Optimising the utilisation of subsea cables in offshore wind farm collector networks

Considering energy storage and GW scale wind farms

Peter Taylor[1]

Olimpo Anaya-Lara[1], David Campos Gaona[1], Hong Yue[1]

Chunjiang Jia[2], Chong Ng[2]

[1] – University of Strathclyde, [2] – Offshore Renewable Energy Catapult

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- Wind farm design optimisation
  - How and why?
- Energy storage system (ESS) hypothesis
- Case study at Lillgrund offshore wind farm
- Scaling up to GW wind farms

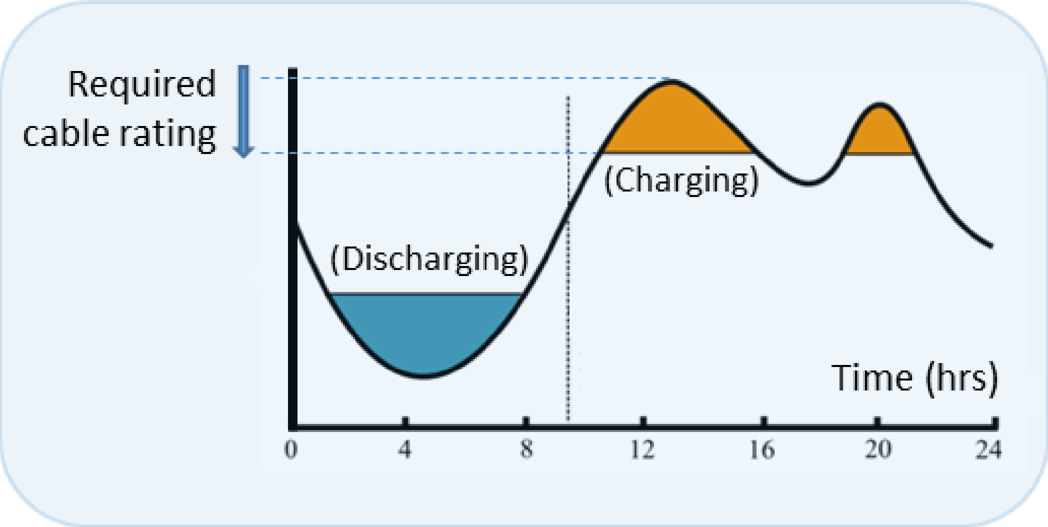
Wind farm optimisation

- Design factors to optimise
  - Turbine placement
  - Cable layout
- Aims
  - Increased energy capture
  - Lower investment costs
  - Reduced electrical losses
  - Reduced LCOE

Image: Wiser, Ryan & Jenni, Karen & Seel, Joachim & Baker, Erin & Hand, Maureen & Lantz, Eric & Smith, Aaron. (2016). Expert elicitation survey on future wind energy costs. Nature Energy. 1. 16135. 10.1038/nenergy.2016.135.

ESS hypothesis

- Cable rating must be high enough to deliver rated power
- Energy storage can charge at times of peak power and discharge at times of low power
- Peak power in the cable is reduced

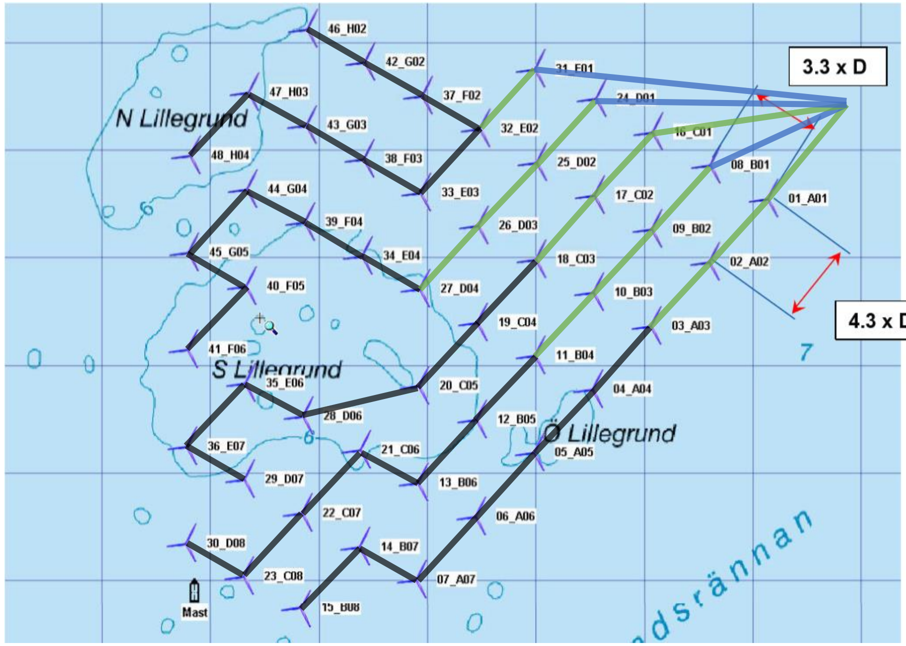


Case Study

University of Strathclyde Glasgow

- 48 turbines
- 2.3MW rated power
- 3 cable sizes used
  - 95mm^2, 185mm^2, 240mm^2

Lillgrund Offshore Wind Farm



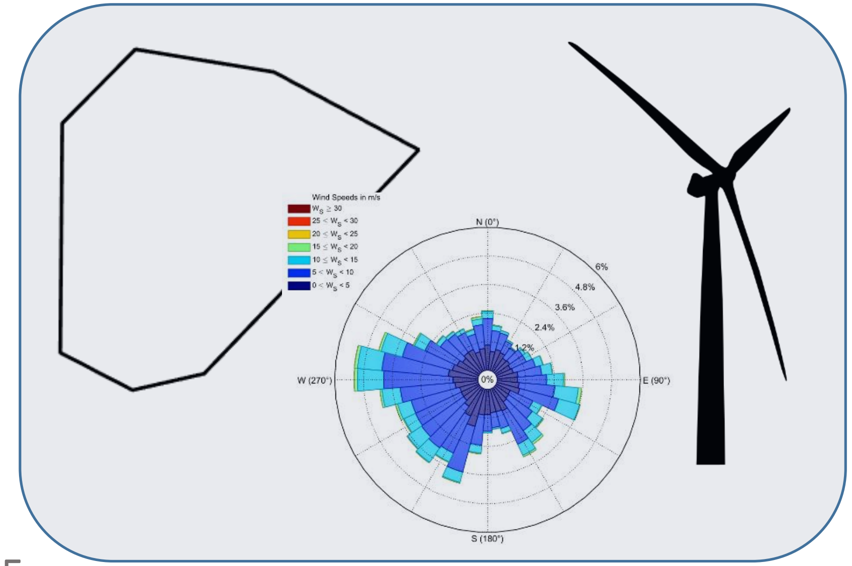
Catapult Offshore Renewable Energy

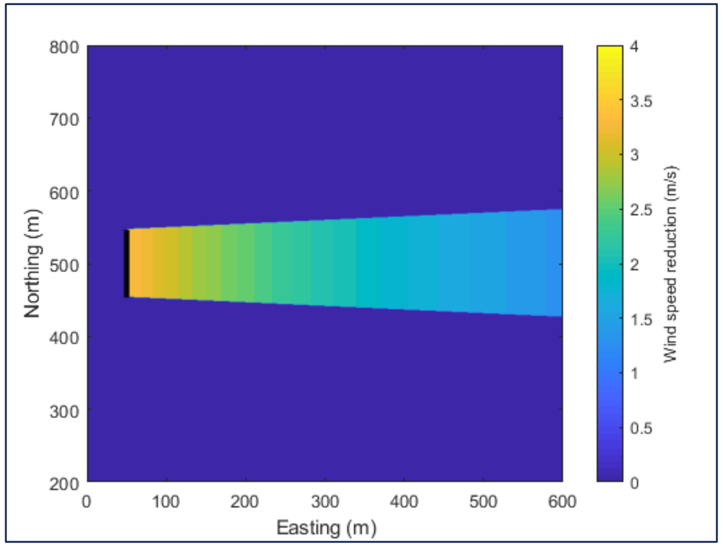
Wind & Marine Energy Systems CDT

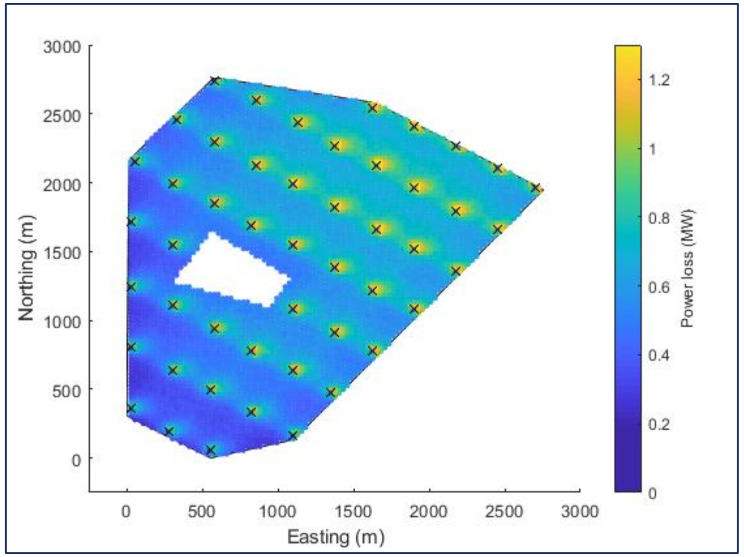
Image courtesy of – Vattenfall – “Assessment of the Lillgrund Windfarm”

Turbine placement pre-processing

- Wind farm area discretised into nodes of possible turbine positions
- Jensen model used to assess each pair-wise interaction of nodes

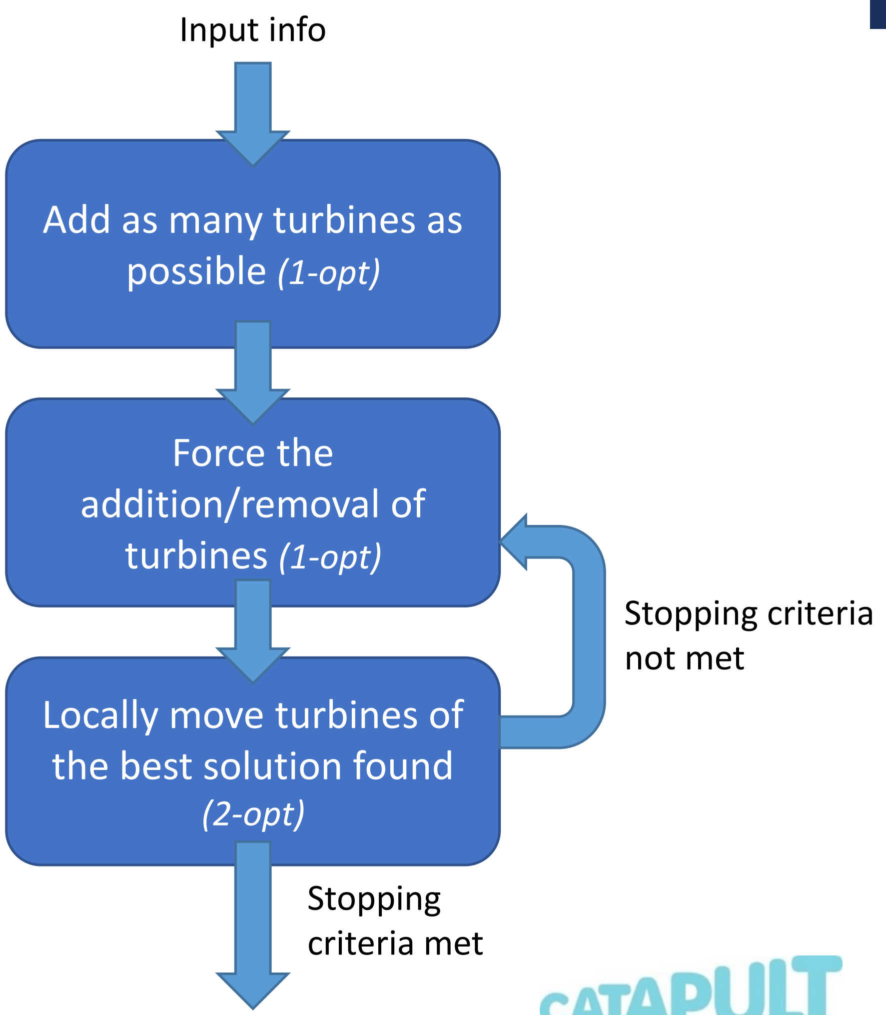




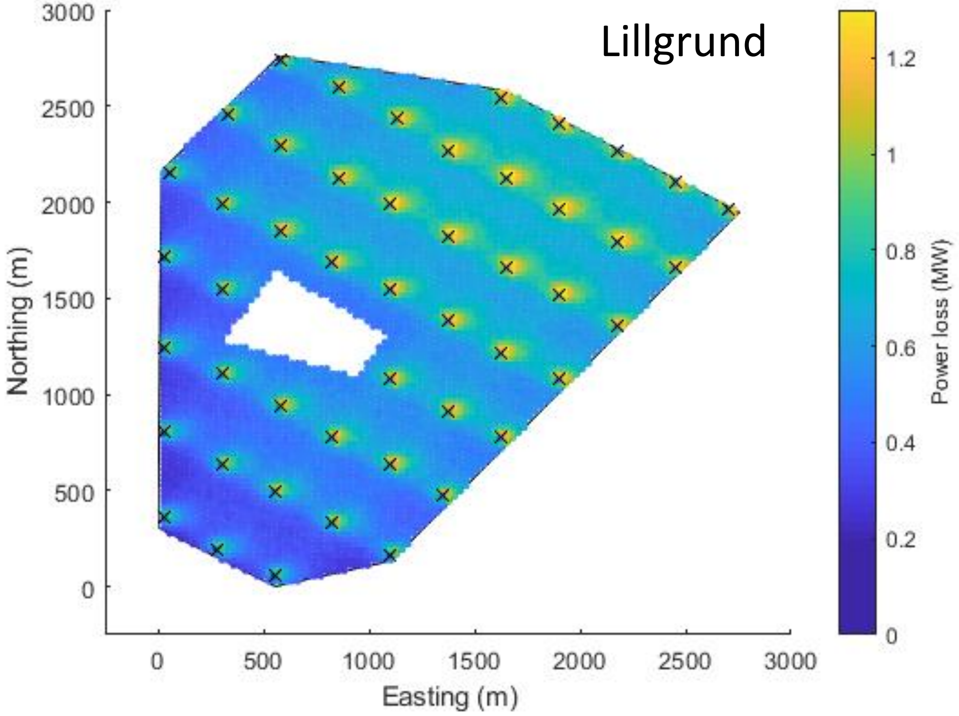


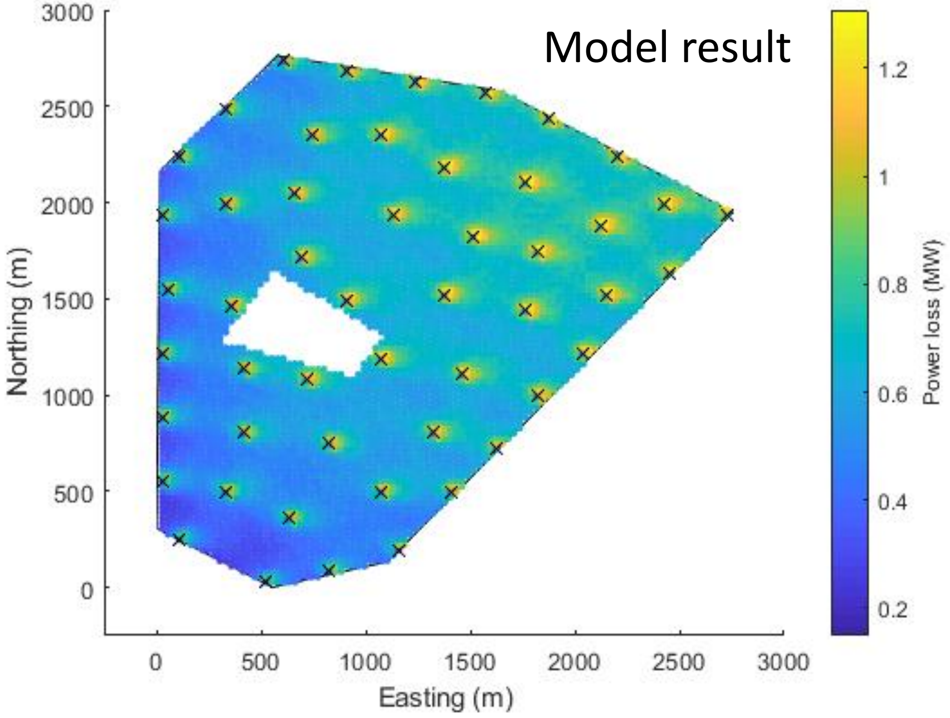
Turbine placement algorithm

- Binary description for if a turbine is built/not built at each node (1/0)
- k-opt heuristic finds the most profitable *k* nodes to 'flip' (0s→1s and 1s→0s)
- Systematically 'flips' the best *k* nodes and updates wake effect matrix



Turbine placement

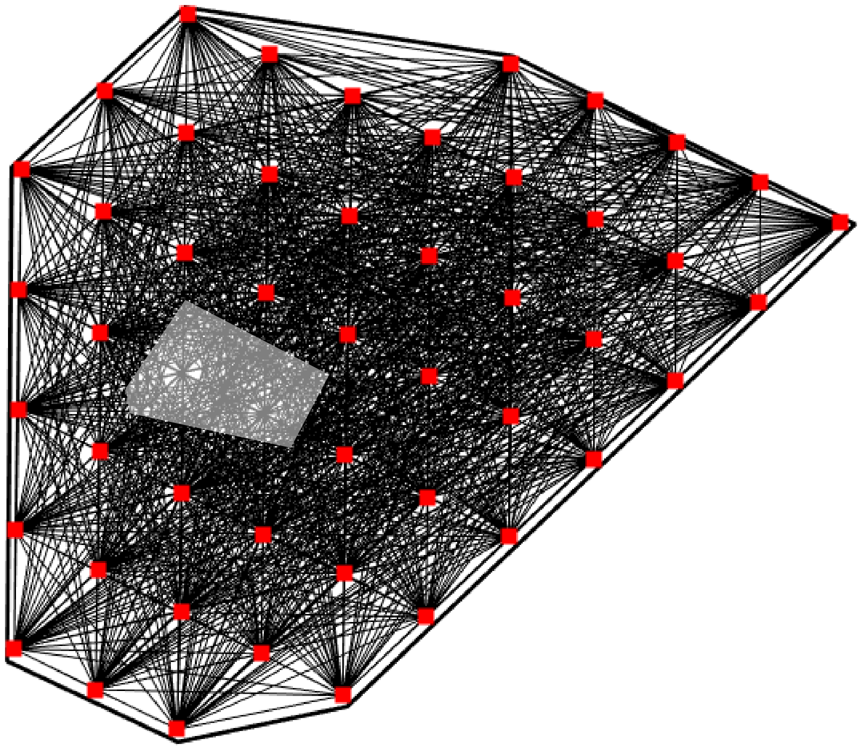




	Lillgrund	Model	
No. turbines	48	50	
WF rated power (MW)	110.4	115.0	
Wake losses (%)	20.82	18.70	-2.12
WF power (MW)	87.42	93.49	+6.07

Cable layout

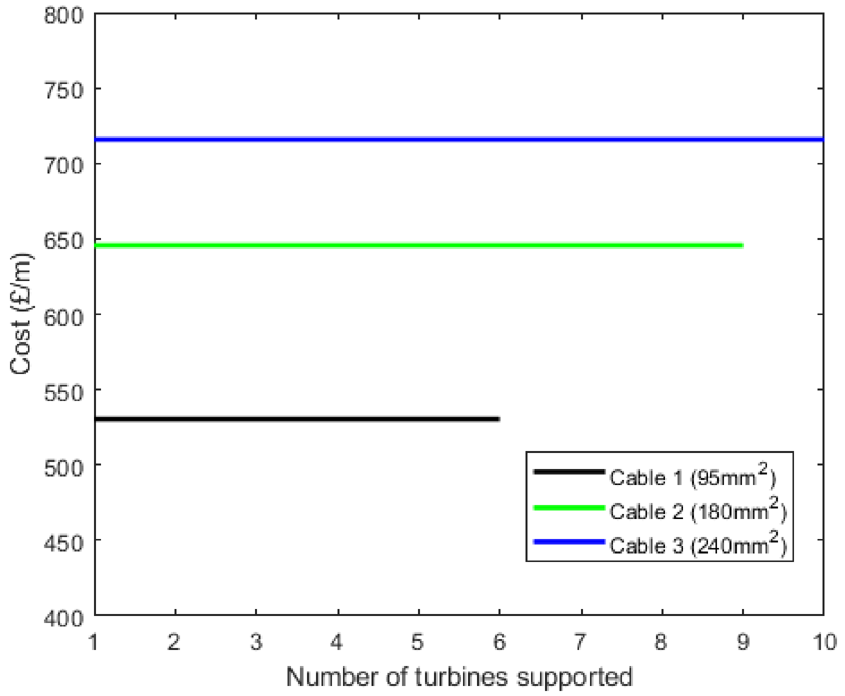
- Many possible connections
- Binary variable for cable present or not
  - Variable for each cable size
- Continuous variable for power in cable
  - Cable capacity constraint



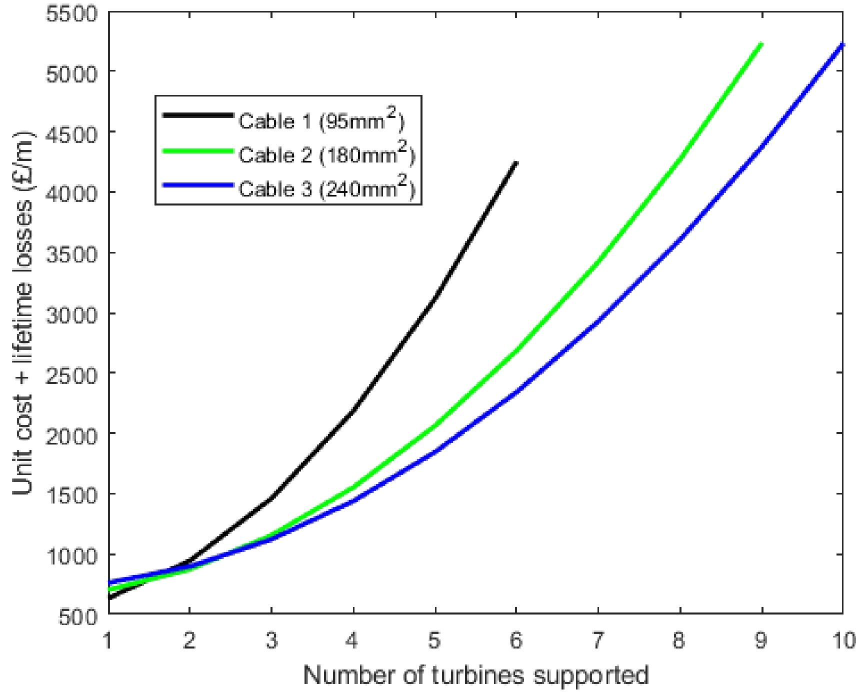
MATLAB MILP solver *intlinprog*

Cable layout

Cable unit costs



Cable unit costs and elec. losses value over lifetime

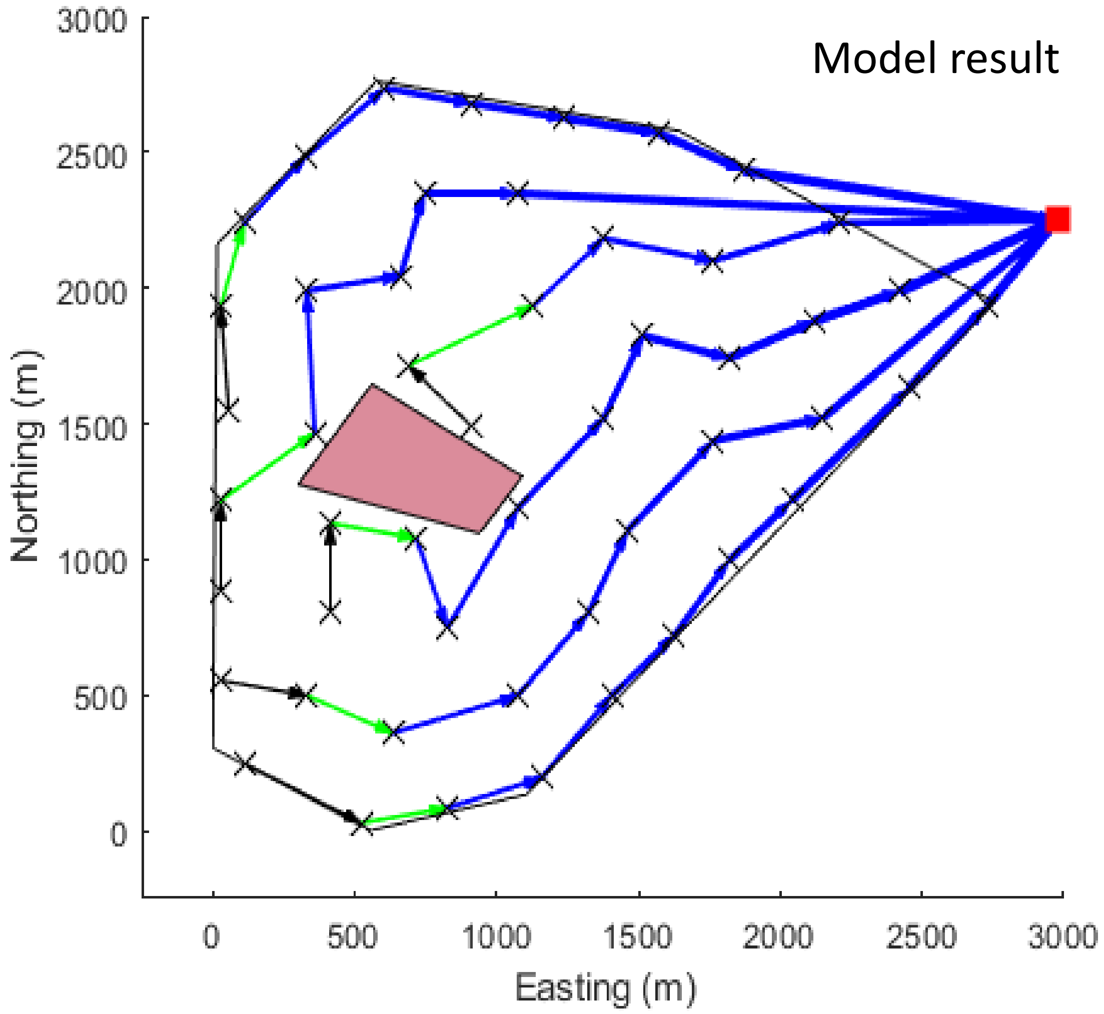


- R reduces with larger cables
- Losses $\propto I^2R$
- Cables limited by current carrying capacity

Electrical losses more significant than cable unit costs

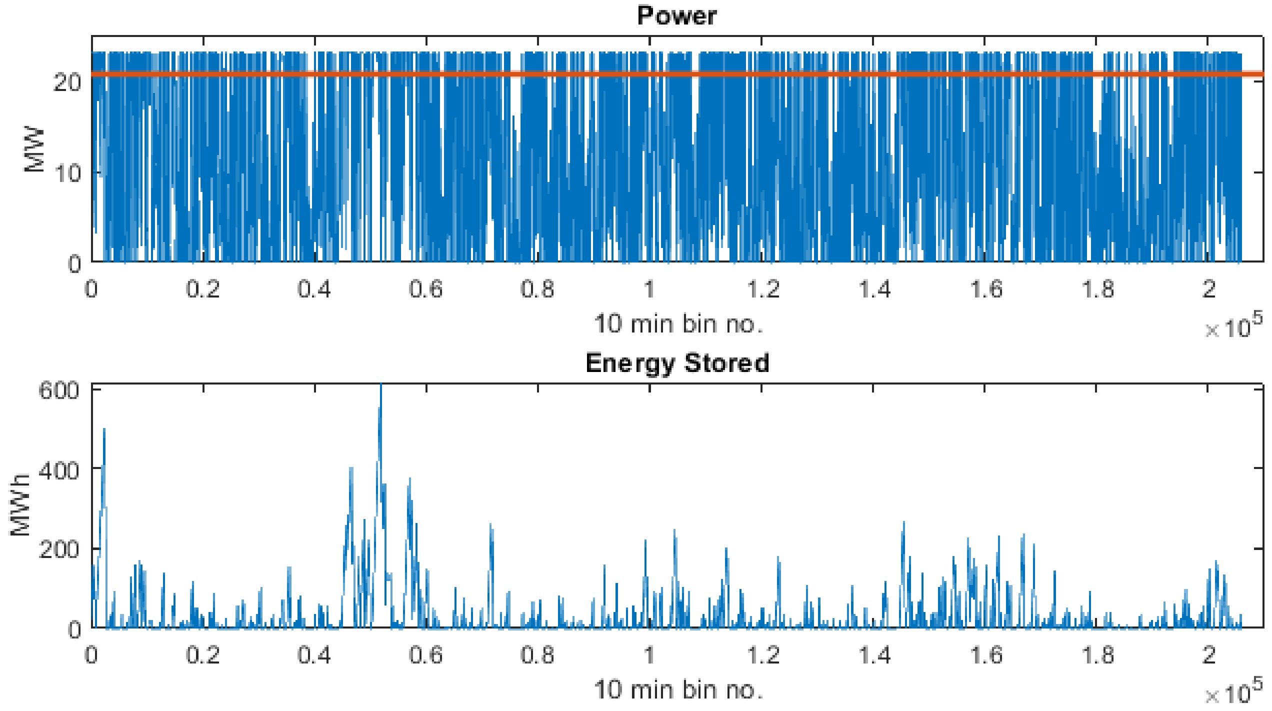
Vastly changes which cables are best to select

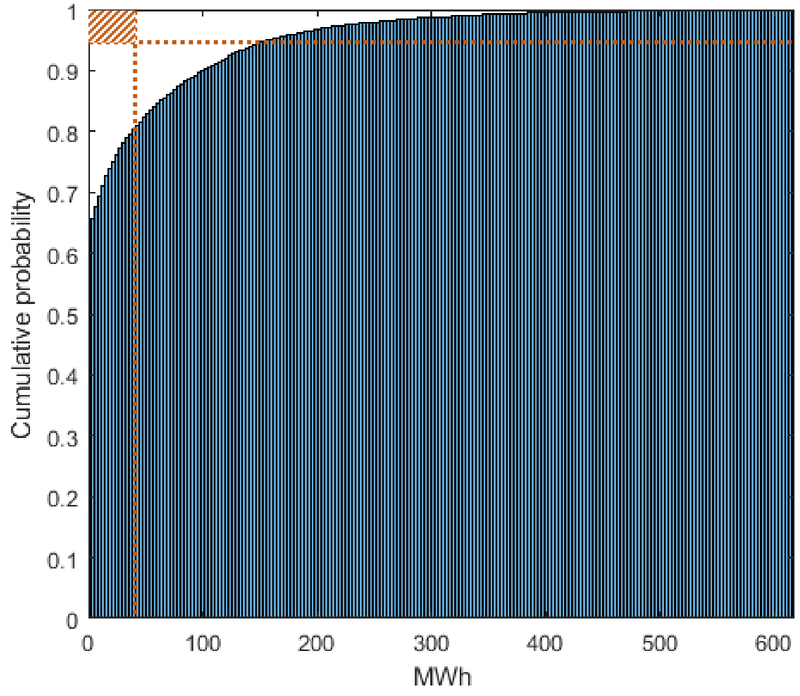
Cable layout



	Lillgrund
Cable cost (£M)	11.87
Electrical losses (£M)	51.26
Total cost (£M)	63.13

Lillgrund – ESS application





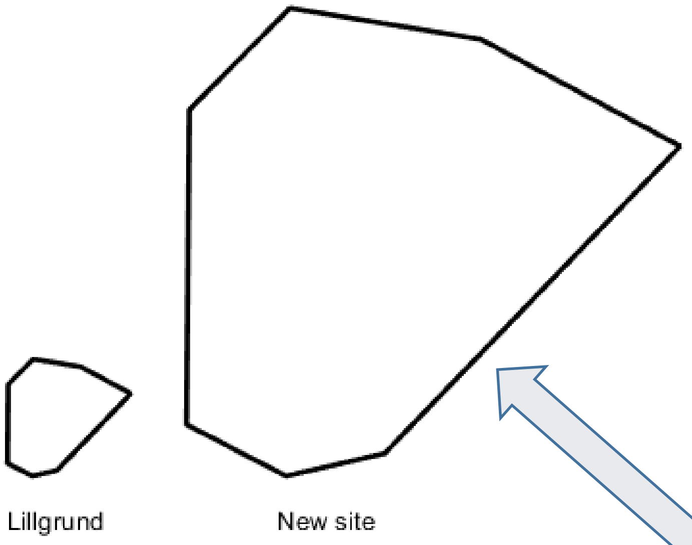
Limitations & improvements

- Loss of the grid structure of the layout
  - Navigation and search and rescue issues

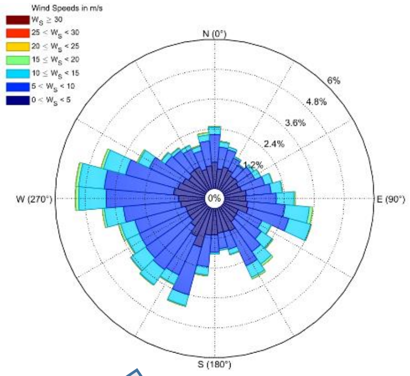
- Computationally complex at large scale
  - Pre-processing wake effects for all node pairs
  - Constraint eq.s for MILP formulation of cable layout problem

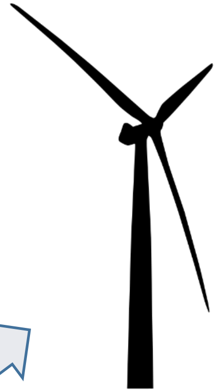
- Not suitable for realistic larger scale WFs

Scaling up to GWs

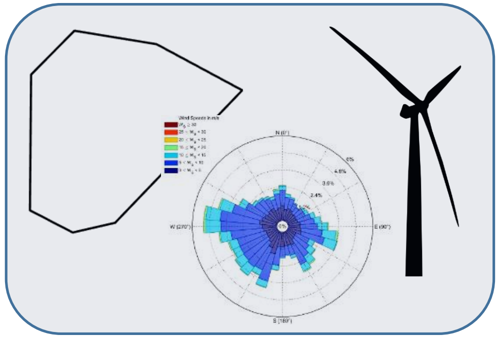


Same wind conditions





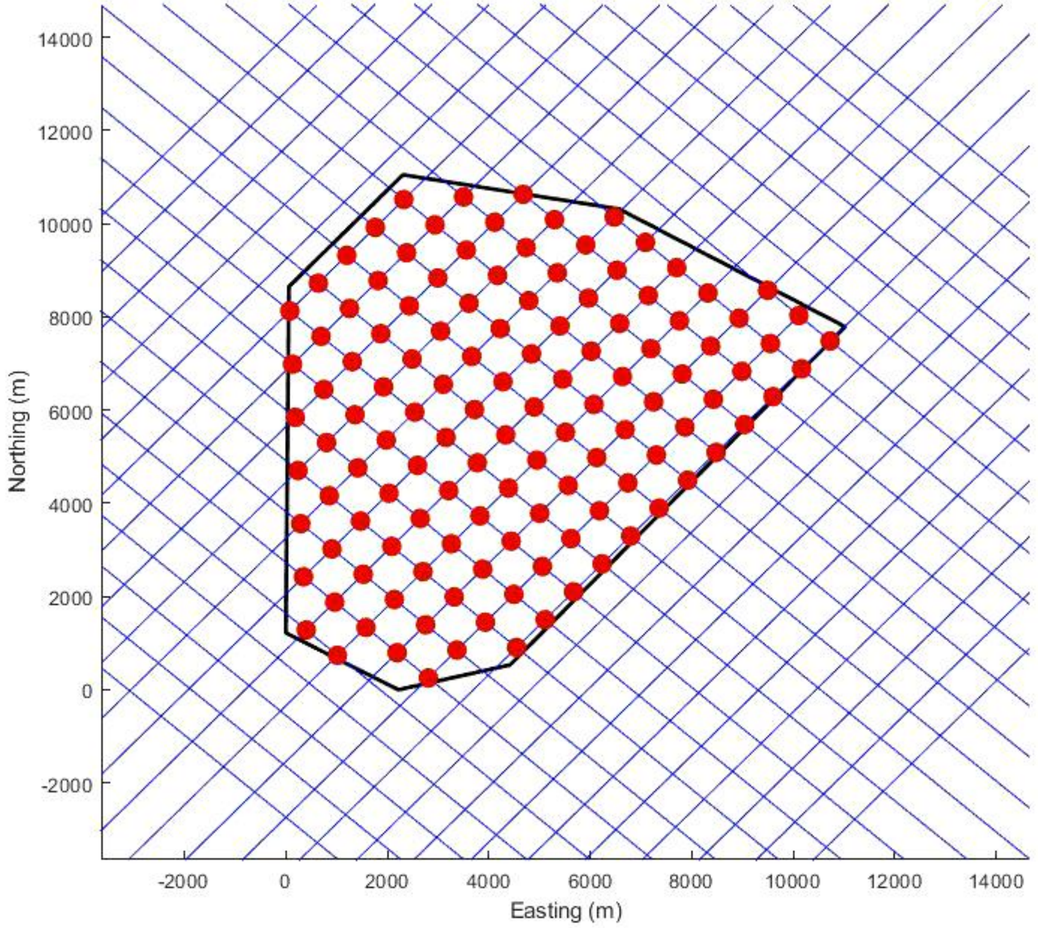
Vestas V164	
Rated power	7-10MW
Rotor Diam.	164m
Cut in speed	4ms^{-1}
Cut out speed	25ms^{-1}
Hub height	138m



Model inputs

Scaling up – turbine placement

- Particle swarm optimisation algorithm
- 8 variables
  - No longer a func of no. turbines
- Larsen wake model
- Much quicker run time

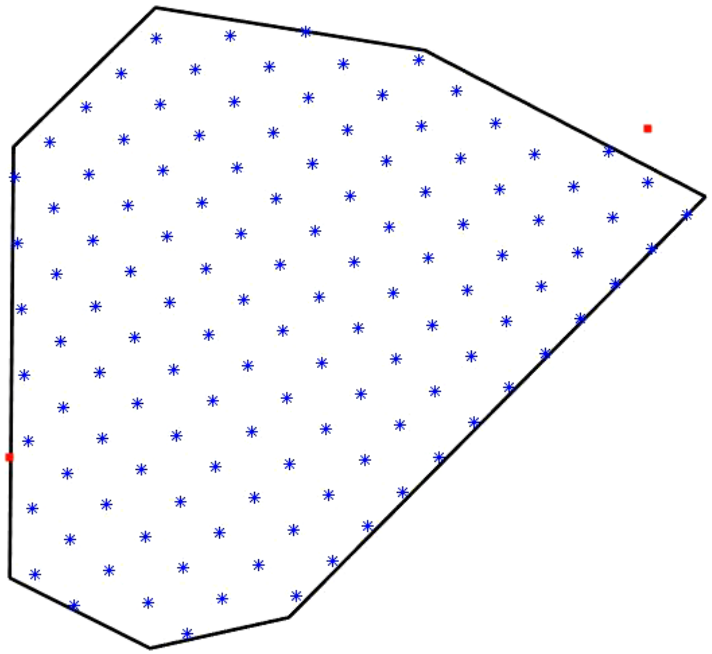


	Variables
m_1	Angle of rows
dm_1	Angle between rows
s_1	Spacing of rows
m_2	Angle of cols
dm_2	Angle between cols
s_2	Spacing of cols
x	Horizontal disp.
y	Vertical disp.

Scaling up – cable layout

- Ant colony optimisation algorithm
  - ‘Tidy-up’ messy random routes
  - With multiple-travelling-salesman-problem approach for cable routing

- Able to deal with more complex problems
  - Computationally efficient



Conclusions

- Clear benefits in considering WF optimisation in design phase
  - Savings can be made if aiming at lifetime cost reduction
- Energy storage systems are not profitable/practical for cable loss reduction and cable de-rating
- Scaling up to GW scale can lead to a huge increase in computational complexity
- Practical design tools are needed to cope with these problems

Thank you

This research is conducted under the **Electrical Infrastructure Research Hub** (EIRH). The EIRH is a 5-year collaboration between ORE Catapult and the Universities of Strathclyde and Manchester.

peter.taylor@strath.ac.uk

Sources and references

Position data: *Vattenfall – Assessment of the Lillgrund Windfarm*

Windfarm information: *Vattenfall – Technical description Lillgrund wind power plant*

Wind data: *BMWi and PTJ – FINO1 project* & *Vattenfall – Meteorological conditions at Lillgrund*