Integrated wind plant simulator for layout and control optimization

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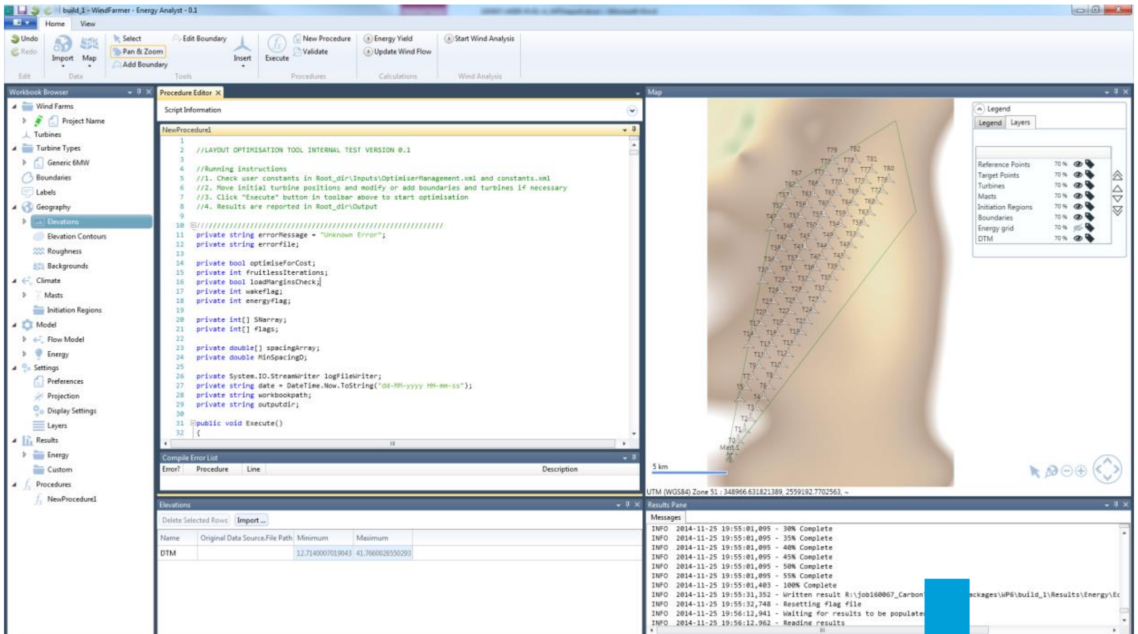
DNV GL – Renewables Advisory

SAFER, SMARTER, GREENER

Wind Plant Optimization Tool Framework

WINDFARMER:

ENERGY ANALYST



- WINDFARMER EA handles wake and energy calculation
- Interface with Python based-codes for aero-elastic load and cost modelling
- User-defined optimisation algorithm
- Steady state only (10-min average conditions)
- Multi-variable sub-models of environment and costs

Levelized **Cost of Energy** Optimization

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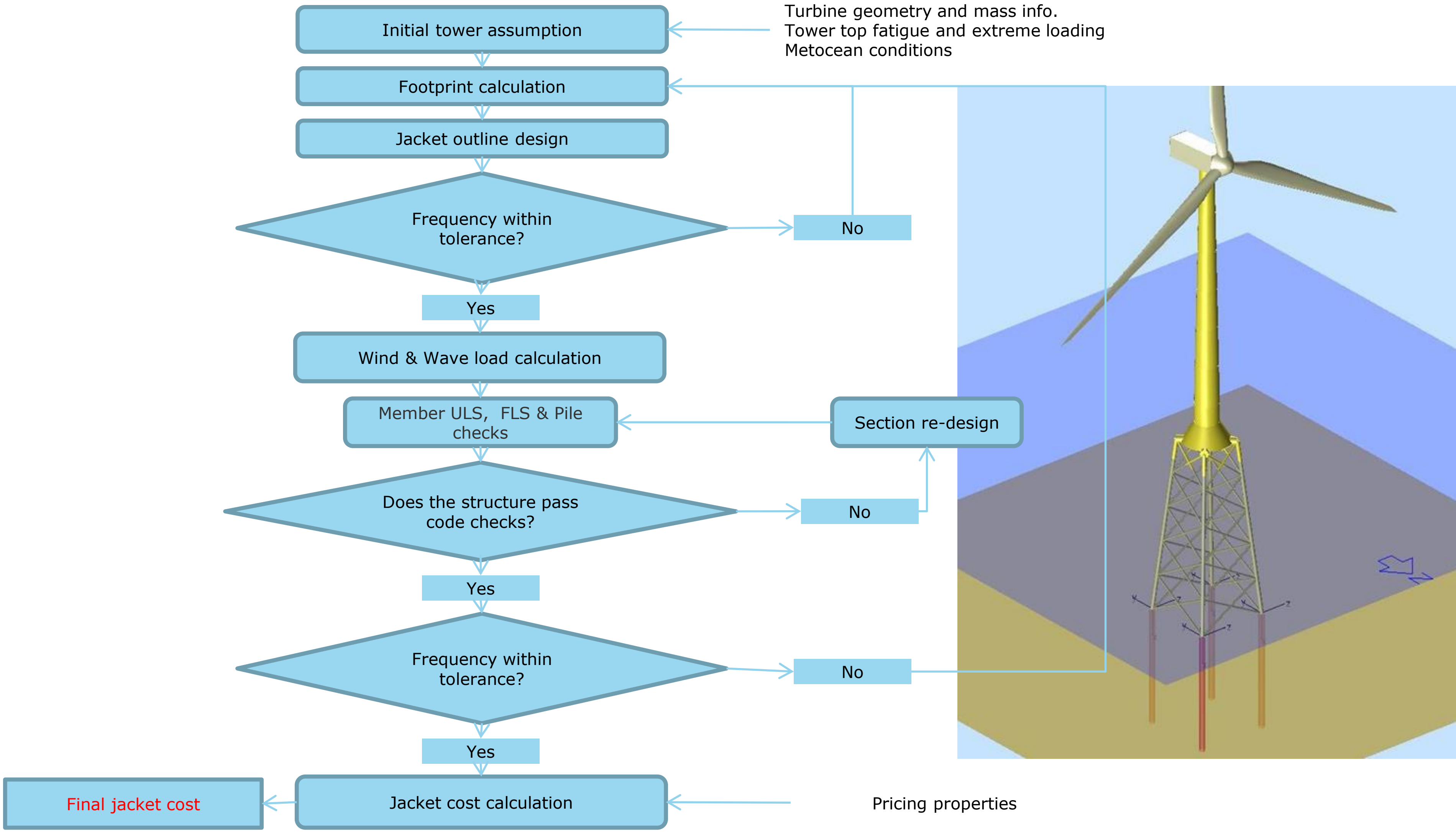
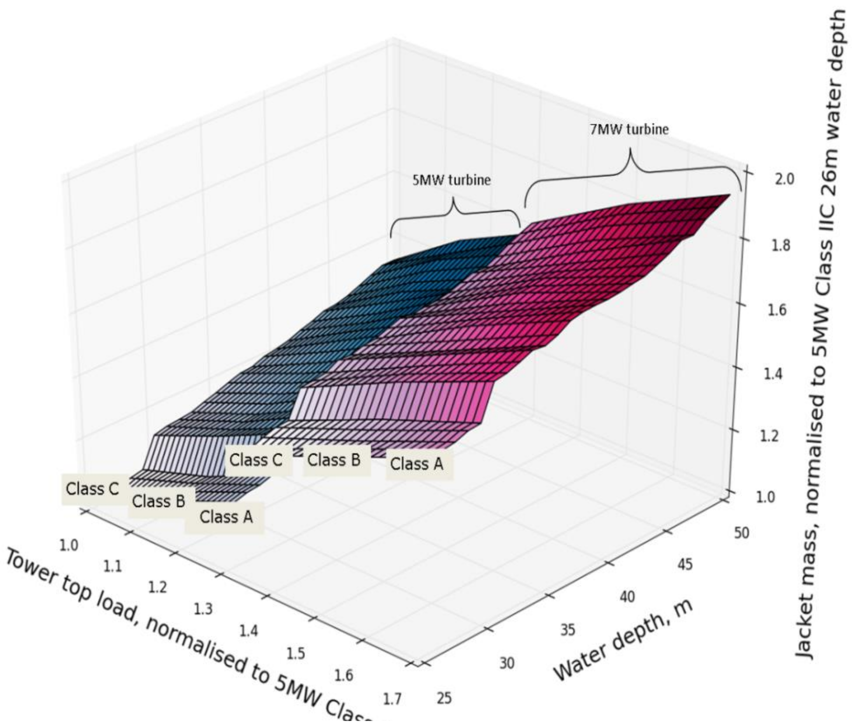
Offshore Sub-Structure Engineering Cost Model

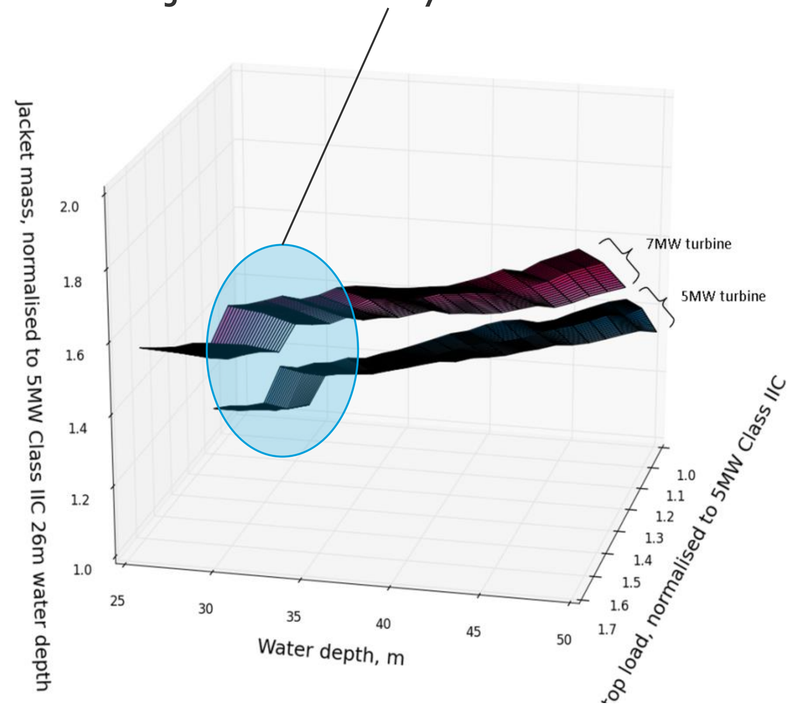


Offshore Sub-Structure Engineering Cost Model

- Automated sub-structure design as function of turbine size, loading, water depth and ground conditions



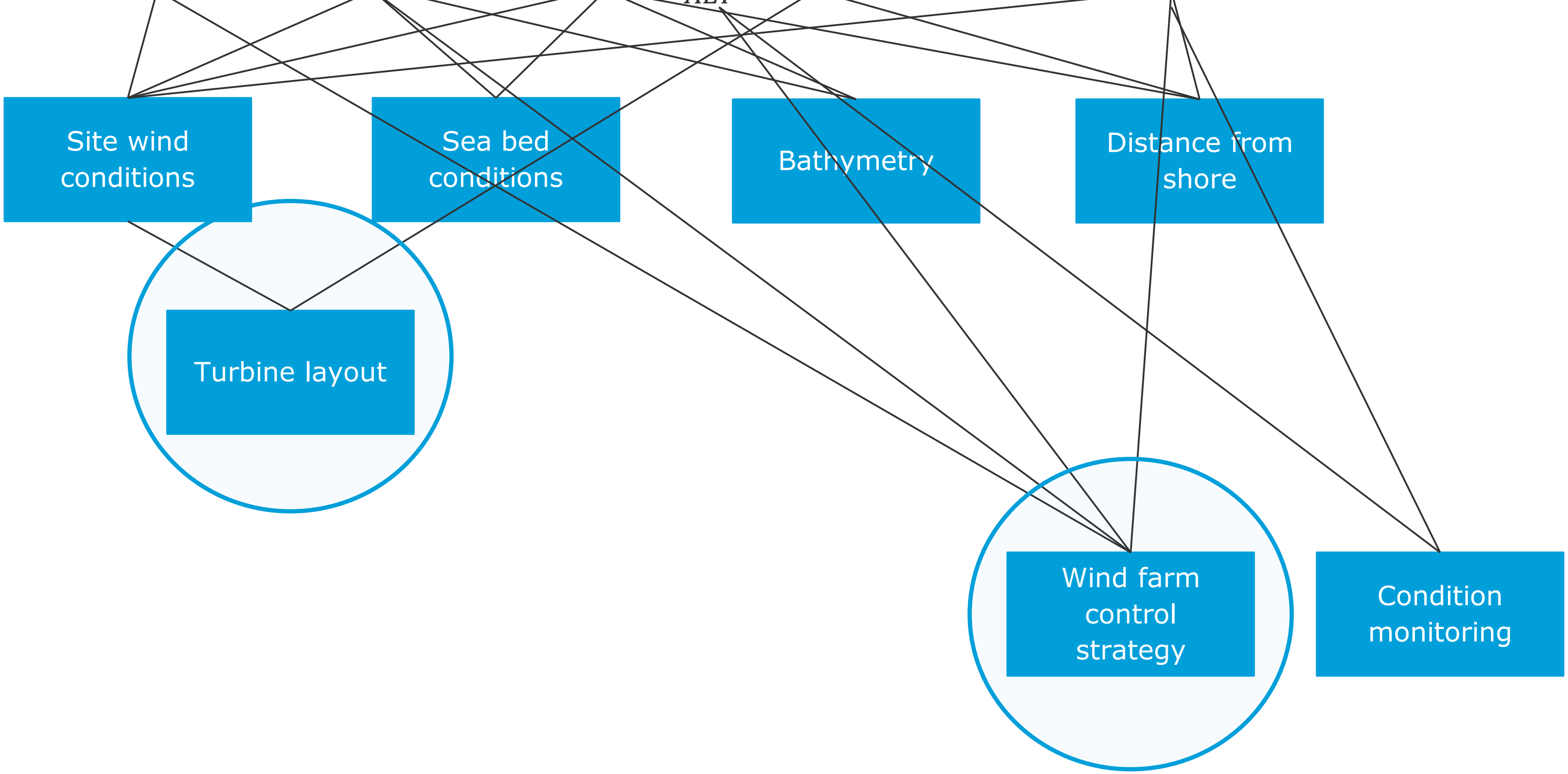
Jump at water depth where extra jacket storey is added



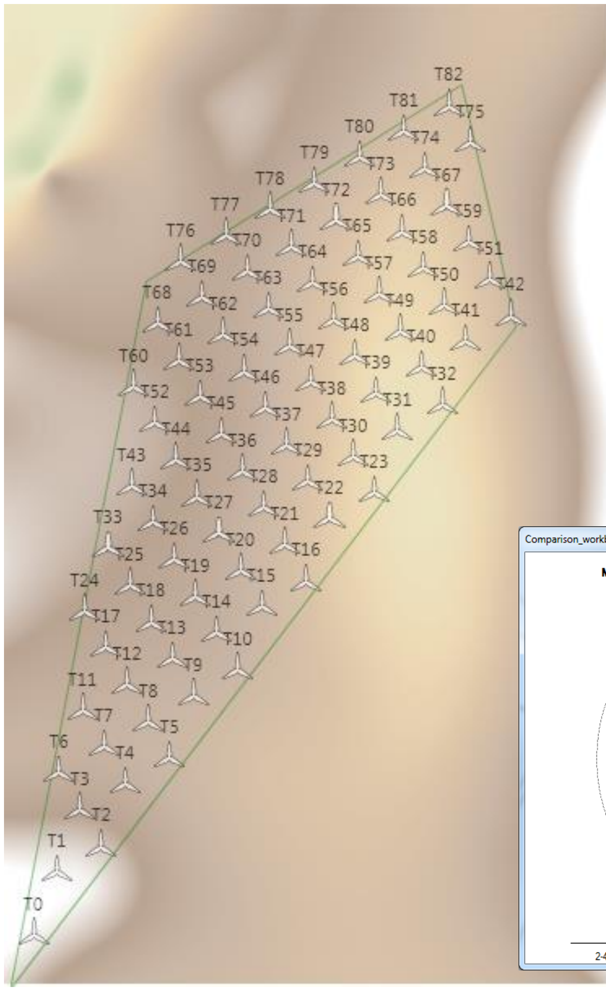
Jacket mass ~20% increase from class C to class A. ~20-30% increase from 26m to 50m water depth

Multiple Variables Feed into Cost of Energy Function

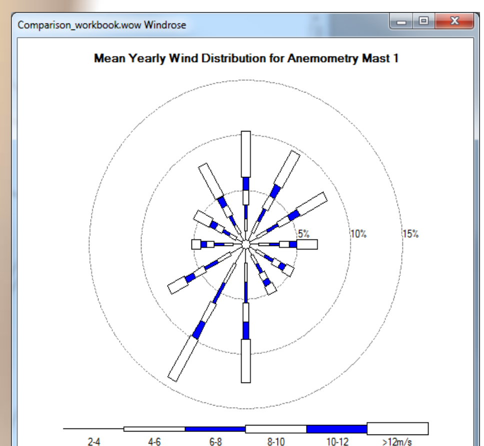
$$Levelised\ Cost\ of\ Energy = \frac{\left[\sum(Cost_{Turbine}+Cost_{Foundation})+Cost_{Installation}+Cost_{Electrical}\right].Capex_{factor}+Cost_{OPEX}.Opex_{factor}}{AEP}$$

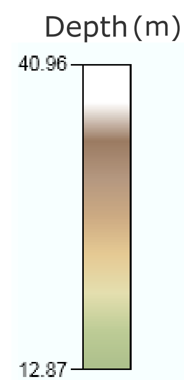


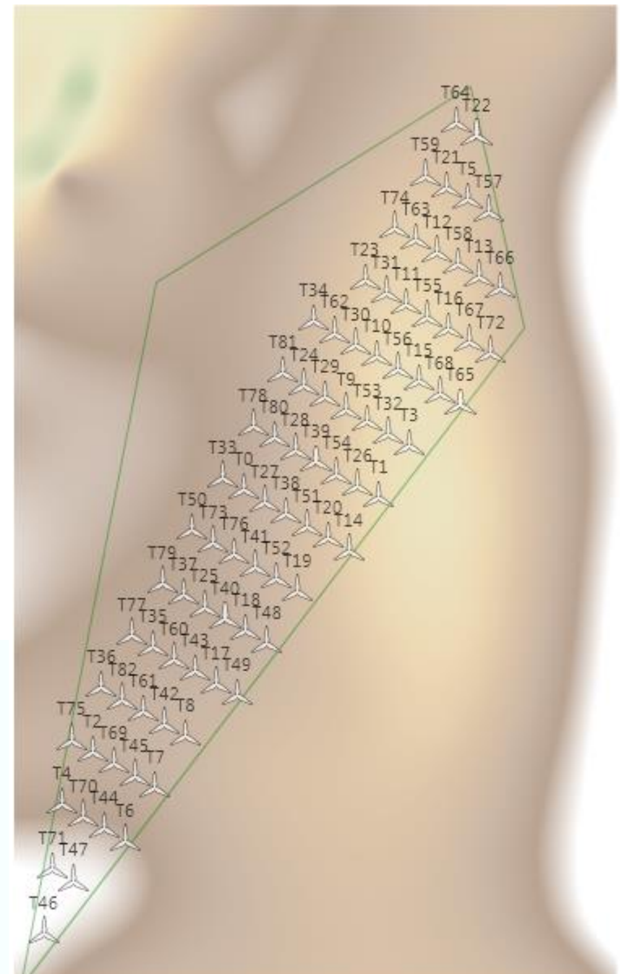
An objective assessment of layout value



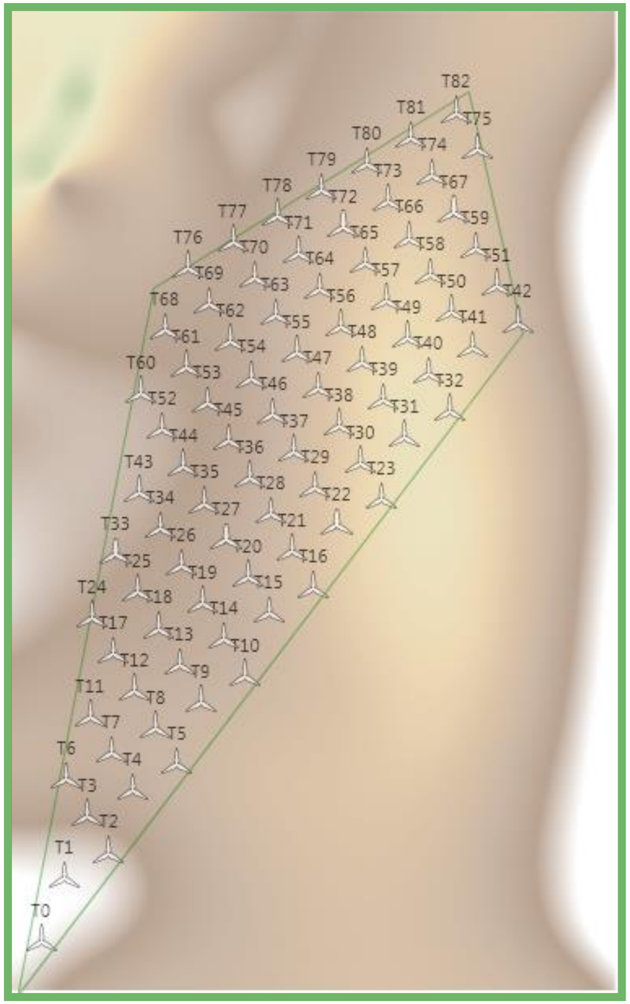
Which layout has higher energy yield?





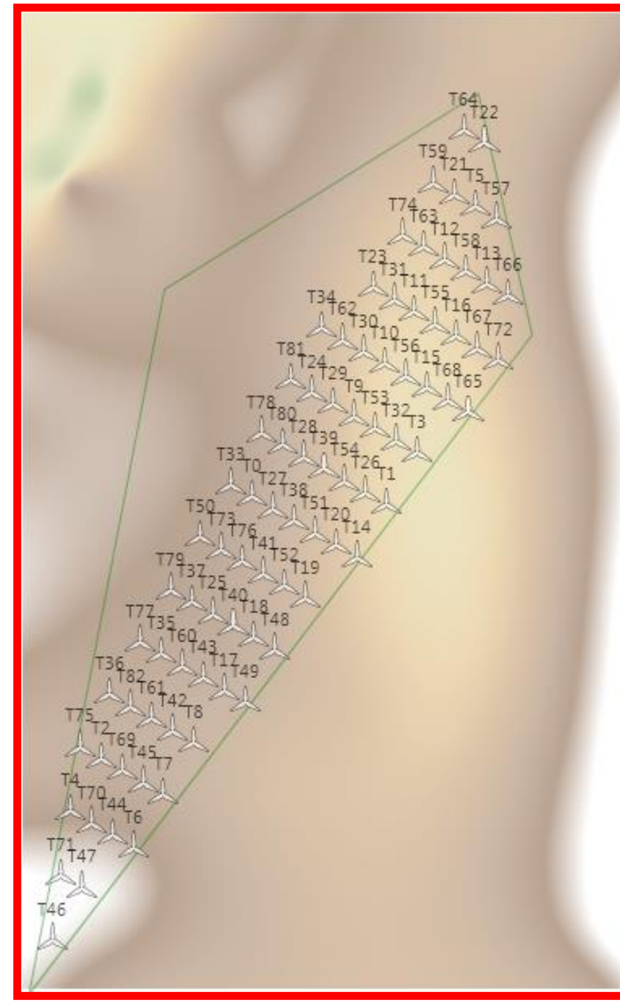


An objective assessment of layout value

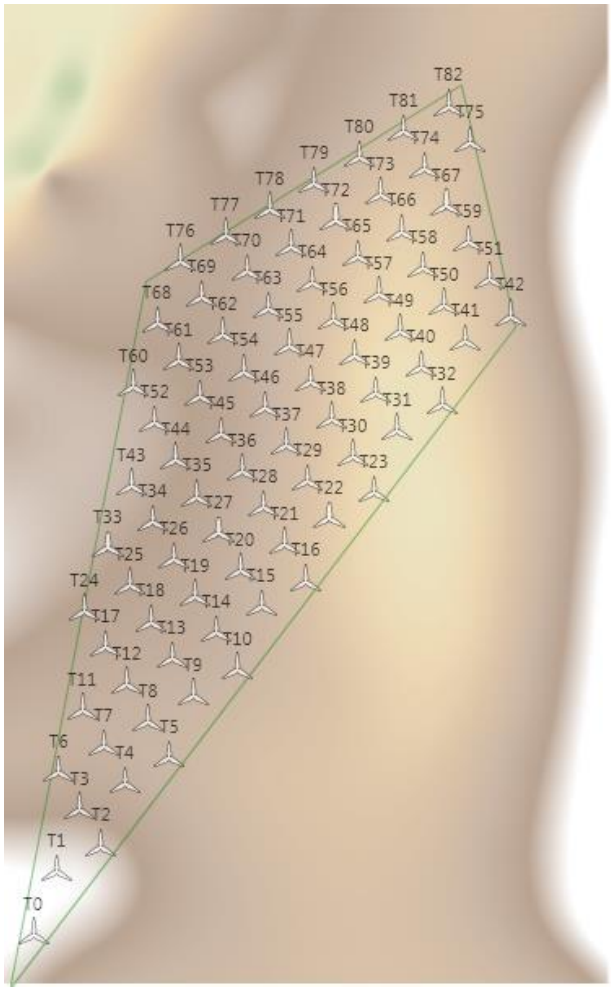


Which layout has higher energy yield?

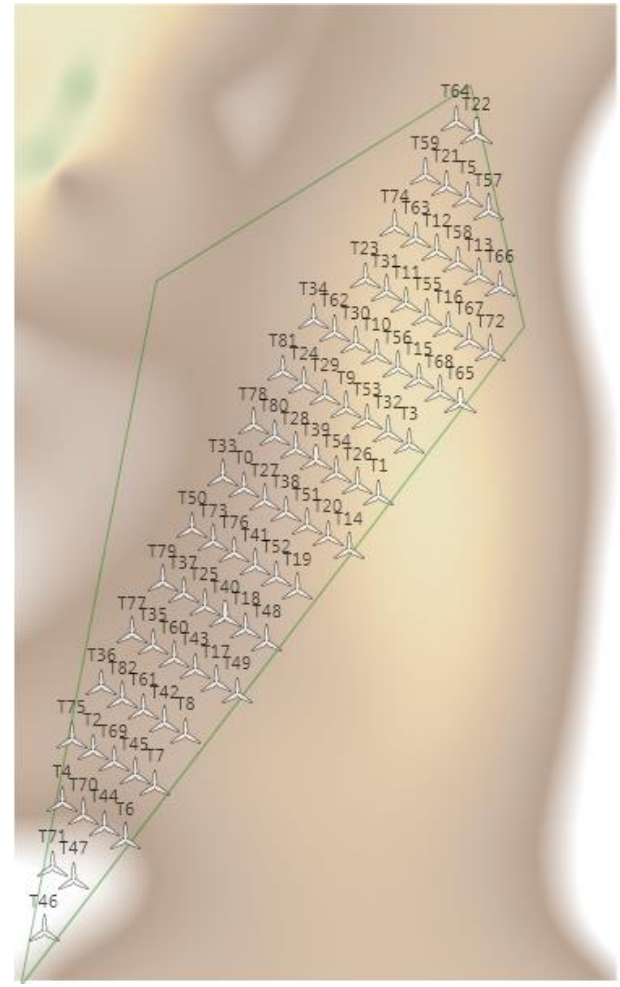
Energy with cabling losses: -0.3%



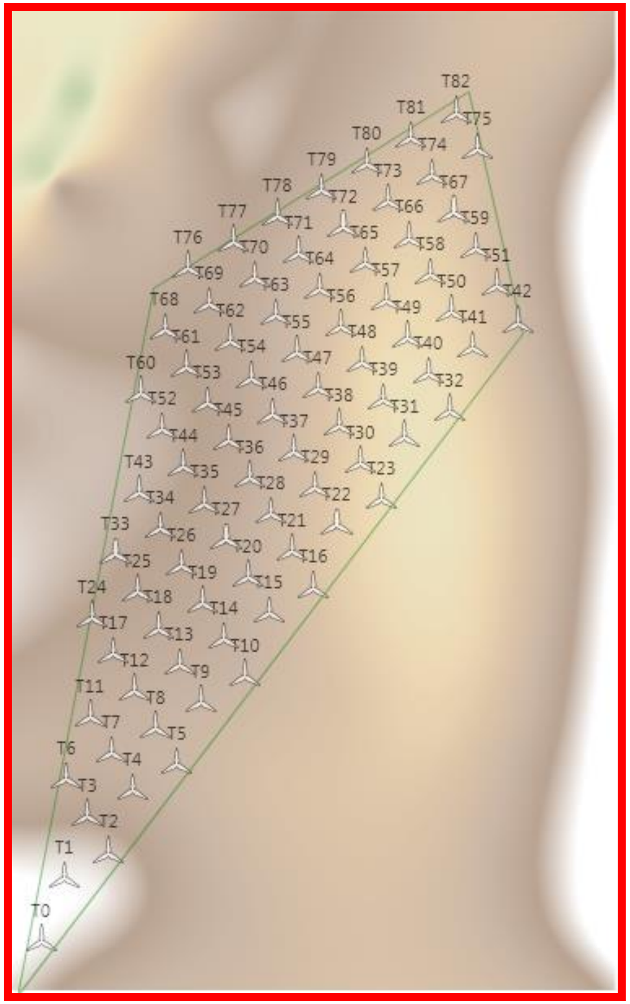
An objective assessment of layout value



What about cost?

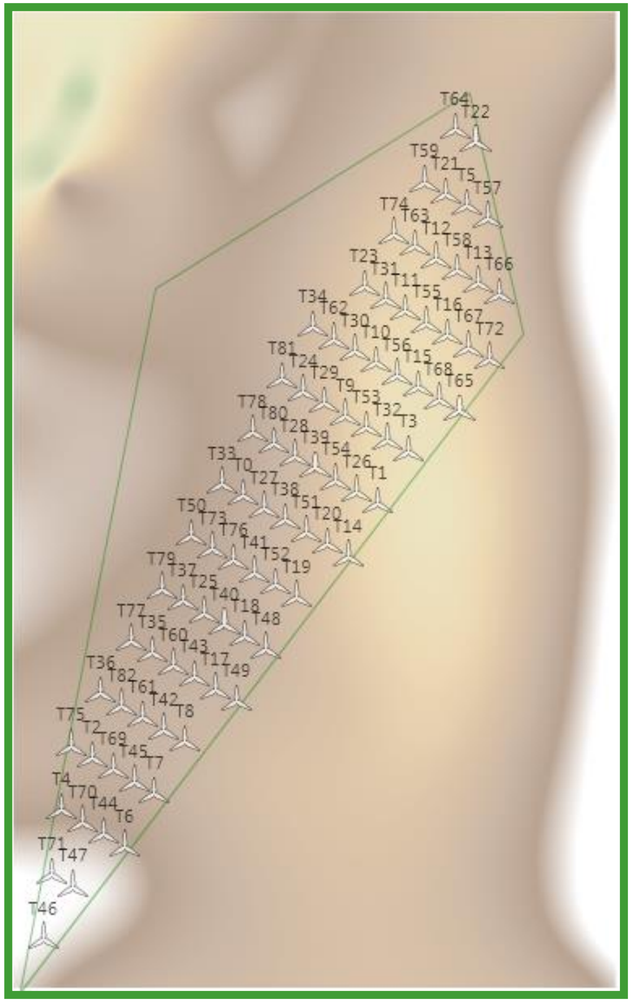


An objective assessment of layout value

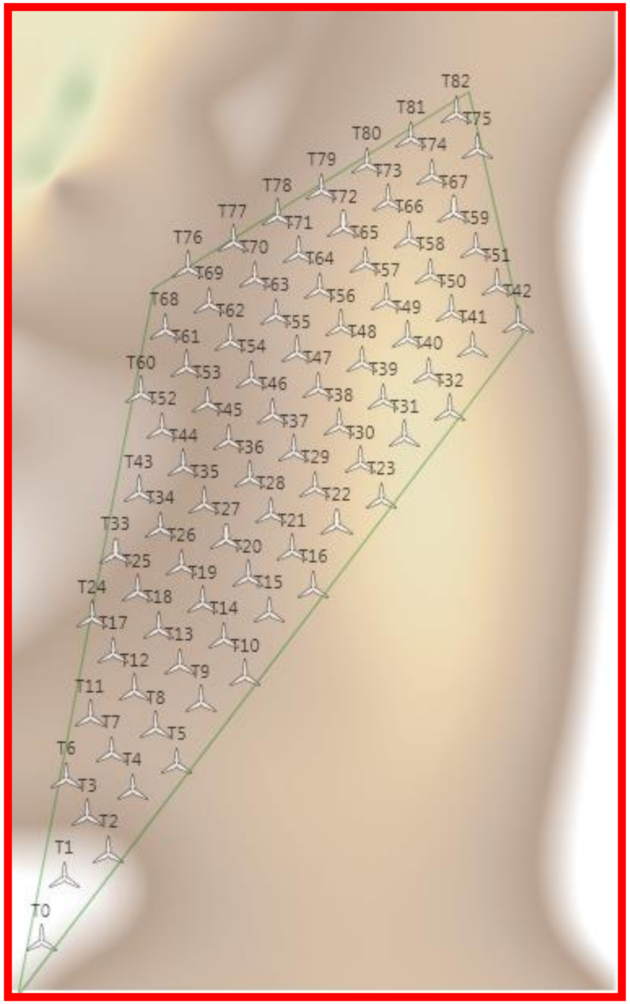


What about cost?

Levelised cost (due to cabling mainly): -0.4%



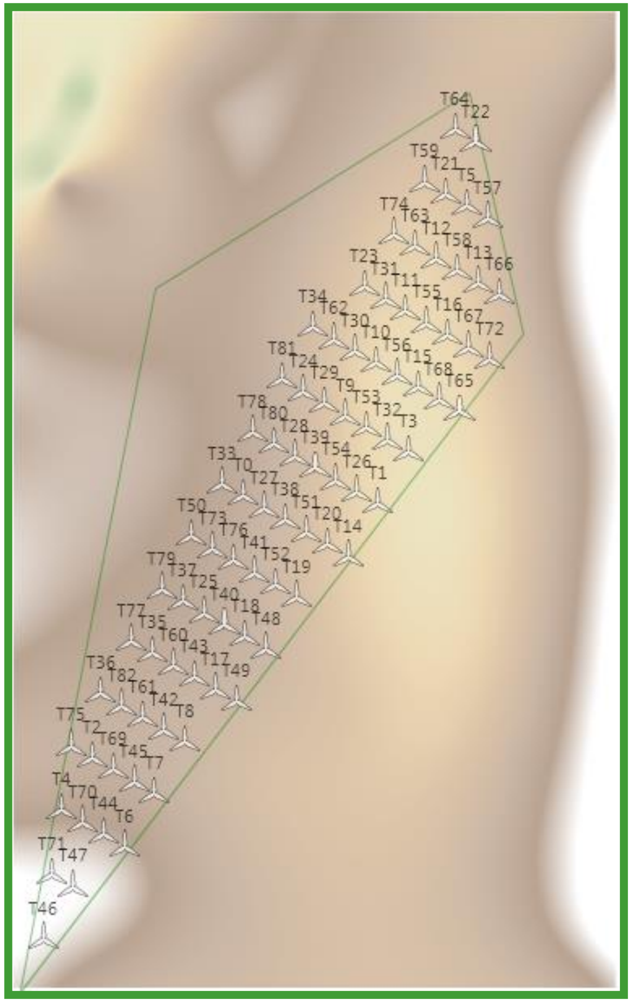
An objective assessment of layout value



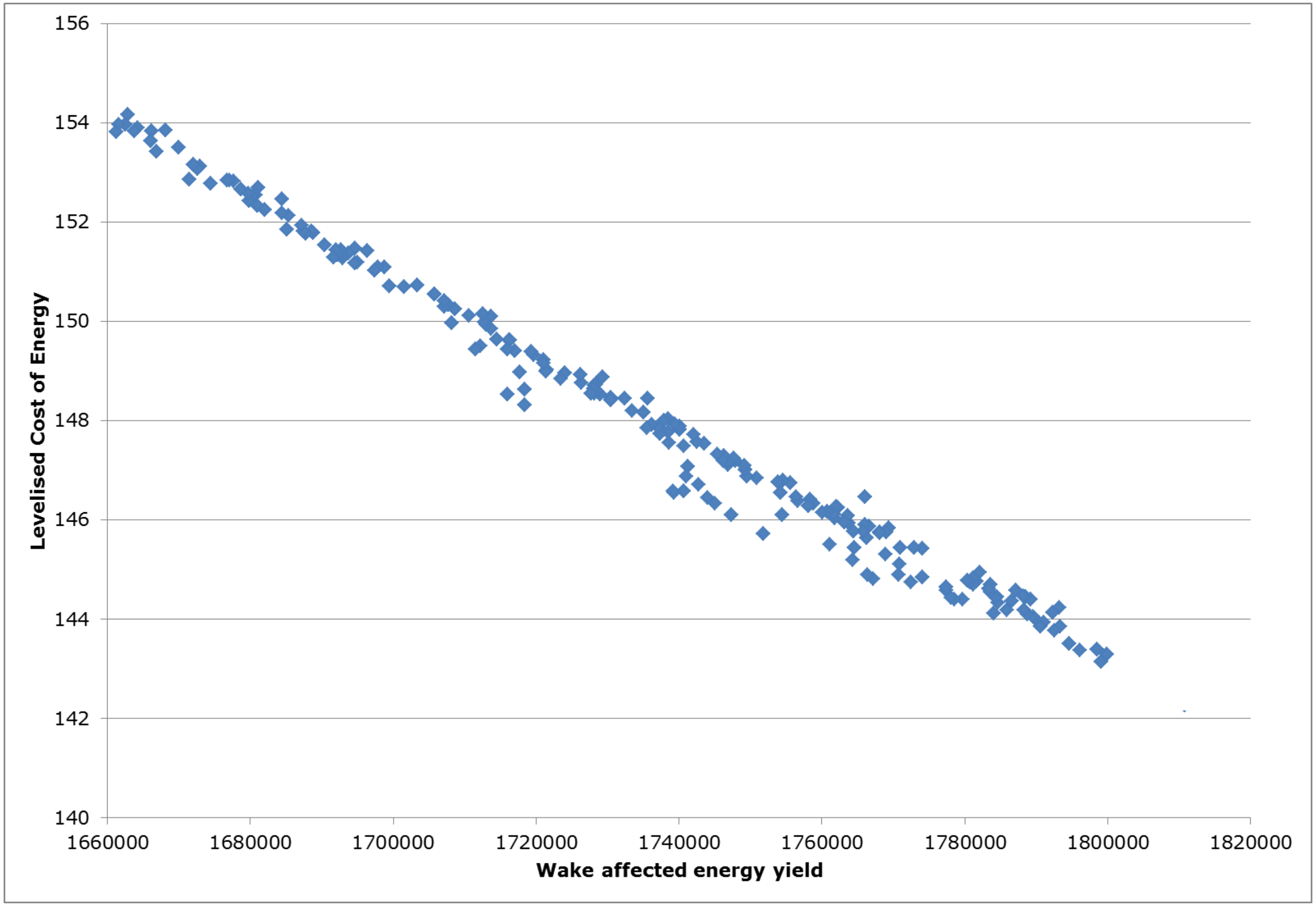
Therefore…

Cost of Energy:

LCoE: -0.1%

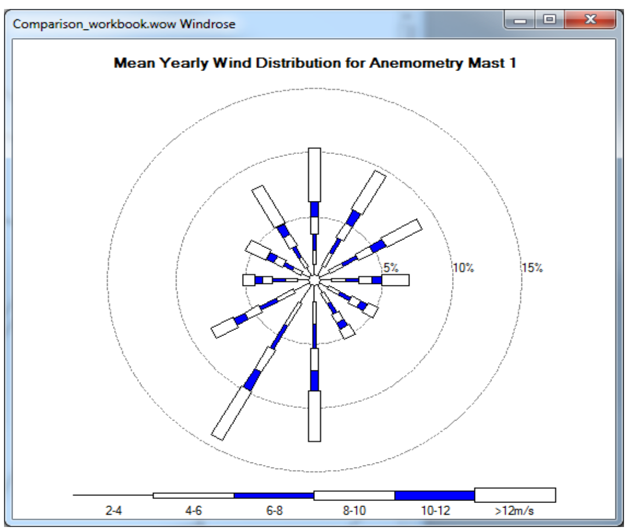


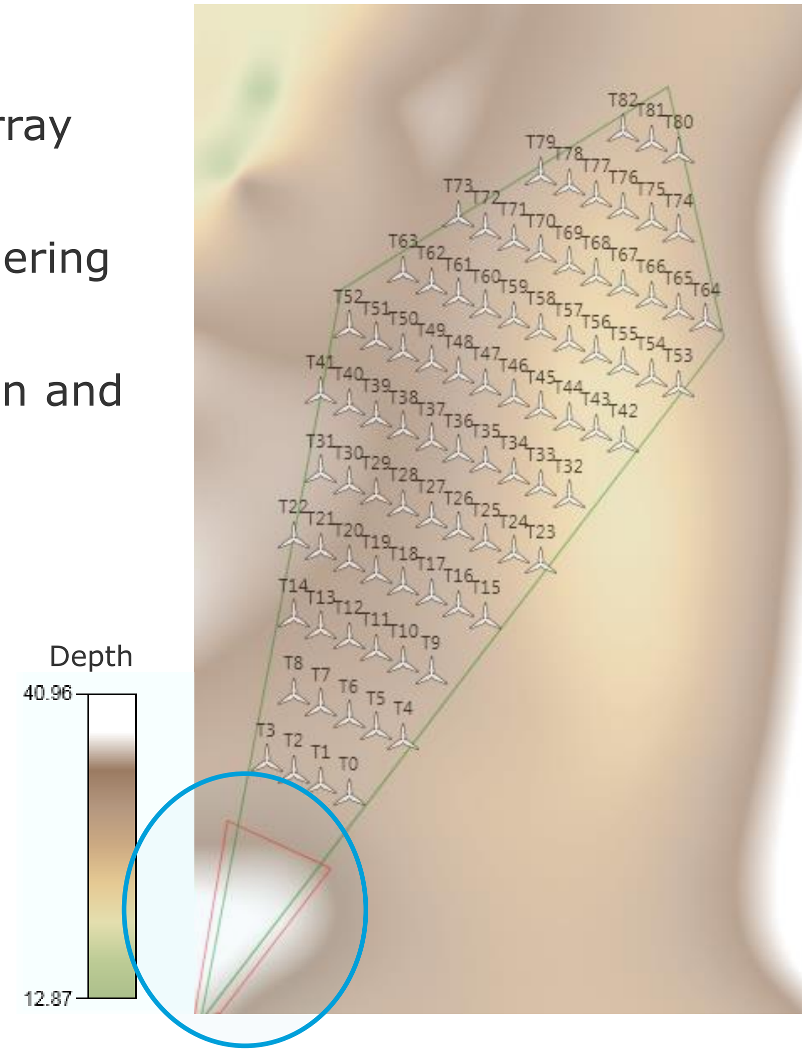
Energy yield - LCoE correlation



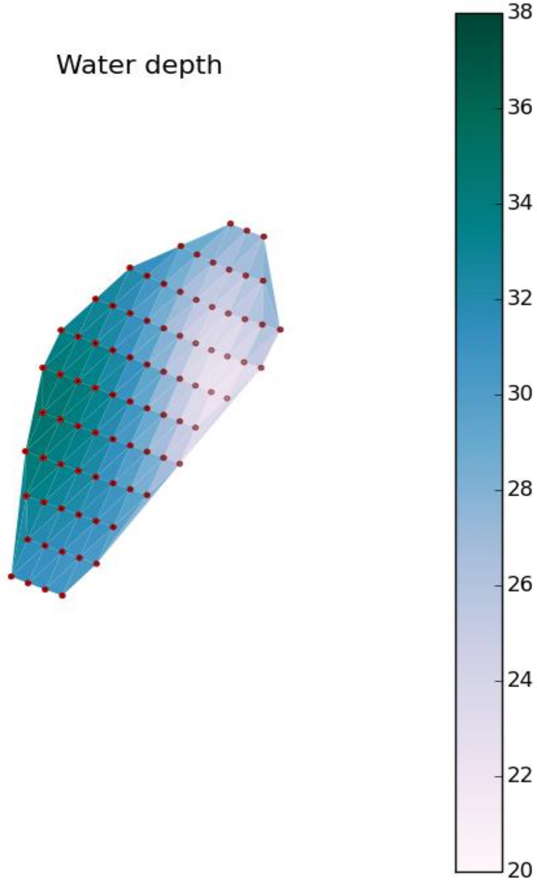
Example: Attempt to refine a ‘baseline’ offshore plant layout

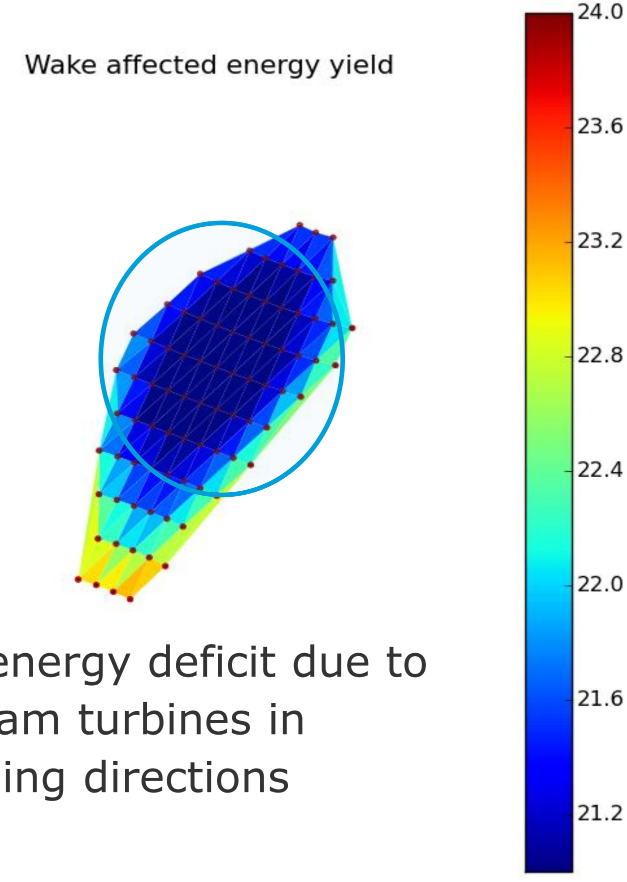
- Baseline layout generated through:
  - Initial energy optimisation deriving best array geometry
  - Manual assessment of project costs considering ‘offline’ cost functions and constraints
  - Manual bridge between energy optimisation and cost optimisation





Baseline conditions

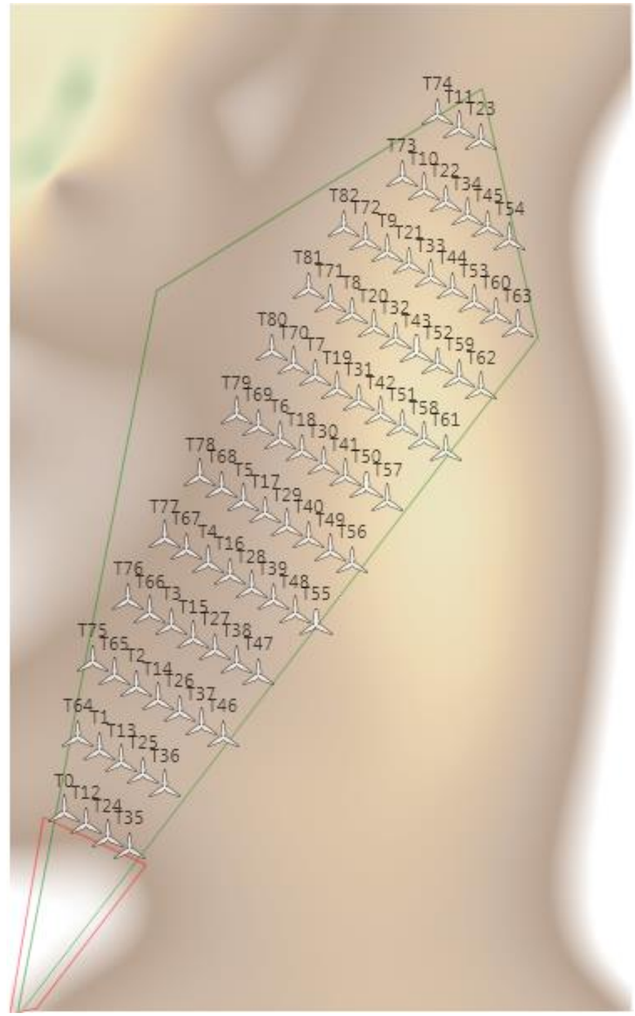




Deep energy deficit due to upstream turbines in prevailing directions

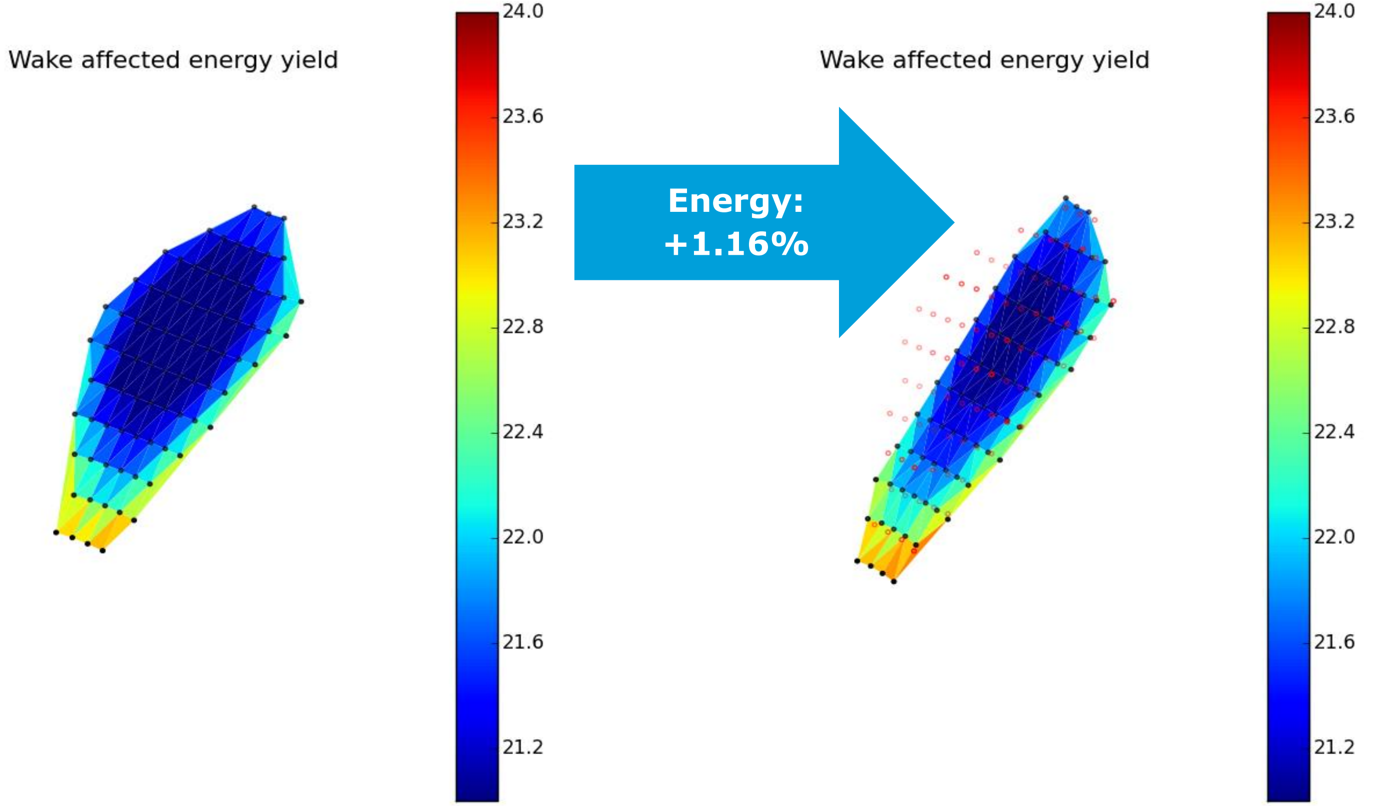
Example: Attempt to optimise a baseline layout

LCoE:
-1.42%



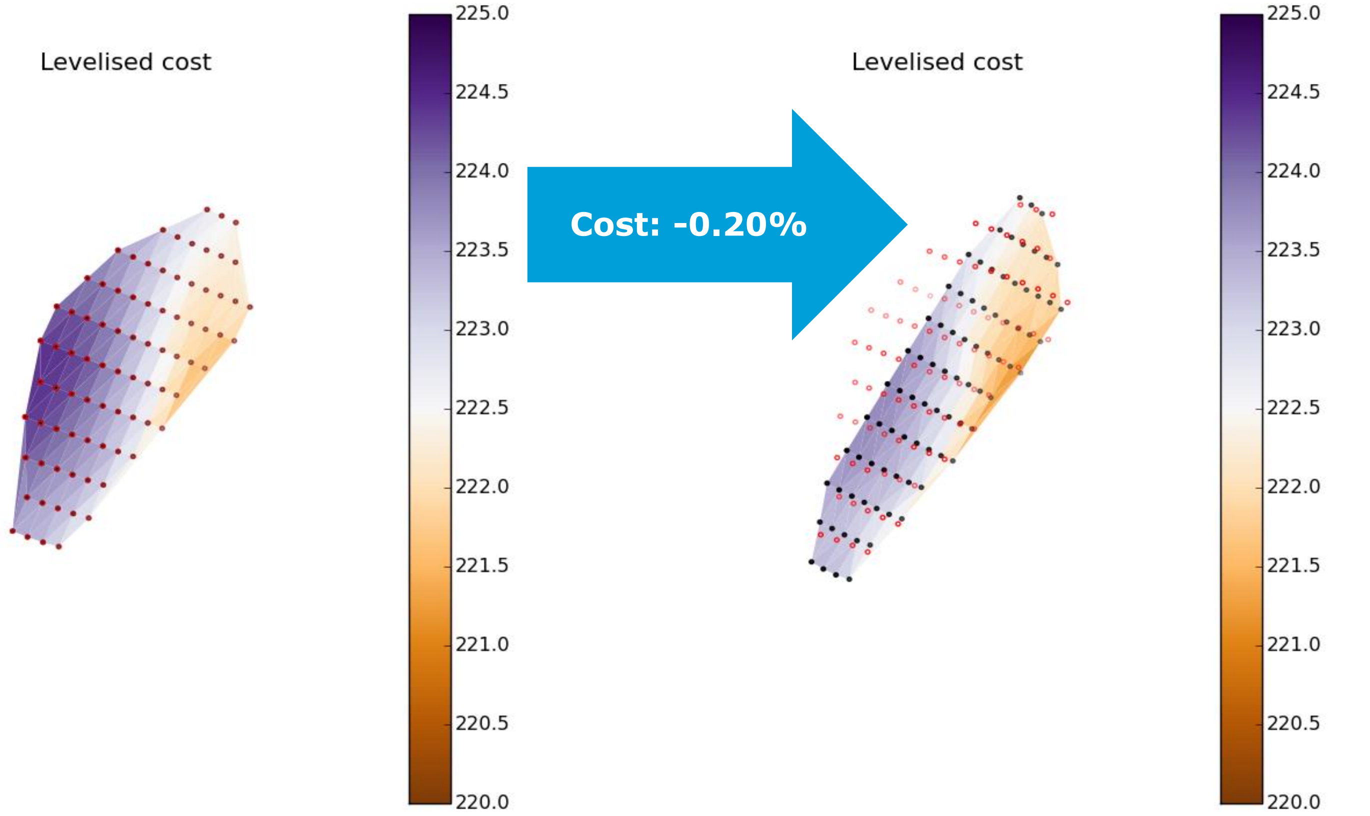
Example: Attempt to optimise a baseline layout

- Energy
- Reduction in row length in N-S direction



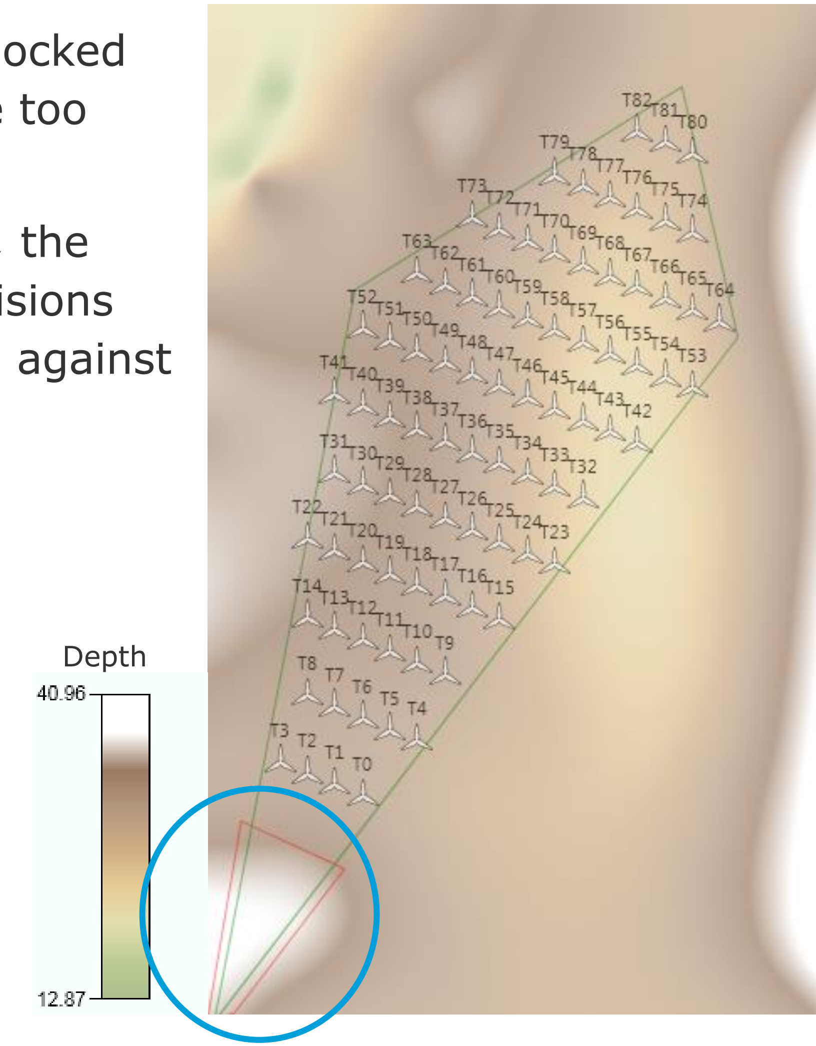
Example: Attempt to optimise a baseline layout

- Levelised cost:
- 0.20% reduction composed of 82% array cabling, 18% reduced jacket costs



Removing manual interventions…

- The Southerly tip (high wind speeds) was blocked out due to high water depth perceived to be too costly for installation
- Provided cost models are of suitable fidelity, the automated tool could make these value decisions directly trading off the benefit of the energy against the increase in project costs



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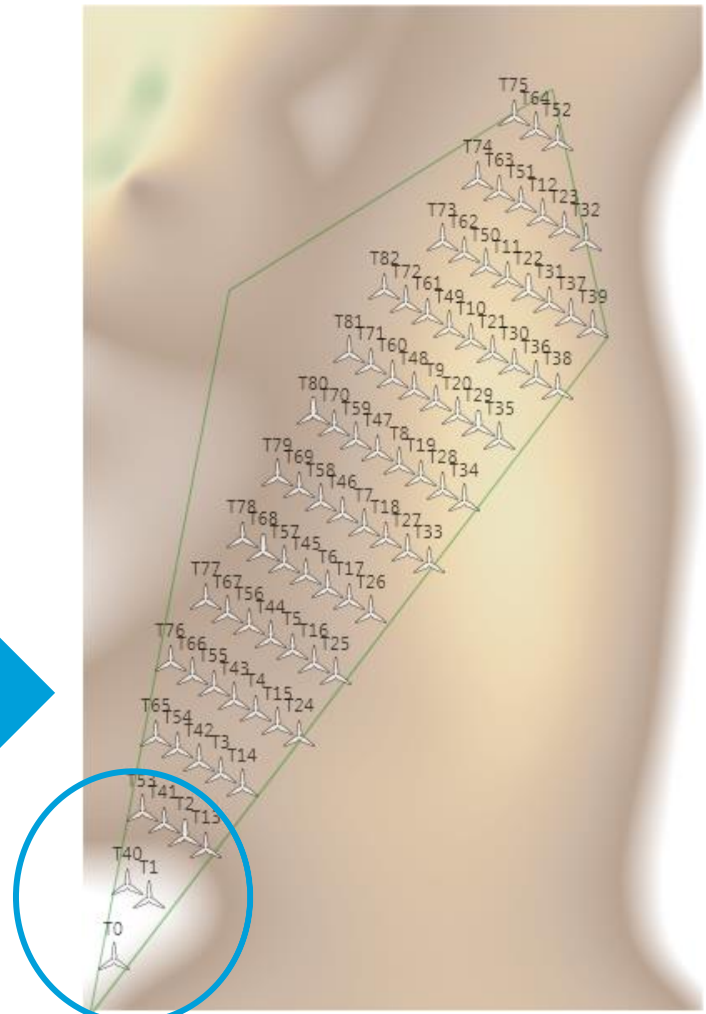
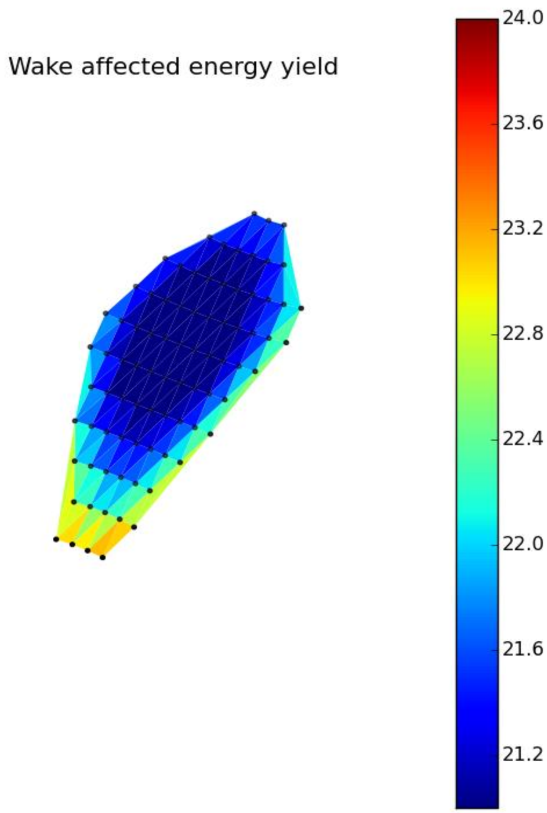
Removing manual interventions…

LCoE:
-1.85%

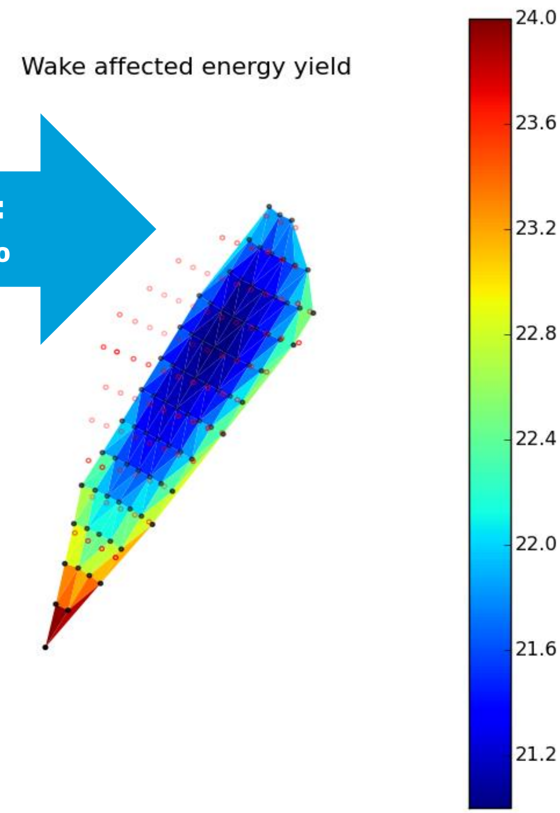


Removing manual interventions…

- Energy

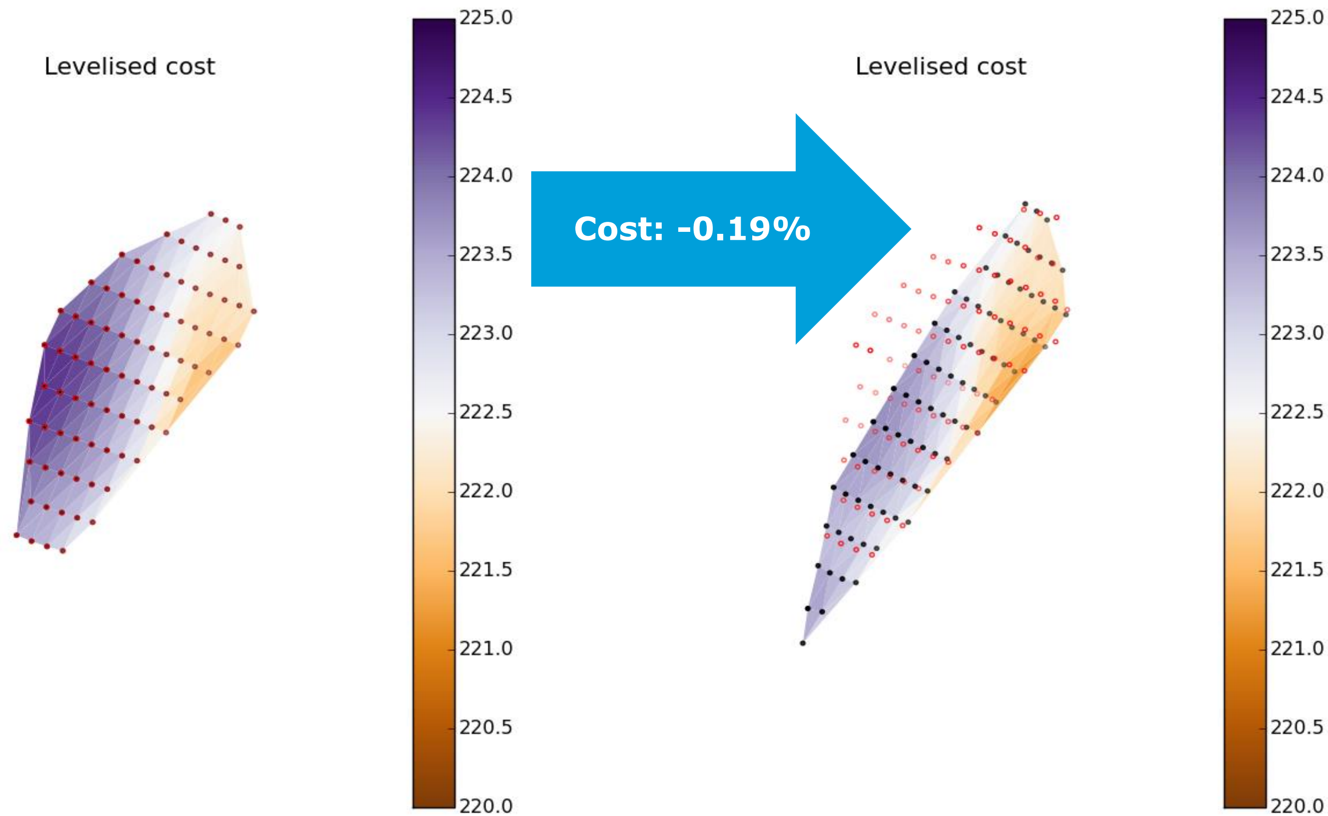


Energy: +1.61%



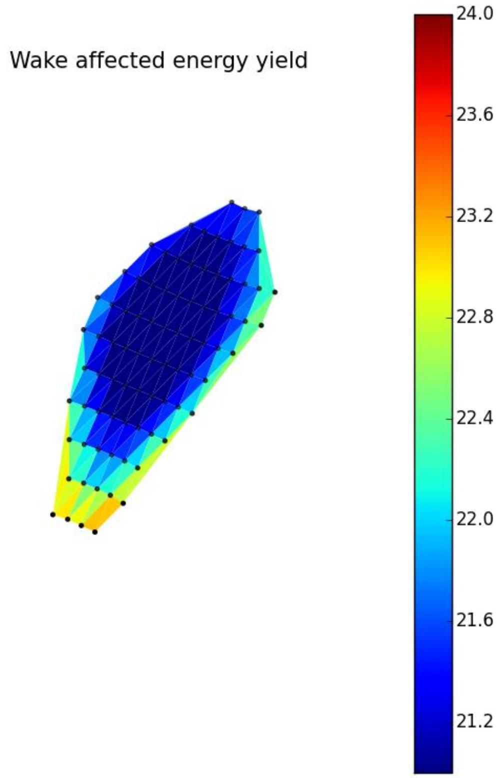
Removing manual interventions…

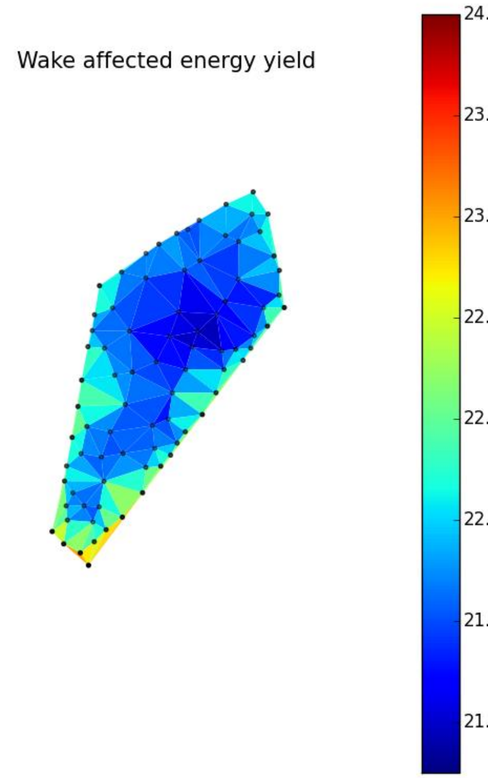
- Levelised cost:
- 0.19% reduction composed of 84% array cabling, 16% reduced jacket costs



What price uniformity?

- When irregularly arranged, turbines tend to hug boundaries with gaps forming internally reducing wake losses





3 movements of each turbine, LPC change of **-2.18%** relative to baseline

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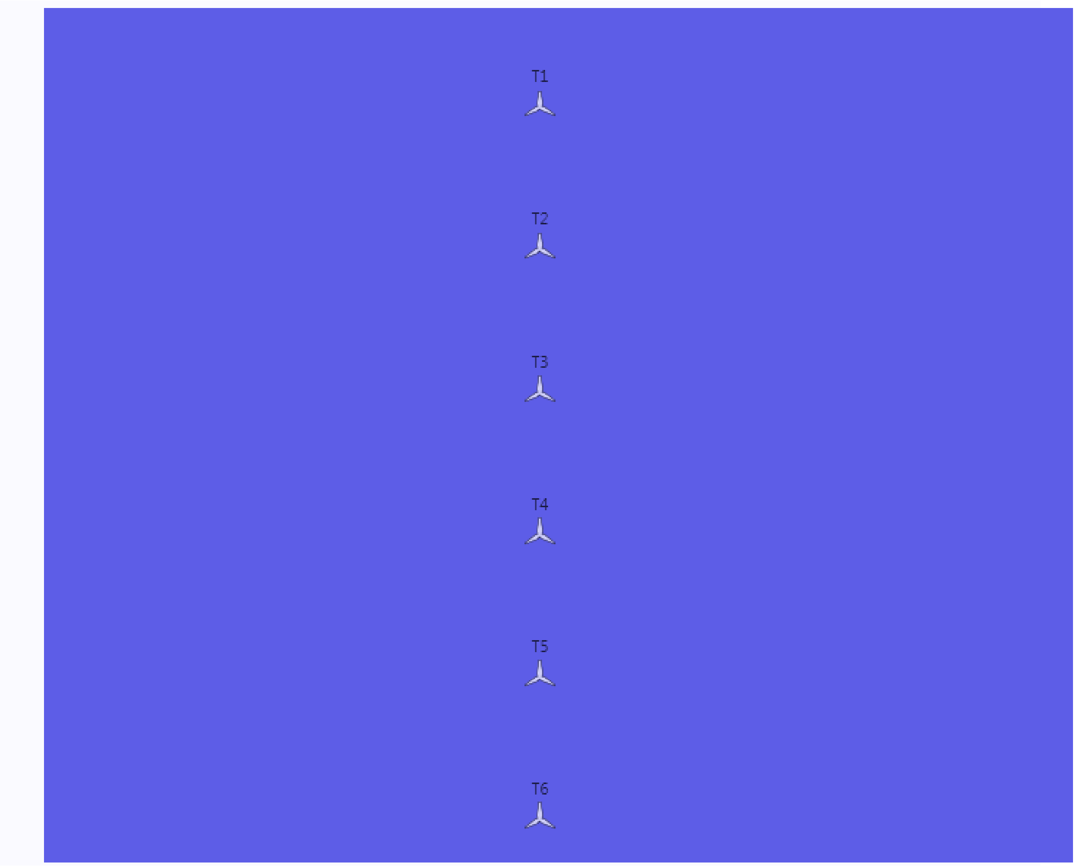
Wind plant-wide control strategies

- Consider wind farm as a power station, not a collection of autonomous turbines
- Turbines interact through their wakes
- When some turbines are wake-affected, optimize power set-points rather than shut down turbines completely

- Goal: Optimise farm-wide control strategies to balance the effects on energy capture and the accumulation of fatigue damage across the wind farm

Consider a simple example…

- Row of six 2MW turbines, regular spacing, wind direction from North.



Optimization variables & simple benefit function

- **Optimisation variables**: de-rating level, $\delta_i,\ i = 1, 2, \dots, N$ (N turbines)
  - Notation: $\delta = (\delta_1, \delta_2, \dots, \delta_N)$

- "**Ideal**" scenario: no turbines are wake affected

- "**Base**" scenario: wakes, but no turbine is de-rated, i.e. $\delta^{base} = (0, 0, \dots 0)$

- 'Simple' **benefit function**: maximised in relation to the ideal scenario $(E^0{}_i, L^0{}_i)$

$$\Delta J(\delta) = \sum_{i=1}^{N} \Delta J_i(\delta), \qquad \Delta J_i(\delta) = \frac{(E_i(\delta) - E^0{}_i)}{E^0{}_i} - 0.1\,\frac{(L_i(\delta) - L^0{}_i)}{L^0{}_i}$$

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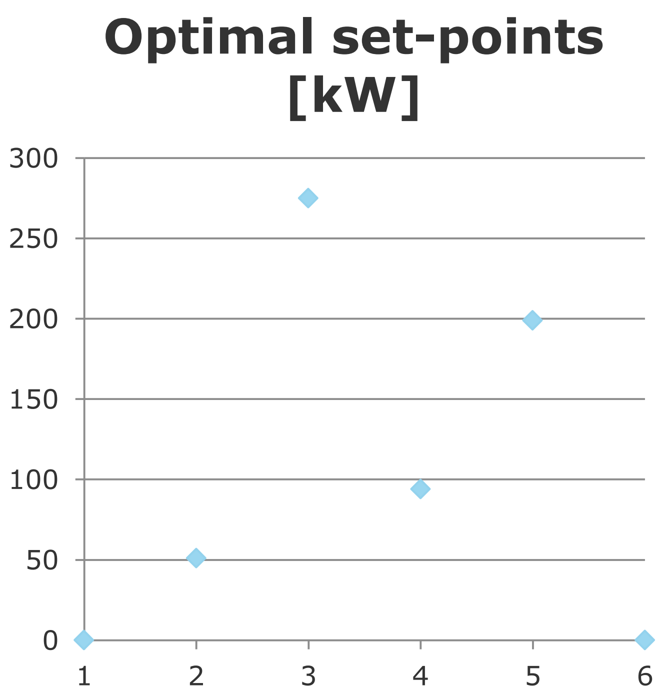
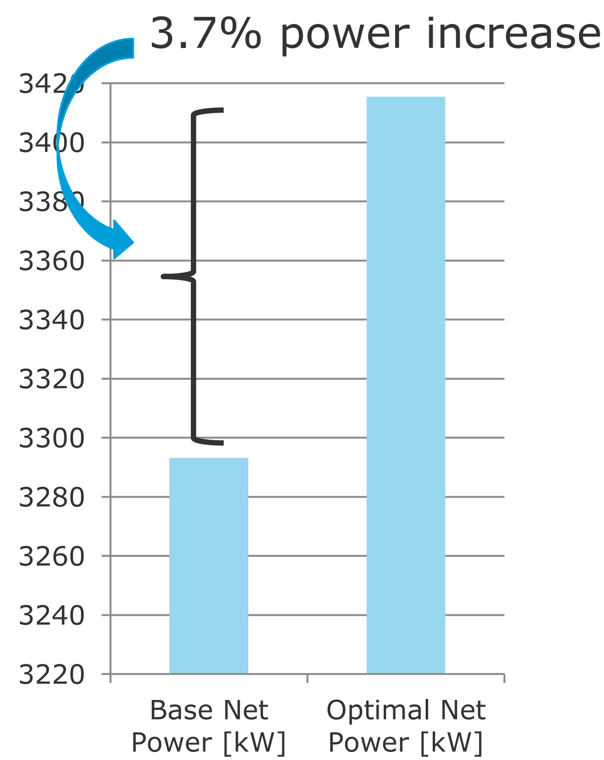
3D spacing results (1)

- 3D spacing
- Average 10 m/s wind speed, 10% turbulence, from North





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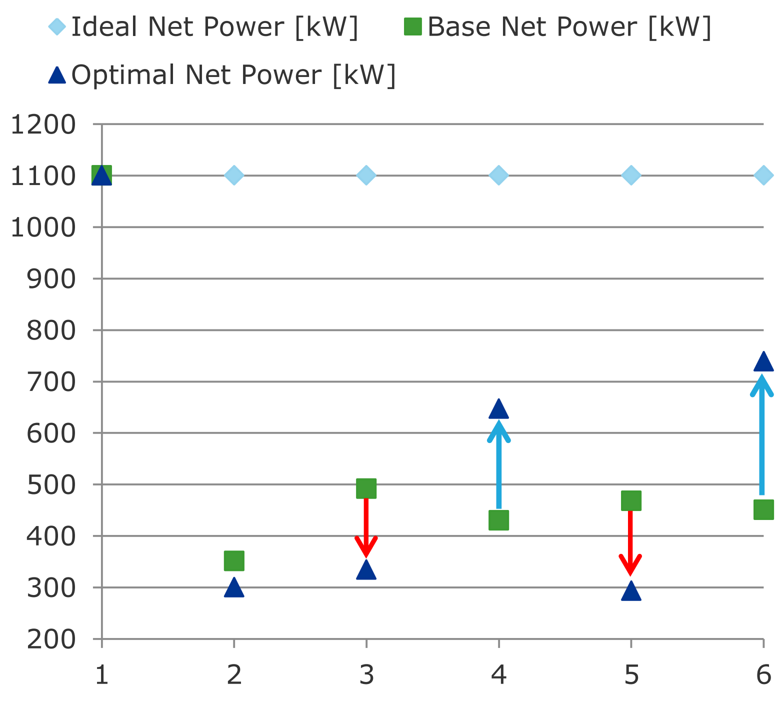
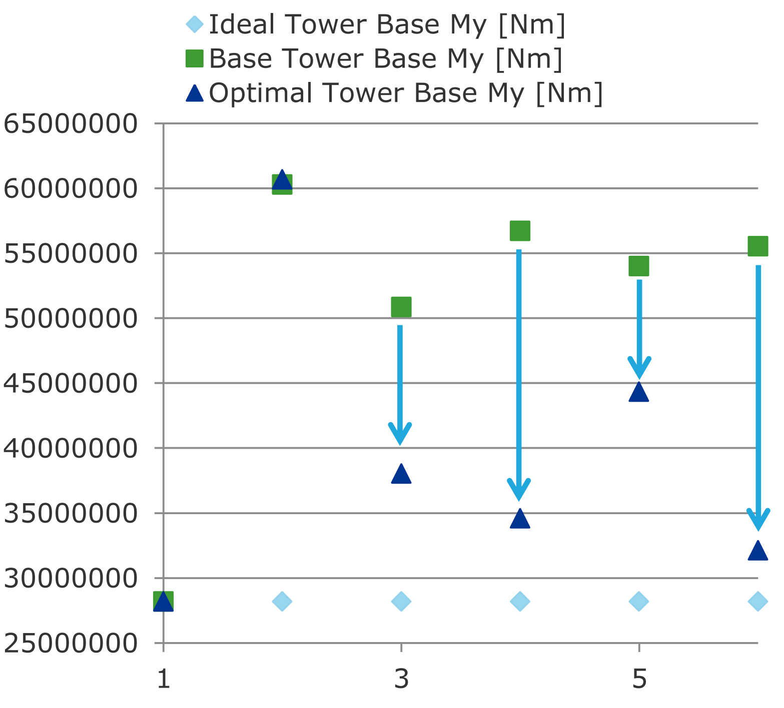
3D spacing results (2)

Power:



Fatigue Load:



Concluding remarks

- An **integrated wind-plant system model** has been demonstrated to aid cost of energy optimization. "Maximum energy yield" still appears to be a fair indicator of global optimal for at least some design scenarios, but further local optimisation is possible by considering more system effects

- Simple **plant-wide control** example suggests there is potential to nuance turbine de-rating/shut-down policies and **improve both energy and loading**

- Results clearly depend on the nature of the benefit functions, and the fidelity of wake model.

- The potential to **optimize layout** *and* **plant-control policies** simultaneously pre-construction could result in significant synergies – but this has yet to be demonstrated.

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Thank you

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