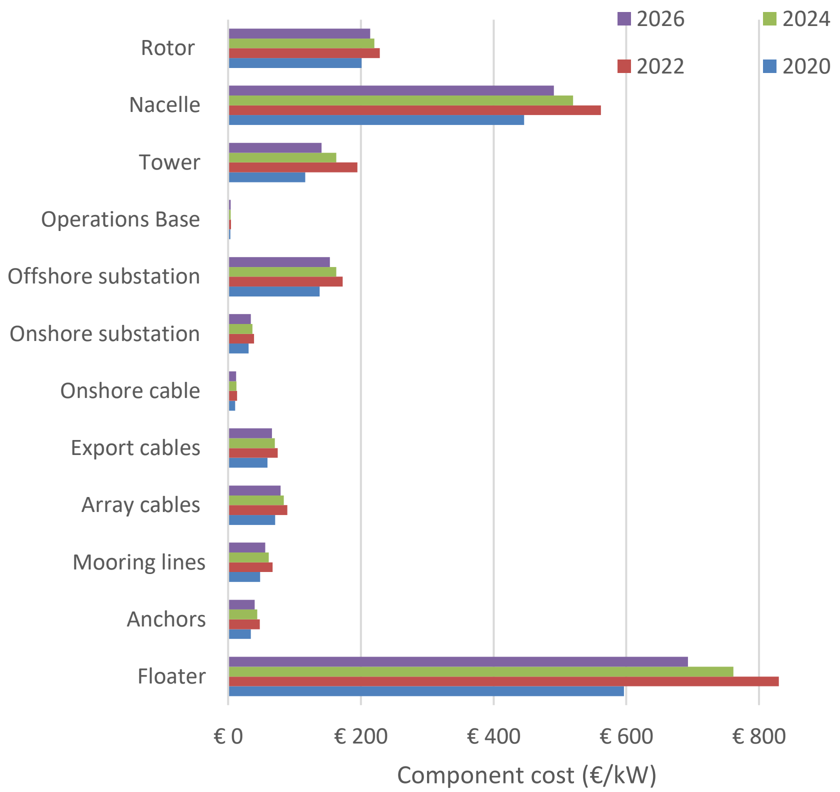


Raw data

Cost function

Commodity adjustment

Results



$$cost_{f(x)} = (0.01x^2 + 3.27x - 181.07) \cdot 1 + \left[\left(\frac{c1_{current}}{c1_{origin}} \cdot weight_{c1} - 1\right) + \ \dots + \left(\frac{cn_{current}}{cn_{origin}} \cdot weight_{cn} - 1\right) \right]$$

$$cost_{f(mass)} = (mass_{component} \cdot cost_{\frac{€}{Mt}}) \cdot 1 + \left[\left(\frac{c1_{current}}{c1_{origin}} \cdot weight_{c1} - 1\right) + \ \dots + \left(\frac{cn_{current}}{cn_{origin}} \cdot weight_{cn} - 1\right) \right]$$

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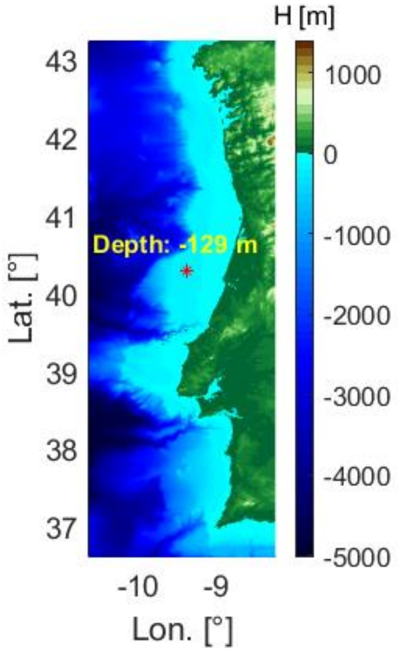
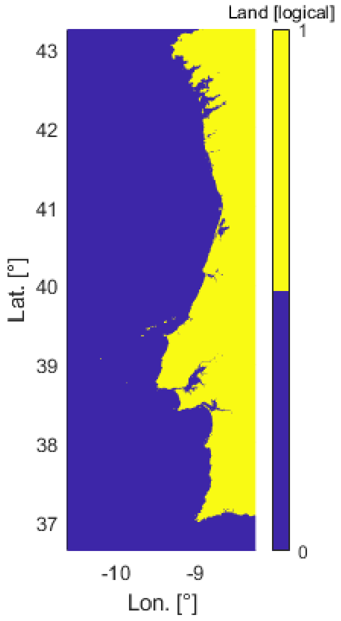
Site assessment tool - bathymetry

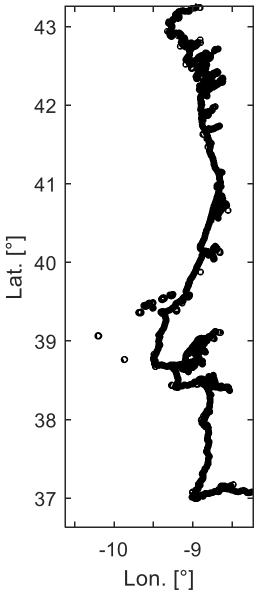
Bathymetry data from GEBCO



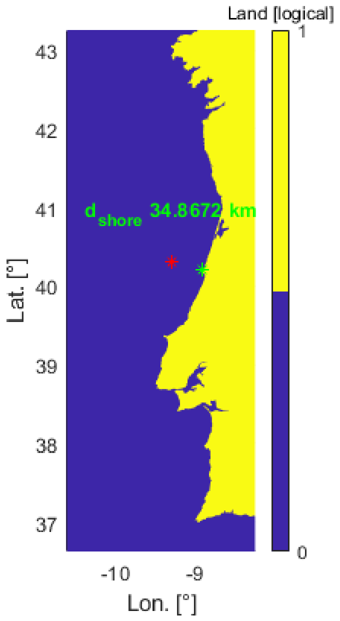
Map onshore/offshore



Find main shore line (exclude islands)



Find distance to shore



Output at a position $f(x_{Site}, y_{Site})$ = [Water depth (elevation), distance to shore, wind farm flag (onshore/offshore)]

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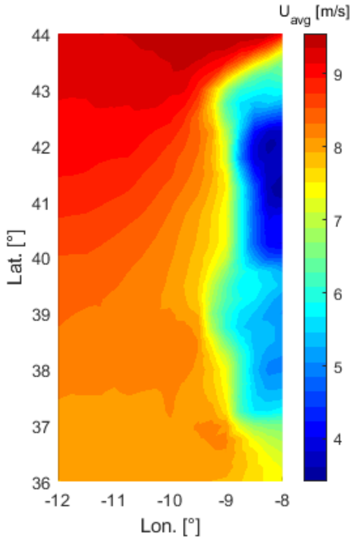
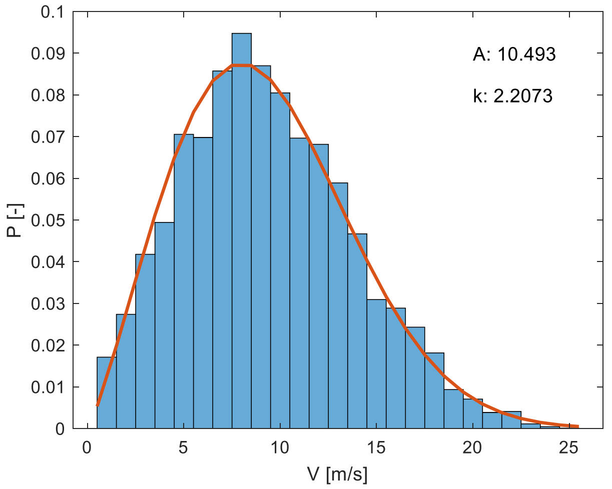
Site assessment tool – wind resource

Wind data from ERA5: Hourly data (from 2021) of **U** and **V** components at 100 m height

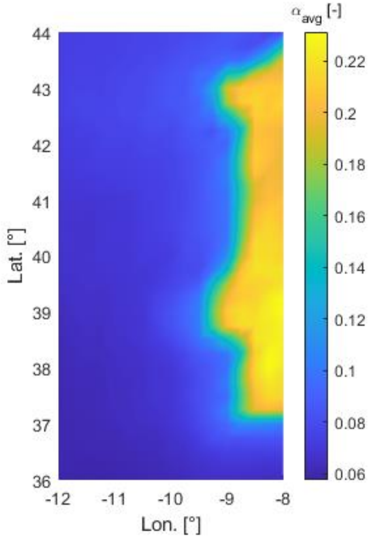
Mean of absolute velocities



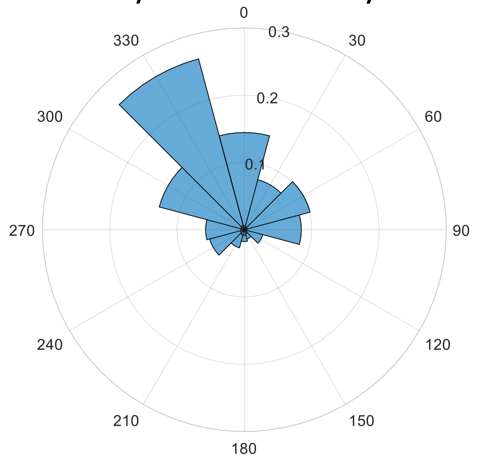
Bin and fit values to Weibull pdf



Shear exponent derived from 10m & 100m data



Wind direction using u- v- components
Probability distribution by binning values



<u>Output</u> at a position $f(x_{Site}, y_{Site})$ = [Weibull parameters A(scale), k(shape), α exponent, direction probability array, TI]

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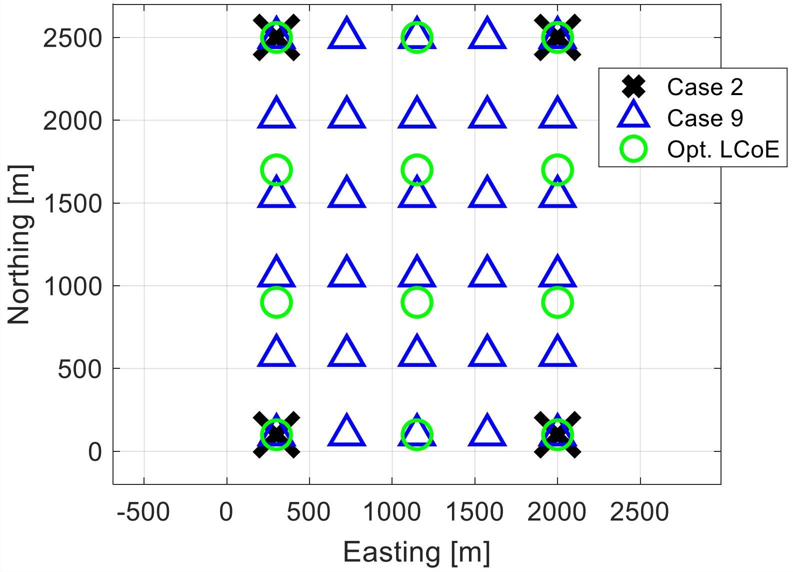
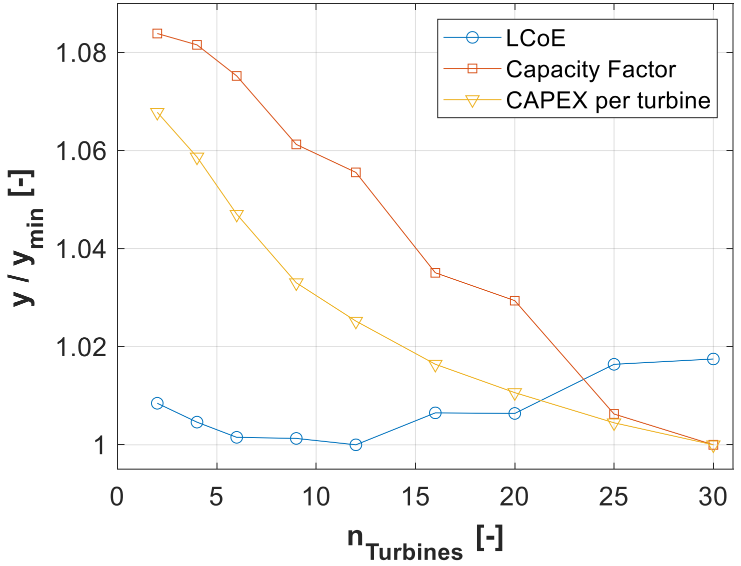
Validation of the cost model

Analysis on two validation cases:

	Alpha Ventus	Hywind Scotland
Substructure	Monopile	Floating (Spar buoy)
Number of turbines	12	5
Total rated power	60 (5x12) MW	30 (6x5) MW
Turbine rotor diameter	126 m	154 m
Turbine hub height	90 m	100 m
Distance to shore	45 km	25 km
Water depth	35 m	120 m





Min. LCoE achieved for actual layout

<u>Assumptions</u>

- Learning rate **LR** on TCC:

  $LR = 1 - 2^{-\alpha}$

  $TCC_{tot} = TCC \times {n_T}^{\alpha}$

  With LR = 5% ⟶ price reduction of 5% every time the number of produced units is doubled. [Meissner 2020]
- Fixed charge rate: 10% for floating wind due to higher risks [Beiter 2016]

LCoE of Hywind is calculated 221 €/MWh, agreeing well with the public value 220 €/MWh found in reports.

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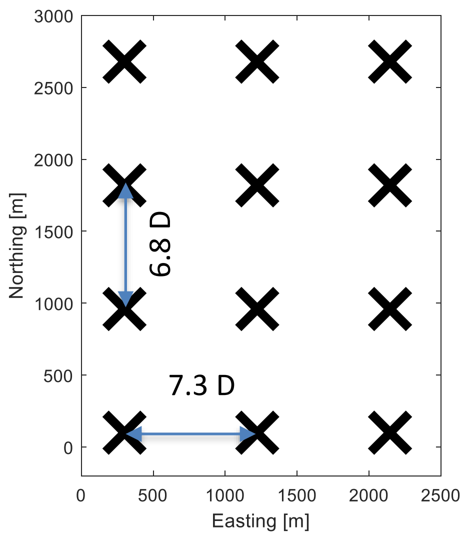
LCoE analysis – Case study Portugal

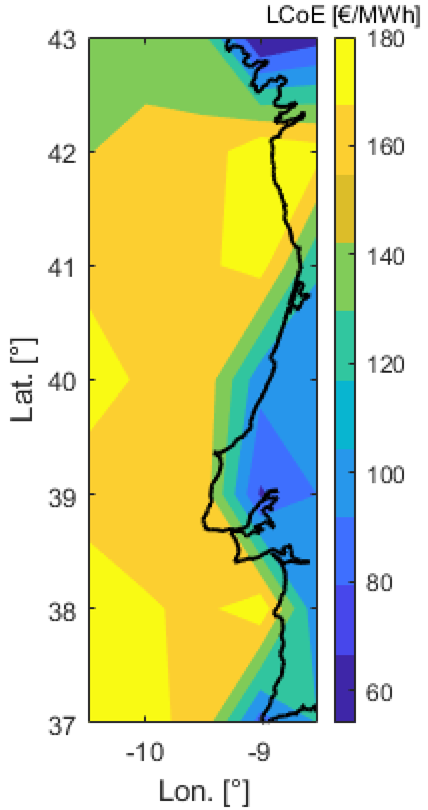
Alpha Ventus wind farm layout 12 x 5MW



A grid of 7 Lat. x 5 Lon. Points:
35 simulations

<u>Cost modelling procedure:</u>

Water depth < -60m	floating
-60m < Water depth < 0	monopile
Water depth >0	onshore



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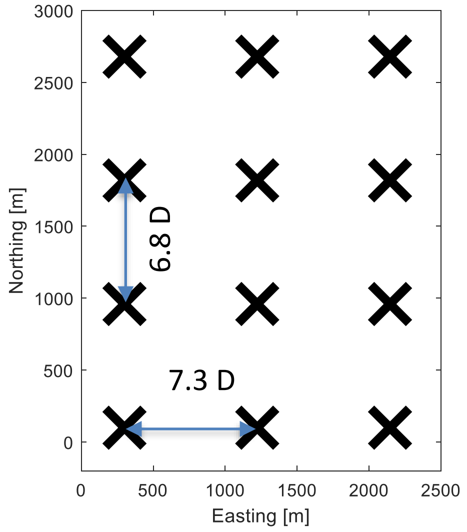
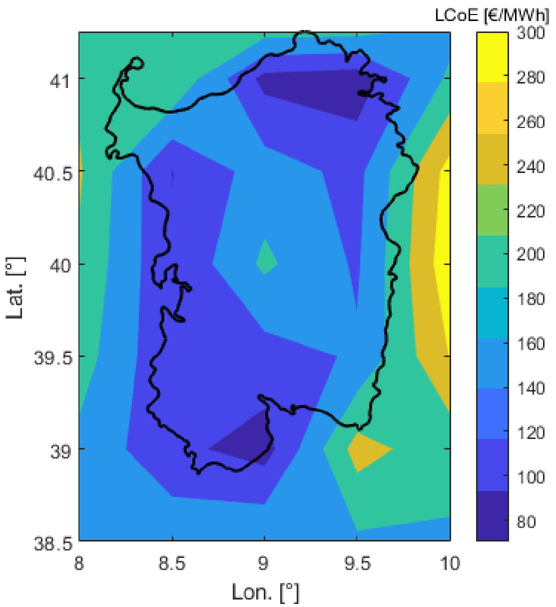
LCoE analysis – Case study Sardinia

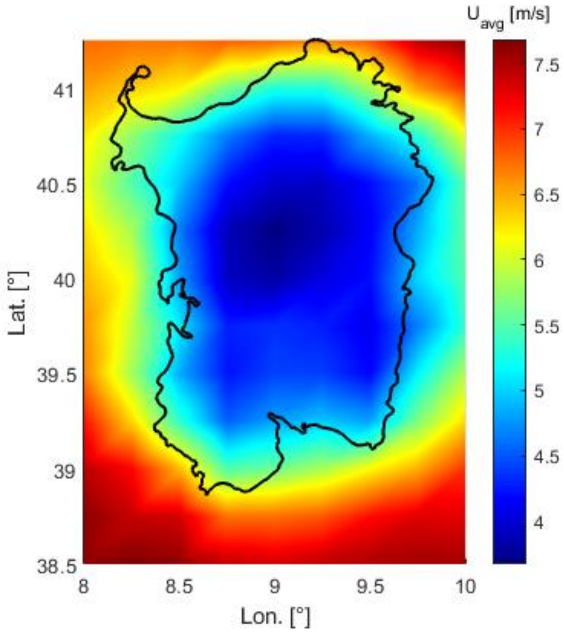
Alpha Ventus wind farm layout 12 x 5MW



LCoE analysis



Average wind speed



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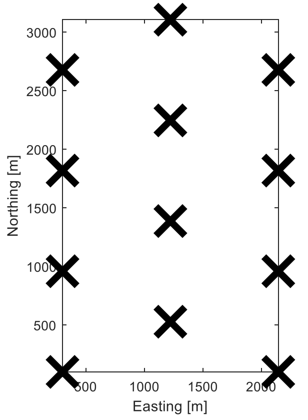
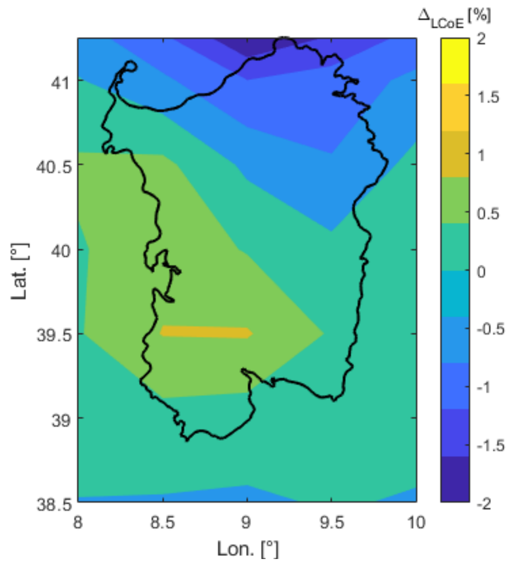
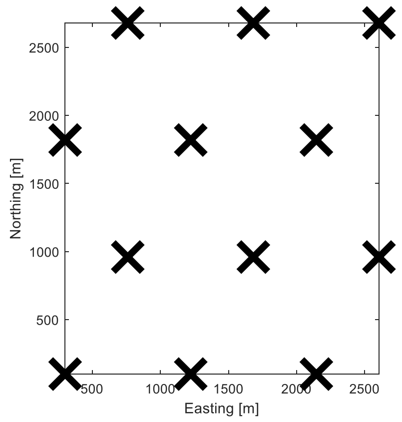
LCoE analysis – Case study Sardinia
Impact of wind farm layout

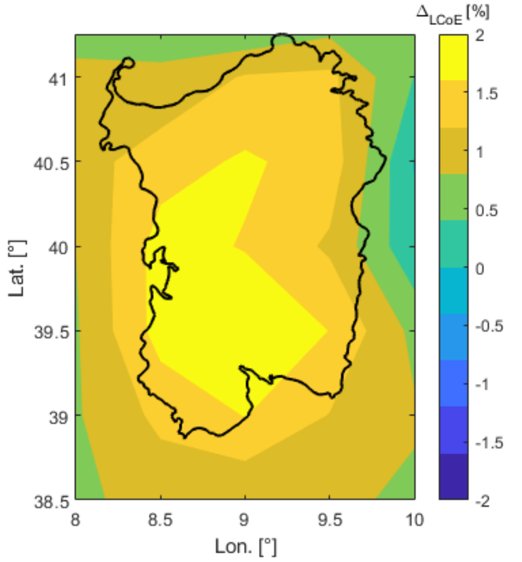
Mid-column shifted towards north (1)





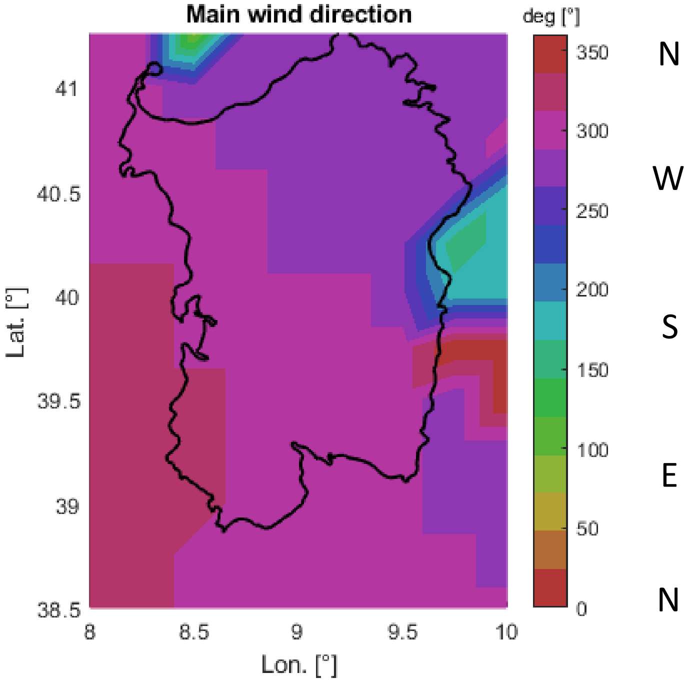
Two rows shifted towards east (2)





LCoE diff. wrt reference layout

- (1) achieves LCoE gains where westerly winds are dominant
- (2) yields generally higher LCoE
- Overall, baseline layout performs best in locations with winds from cross compass directions (here NW)



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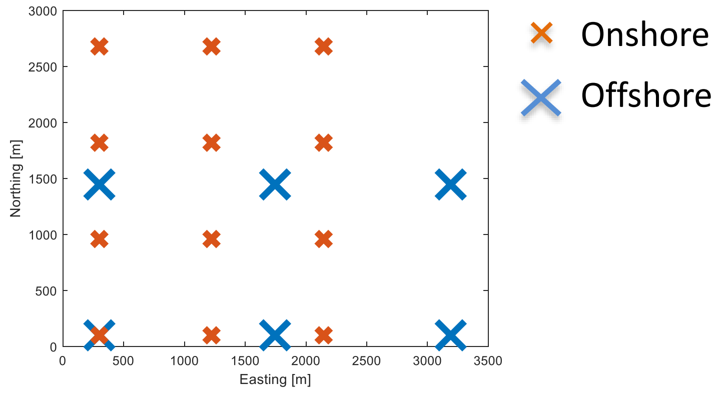
LCoE analysis – Case study Sardinia
Impact of selected wind turbine

Total nominal power = constant

Selecting turbine design based on onshore/offshore:

Onshore: 5MW x 12 turbines

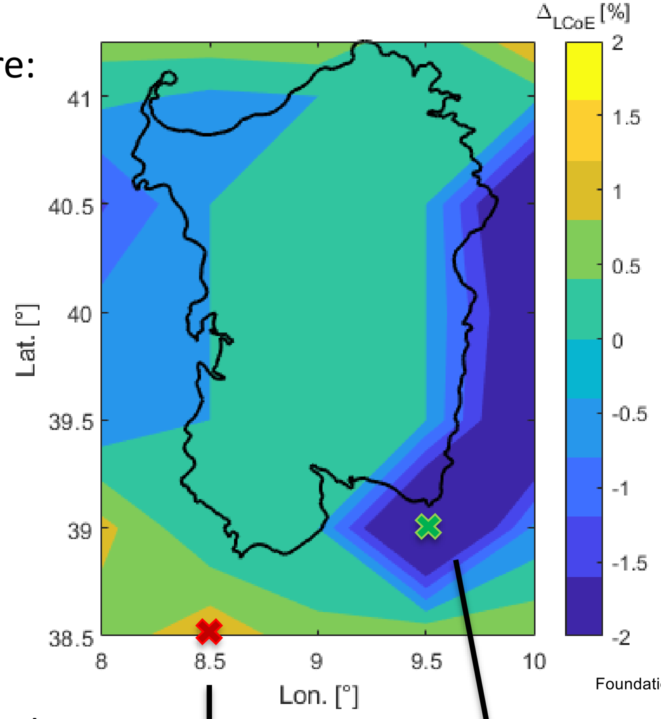
Offshore: 10MW x 6 turbines



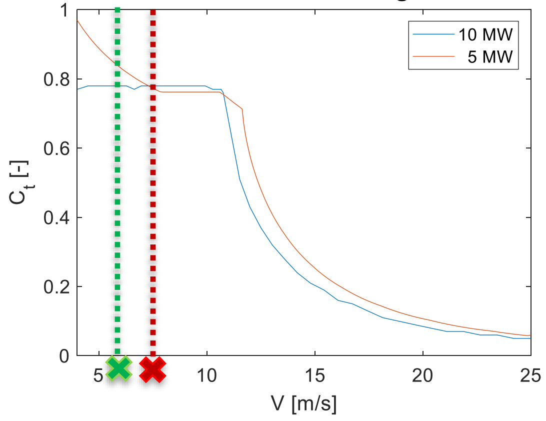
- Less wake losses with less turbines
- More impact on LCoE for sites with lower wind speeds

  Low U_{avg} → High C_t → High wake losses

LCoE diff. wrt reference case



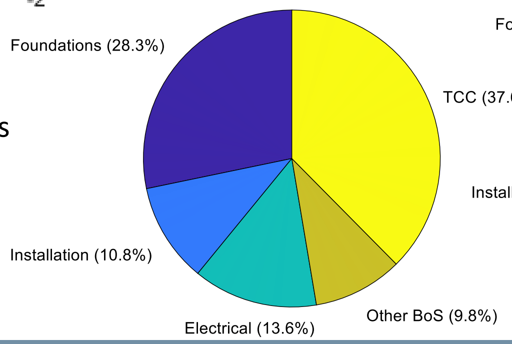
Comparing two U_{avg} on C_t curves



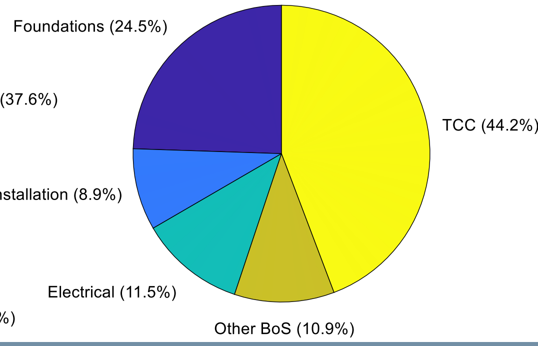
High wind speed locations are impacted less (in this case even negatively between 7-10 m/s) by switching to 10MW turbine.

CAPEX breakdown for location ✖

5 MW Turbine



10 MW Turbine



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Conclusion & Outlook

Conclusions:

- Demonstrated the capabilities of the developed cost model
- Dynamic cost functions applied to forecast costs for a given year in future
- Preliminary sensitivity analysis on wind farm layout and turbine size performed
- Calculated LCoE values tend to be overestimated due to low wind speeds acquired from ERA5 database. Significant discrepancies with global wind atlas are noted.

Outlook:

- Installation module taking into account wave characteristics (height, period, direction) to be implemented
- Setting up an optimization problem based on a MCDM with genetic algorithm
- Sensitivity analysis on component designs with commodity price considerations

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Q&A

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