Cost and Uncertainty in Overplanting the Design of Offshore Wind Farms

Esteve Borràs Mora[1,2] James Spelling [2] Adriaan H. van der Weijde [3]
Marie Berthelot [2]

[1]Industrial Doctoral Centre for Offshore Renewable Energy (IDCORE), University of Edinburgh
Edinburgh, EH9 3JL, UK

[2]EDF Energy R&D UK Centre
Interchange, 81-85 Station Road, Croydon, CR0 2AJ, UK

[3]University of Edinburgh School of Engineering and the Alan Turing Institute
Faraday Building, The King's Buildings, Mayfield Road, Edinburgh, EH9 3DW, UK

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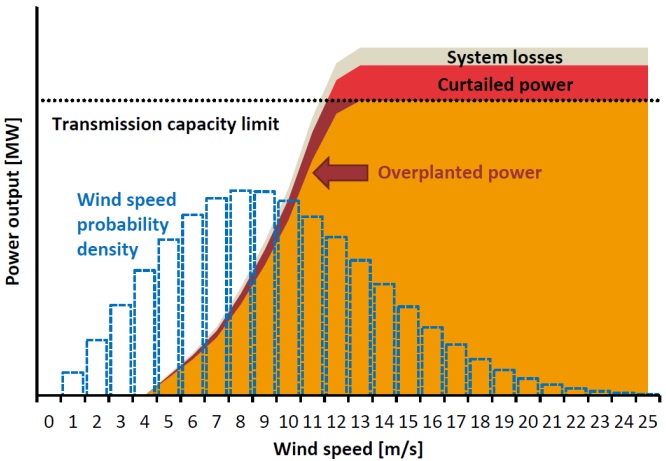
Motivation

- Farms subjected to a maximum export capacity agreed with the TSO
- Generators can export up to their contracted maximum export capacity
- Majority of the time offshore wind farms are not generating at full power
- Can overplanting result in better overall economics despite power output being curtailed at generations' peaks?



[Wolter et al. 2016]

Overplanting

Optimising the offshore wind capacity to the fixed electrical infrastructure

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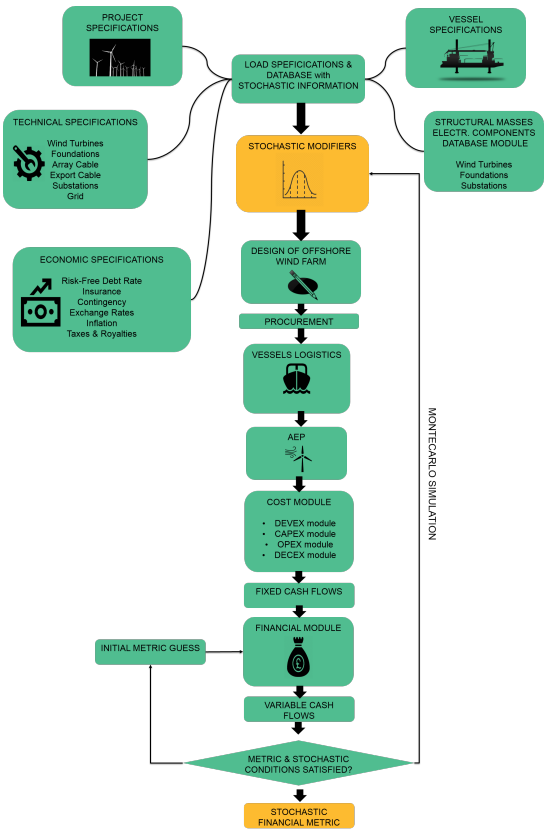
Offshore Wind Cost Modelling Tool



[Borras Mora 2017]

Characteristics

- **Aim** : rapidly evaluate the financial performance of a farm
- **Inputs** : project specifications, technology choices and market trends
- **Outputs** : financial metrics based on LCOE
- **Structure** : 4 main modules - Design, Cost, Financial and Stochastic
- **Stochastic Framework**: Quantitative uncertainty management, Double loop Monte Carlo Simulation - inner loop within AEP

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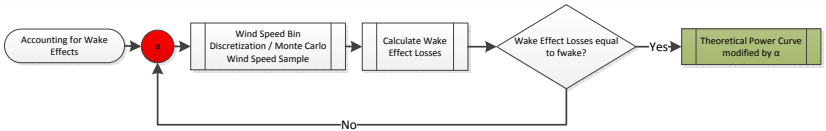
Factors Affecting Overplanting

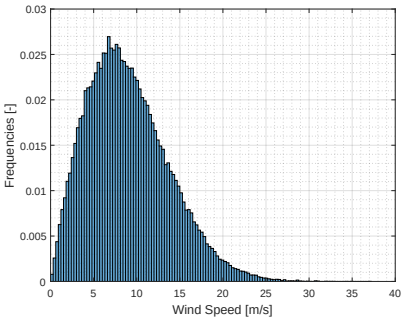
[1]

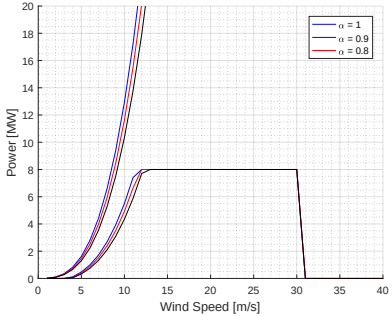
Factors

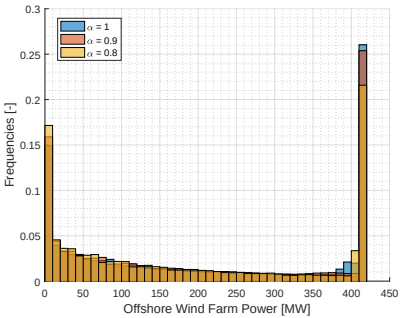
- Ratio of wind turbine expenditure to electrical infrastructure
- Wind speed distribution
- Wind turbine availability
- Inter-array cable availability
- Wake effects
- Electrical losses
- Degradation factor

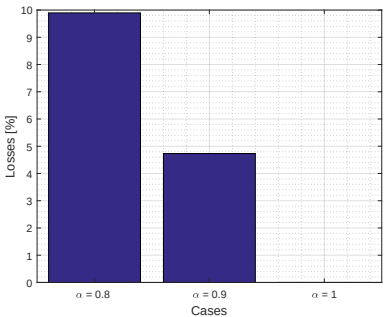
Modelling of Overplanting

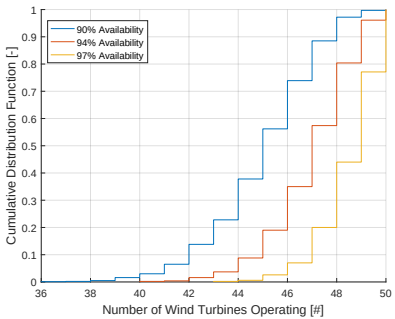


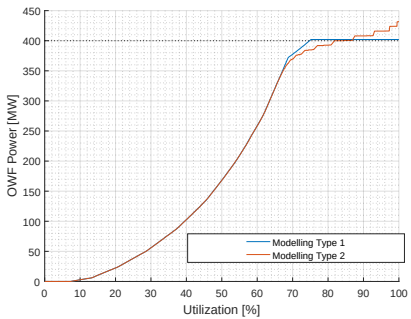












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Case Study

Reference Case

400MW commercial offshore wind farm
400MW fixed maximum export capacity
50-8MW WTGs
0-14% overplanting

2% overplanting = 1 additional WTG

Characteristic	Value	Uncertainty
Water Depth [m]	25	None
Distance from shore [km]	25	None
Mean Wind Speed @ 100m [m/s]	9	$\mathcal{N}(9, 0.1^2)$
Wind Turbine Availability [%]	95	$\mathcal{U}(90, 97)$
Inter-Array Cable Availability [%]	99	$\mathcal{U}(97, 99)$
Foundation Type [-]	Monopile	None
Electrical Infrastructure [-]	HVAC	None
Wind Turbine Type [-]	164-8 MW	None
Wake effect [%]	10	None
Degradation Factor [%]	0.5	None

Configurations

Capacity[MW]	WTG[MW]	Distance [km]	Depth[m]
400	4	25	25
1000	8	50	40
2000	12	75	60

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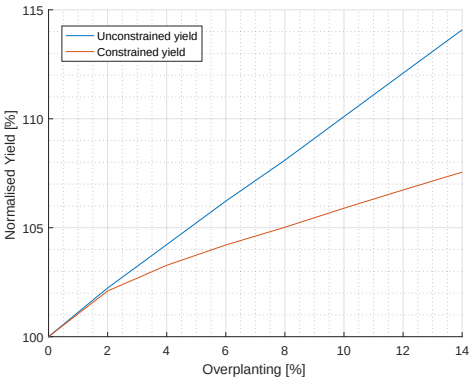
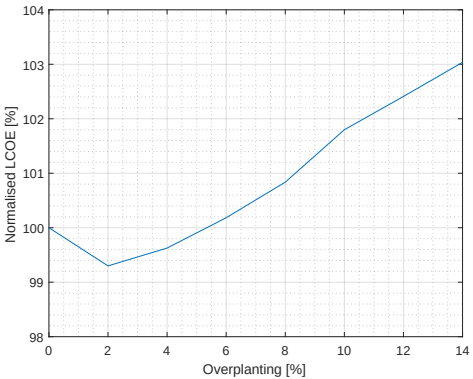
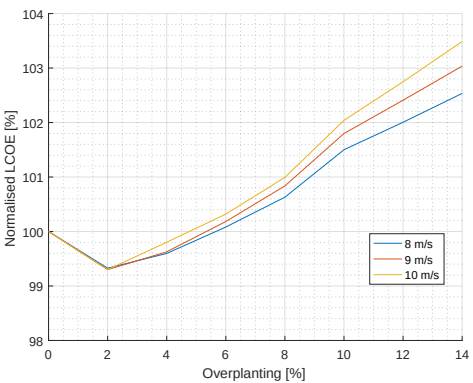
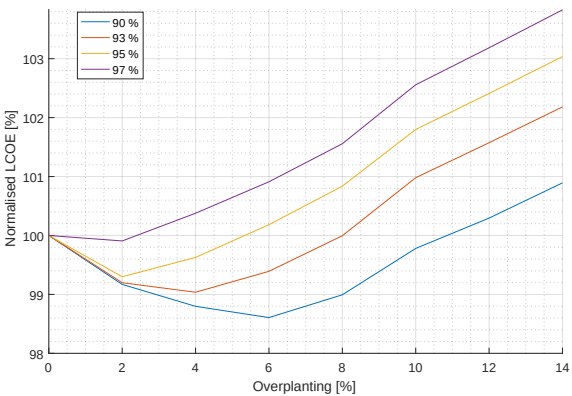
Deterministic Results & Local Sensitivity Analysis









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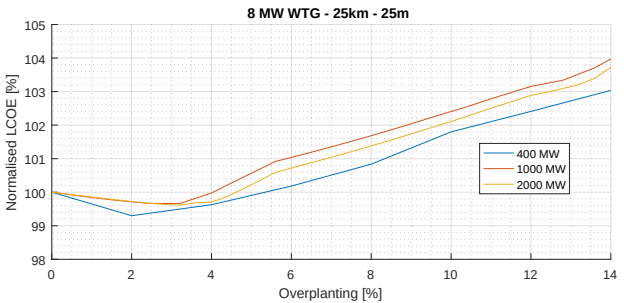
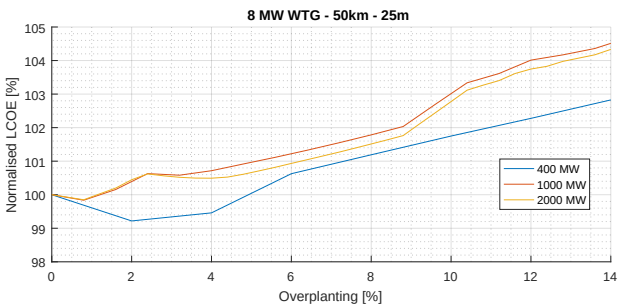
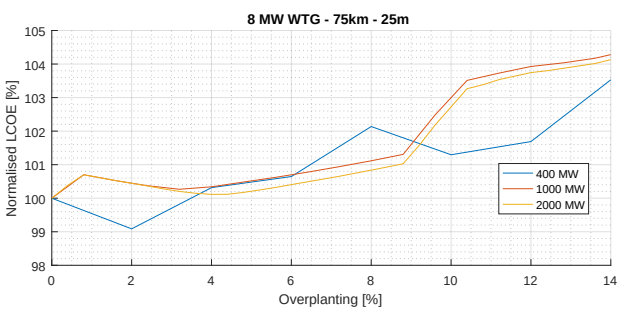
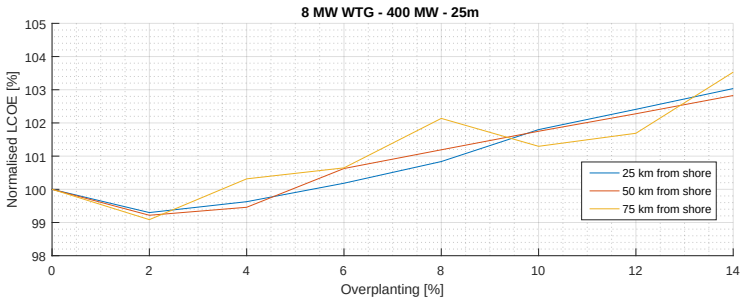
Distance from Shore

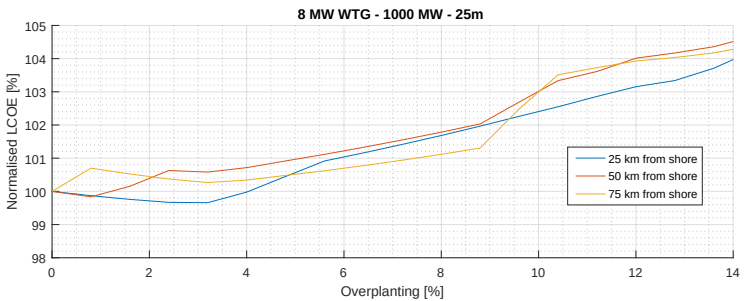


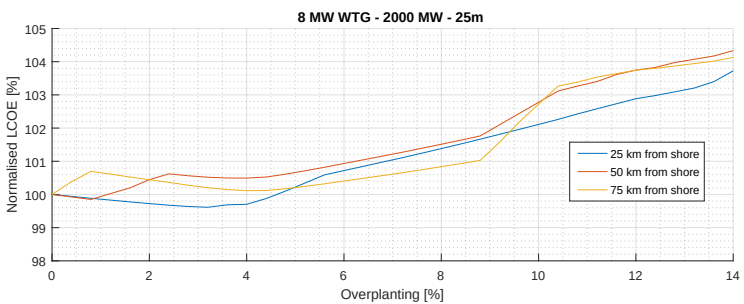




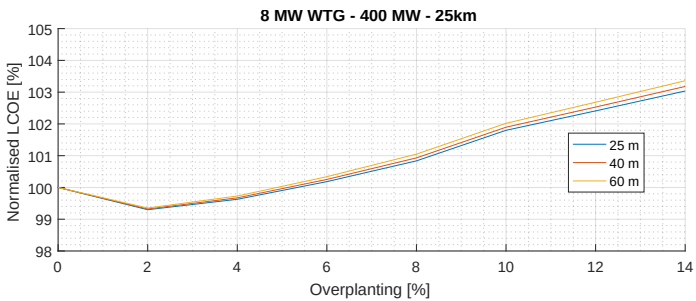
Capacity

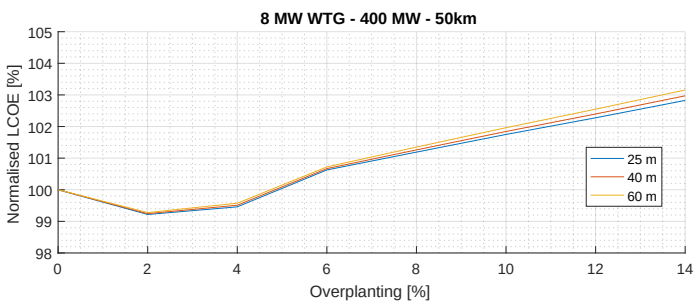

8 MW WTG - 400 MW - 25m
Normalised LCOE [%]
Overplanting [%]
25 km from shore
50 km from shore
75 km from shore

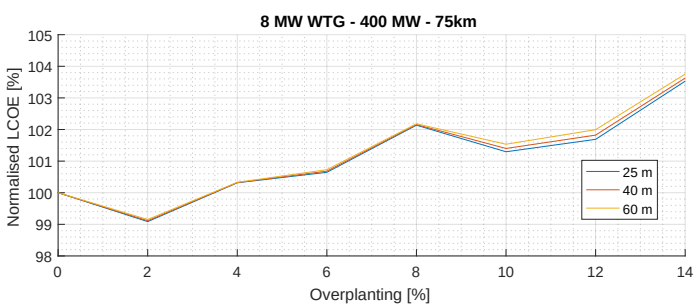

8 MW WTG - 1000 MW - 25m
Normalised LCOE [%]
Overplanting [%]
25 km from shore
50 km from shore
75 km from shore


8 MW WTG - 2000 MW - 25m
Normalised LCOE [%]
Overplanting [%]
25 km from shore
50 km from shore
75 km from shore

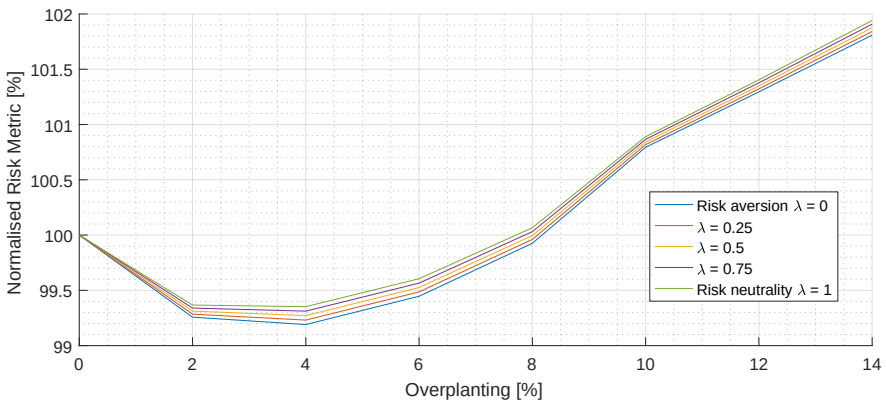
Water Depth

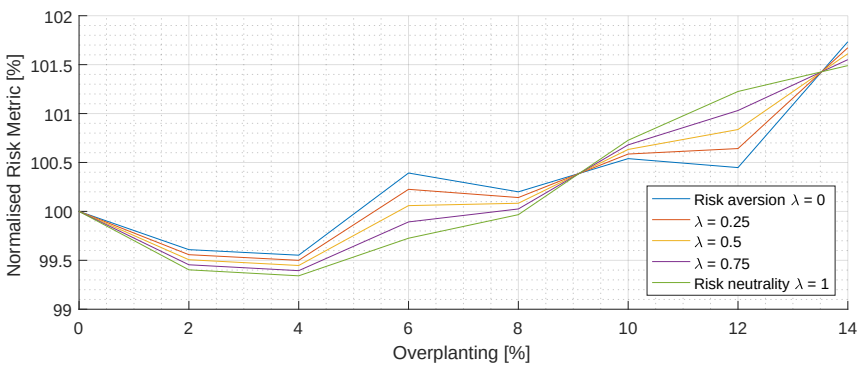

8 MW WTG - 400 MW - 25km
Normalised LCOE [%]
Overplanting [%]
25 m
40 m
60 m


8 MW WTG - 400 MW - 50km
Normalised LCOE [%]
Overplanting [%]
25 m
40 m
60 m


8 MW WTG - 400 MW - 75km
Normalised LCOE [%]
Overplanting [%]
25 m
40 m
60 m

Stochastic Results $\rho_\alpha[\lambda, \textit{overplanting}]$





Risk metric

$$\rho_\alpha[\lambda, LCOE] = (1-\lambda)\mathbf{CVaR}_\alpha[LCOE]$$

$$+\lambda\mathbf{Median}[LCOE]$$

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Conclusions and Future Work

Conclusions

- Development of a novel framework to evaluate overplanting under uncertainty
- Wind turbine availability is the most sensitive parameter to overplanting. Consequently, previous studies based on low wind turbine availabilities rates need to be revisited
- Optimal overplanting setup increased when considering the uncertainty quantification framework regardless of risk appetite (from 2% to 4%)
- Overplanting the reference farm from 2% to 8% gives a better result than with no overplanting for a risk neutral setting
- Wind farm capacities, turbine sizes and distances from shore are sensitive parameters to overplanting, whereas water depths play a secondary role
- Sites located further from shore, with bigger wind turbines and less units for a given wind farm capacity will most likely have small benefits from overplanting

Future Work

- How is overplanting influence by the degradation factor?
- How does risk aversion influence the decision for these new sites?

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Questions

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Esteve.BorrasMora@edfenergy.com

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