How does risk aversion shape overplanting in the design of offshore wind farms?

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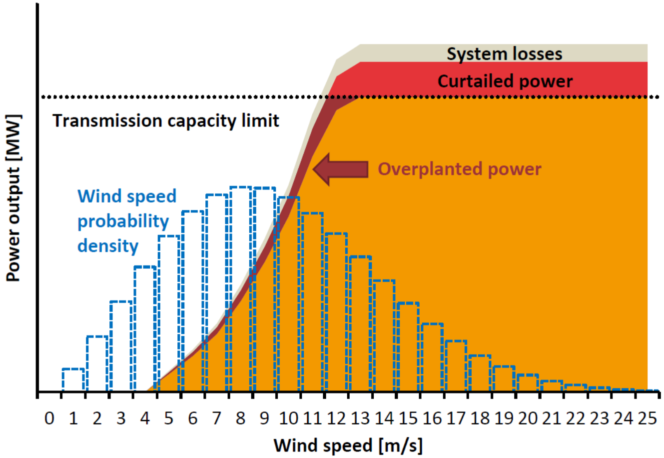
Outline

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?

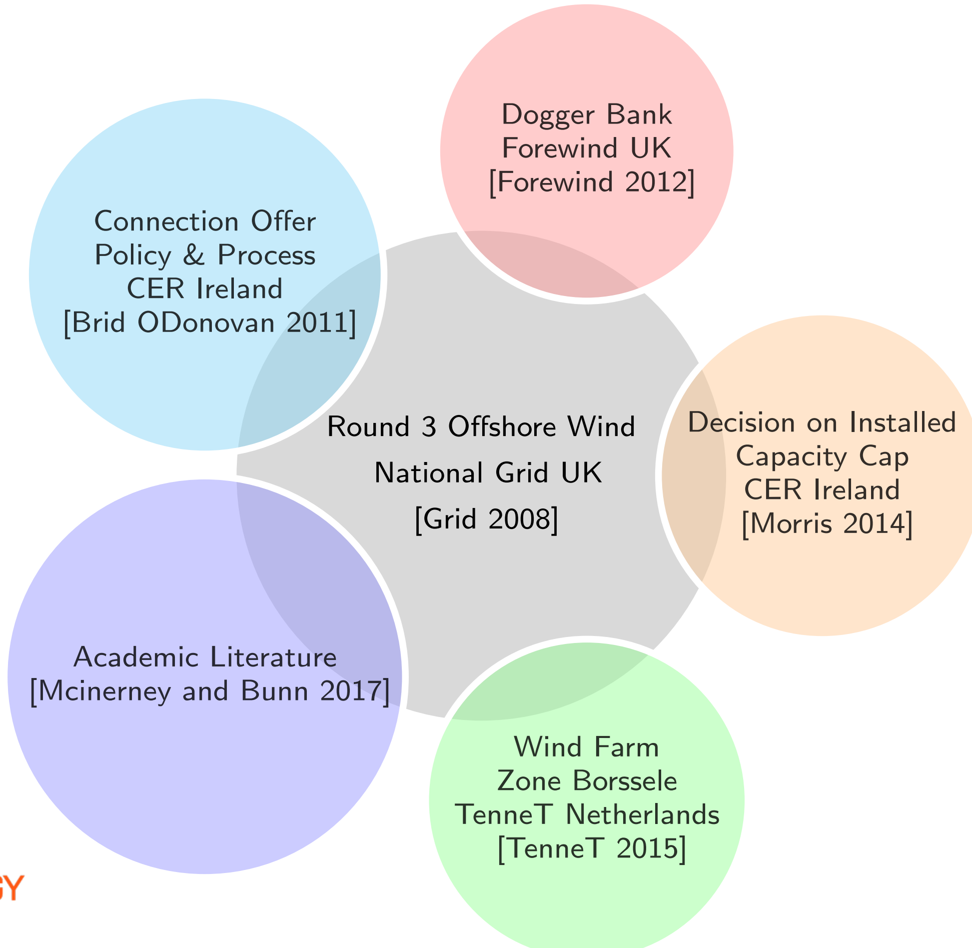


[Wolter et al. 2016]

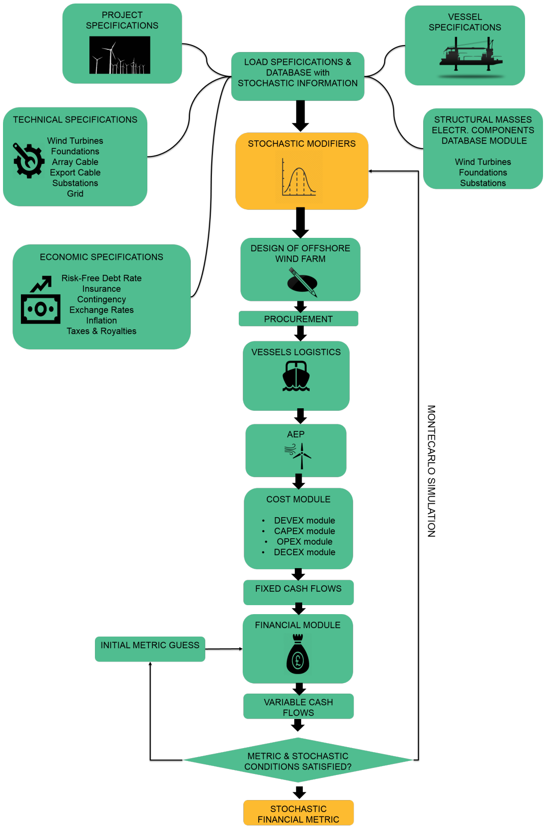
Overplanting

Over installing the offshore wind capacity to the fixed electrical infrastructure

Overplanting Studies



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

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

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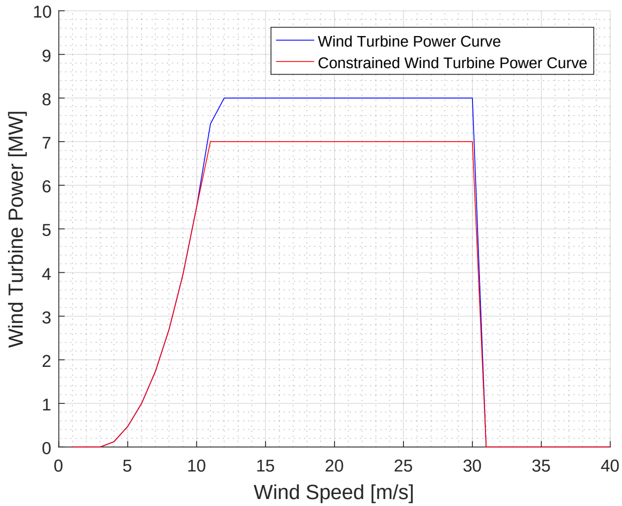
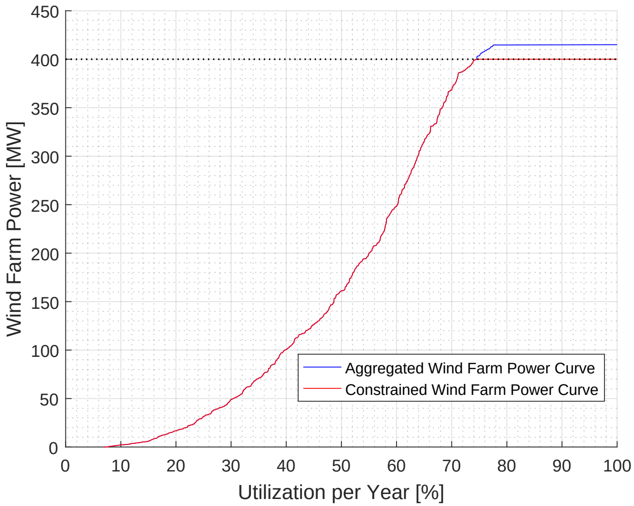
Modelling of Overplanting



Modelling Type 1



Modelling Type 2

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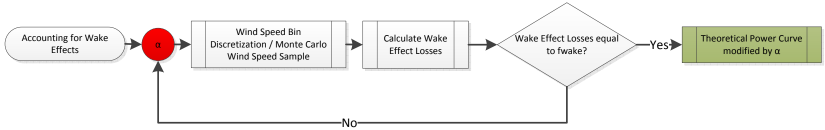
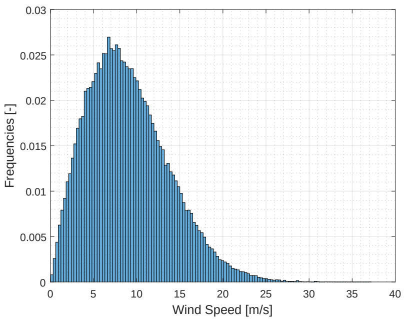
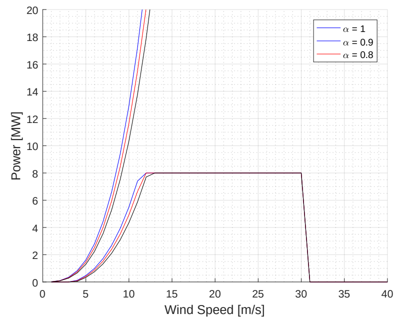
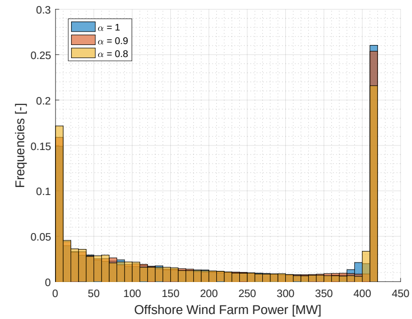
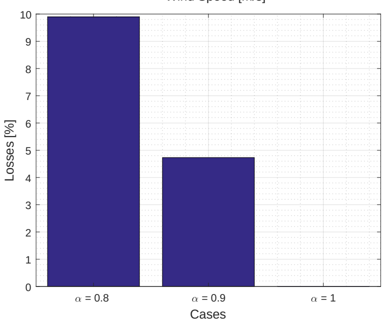
Modelling of Overplanting

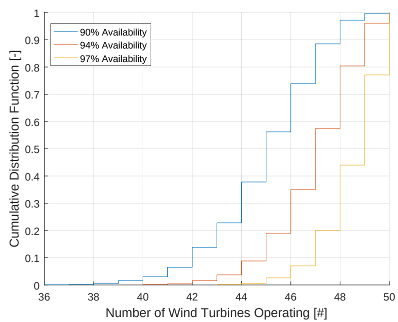


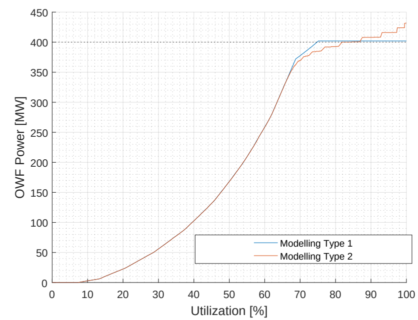












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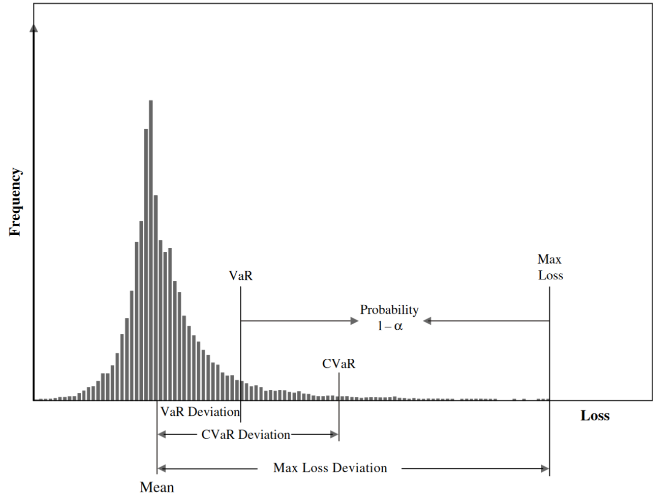
Modelling Risk Aversion



[Rockafellar and Uryasev 2002]

Risk metric

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

Case Study

Case Study

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

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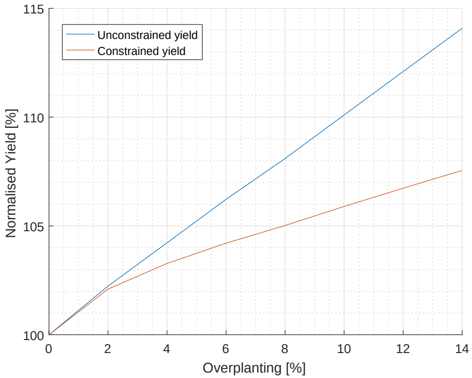
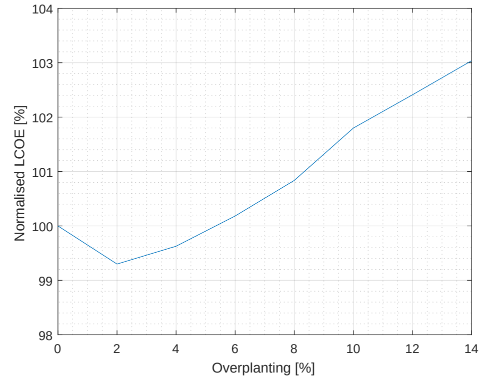
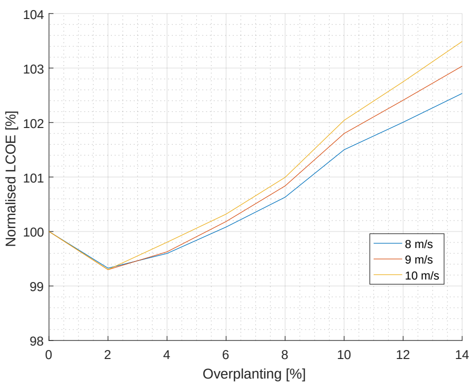
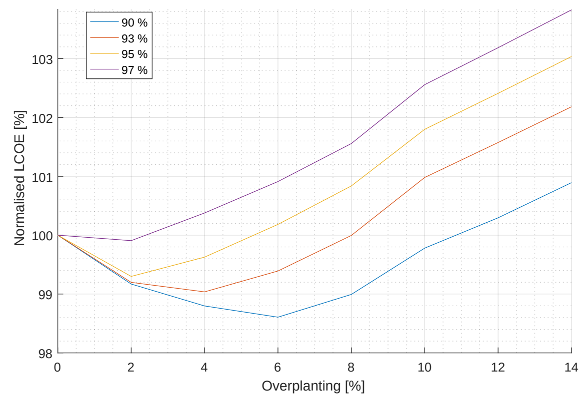
Deterministic Results & Local Sensitivity Analysis

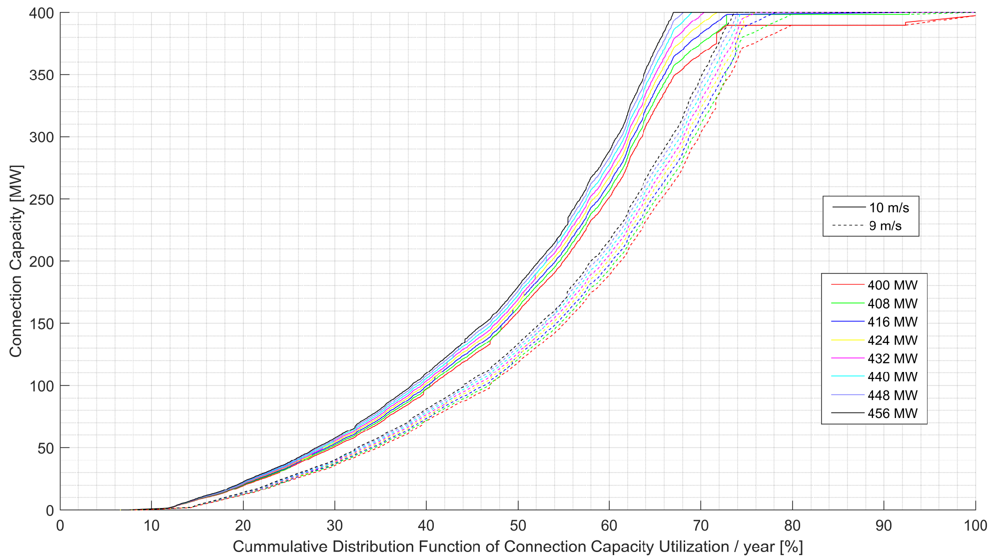




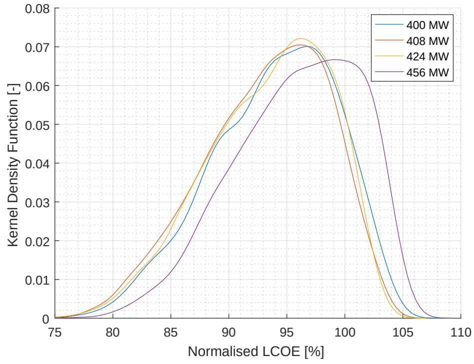


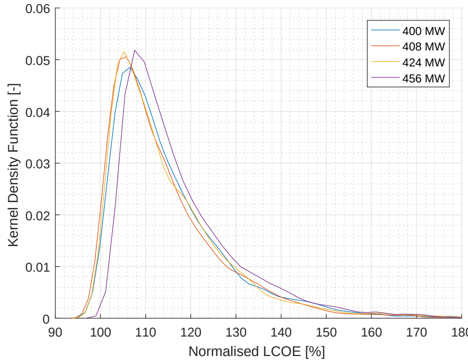


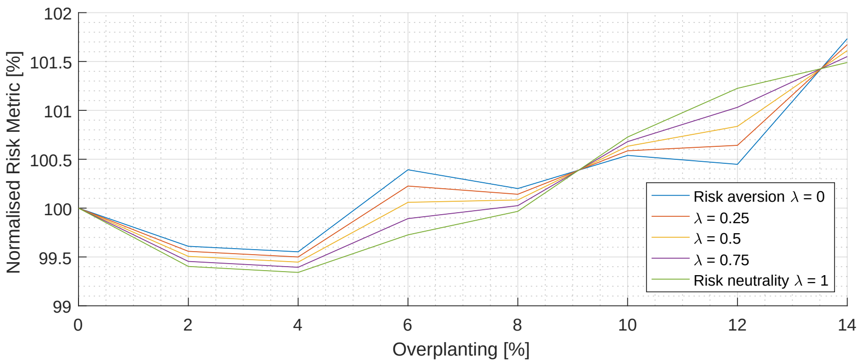
Local Sensitivity Analysis - wind speed



Stochastic Results $\rho_\alpha[\lambda, overplanting]$







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Conclusions and Future Work

Conclusions

- Development of a novel framework to evaluate overplanting
- Modelling Type 1 is easier to implement but may lead to an overestimation of the annual energy production
- Modelling Type 2 is more accurate but requires higher computational costs
- Wind turbine availability is the most sensitive parameter to overplanting
- Previous studies based on low wind turbine availabilities rates or on Modelling Type 1, 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

Future Work

- How is overplanting influence by larger turbines and sites located futher from shore?
- How does risk aversion influence the decision for these new sites?

References

- Borras Mora, Esteve (2017). "Transition from Deterministic to Stochastic Cost Models for Offshore Wind Farms". In: *Offshore Wind Energy Conference* 44.June.
- Brid ODonovan (2011). *Connection Offer Policy & Process (COPP)*. Tech. rep. Commission for Energy Regulation.
- Forewind (2012). *Environmental Statement Chapter 6 Appendix B Offshore Project Boundary Selection Report*. Tech. rep. March.
- Grid, National (2008). *Round 3 Offshore Wind Farm Connection Study*. Tech. rep.
- Mcinerney, Celine and Derek W Bunn (2017). "Optimal over installation of wind generation facilities". In: *Energy Economics* 61, pp. 87–96. ISSN: 0140-9883. DOI: 10.1016/j.eneco.2016.10.022. URL: http://dx.doi.org/10.1016/j.eneco.2016.10.022.
- Morris, Nigel (2014). *Decision on Installed Capacity Cap Installed Capacity Cap*. Tech. rep. Commission for Energy Regulation.
- Rockafellar, R Tyrrell and Stanislav Uryasev (2002). "Conditional value-at-risk for general loss distributions". In: *Journal of Banking & Finance* 26, pp. 1443–1471.
- TenneT (2015). *POSITION PAPER Overplanting*. Tech. rep. TenneT, pp. 1–7.
- Wolter, C et al. (2016). "Overplanting in Offshore Wind Power Plants in Different Regulatory Regimes". In: *15th Wind Integration Workshop* 49.0, pp. 0–4. DOI: 10.1146/annurev.matsci.35.100303.110641.

Questions

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