How we engineer wind energy systems

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Shell's Net Carbon Intensity

Also, in this presentation we may refer to Shell's "Net Carbon Intensity" (NCI), which includes Shell's carbon emissions from the production of our energy products, our suppliers' carbon emissions in supplying energy for that production and our customers' carbon emissions associated with their use of the energy products we sell. Shell's NCI also includes the emissions associated with the production and use of energy products produced by others which Shell purchases for resale. Shell only controls its own emissions. The use of the terms Shell's "Net Carbon Intensity" or NCI are for convenience only and not intended to suggest these emissions are those of Shell plc or its subsidiaries.

Shell's net-zero emissions target

Shell's operating plan, outlook and budgets are forecasted for a ten-year period and are updated every year. They reflect the current economic environment and what we can reasonably expect to see over the next ten years. Accordingly, they reflect our Scope 1, Scope 2 and NCI targets over the next ten years. However, Shell's operating plans cannot reflect our 2050 net-zero emissions target, as this target is currently outside our planning period. In the future, as society moves towards net-zero emissions, we expect Shell's operating plans to reflect this movement. However, if society is not net zero in 2050, as of today, there would be significant risk that Shell may not meet this target.

Forward-Looking non-GAAP measures

This presentation may contain certain forward-looking non-GAAP measures such as [cash capital expenditure] and [divestments]. We are unable to provide a reconciliation of these forward-looking non-GAAP measures to the most comparable GAAP financial measures because certain information needed to reconcile those non-GAAP measures to the most comparable GAAP financial measures is dependent on future events some of which are outside the control of Shell, such as oil and gas prices, interest rates and exchange rates. Moreover, estimating such GAAP measures with the required precision necessary to provide a meaningful reconciliation is extremely difficult and could not be accomplished without unreasonable effort. Non-GAAP measures in respect of future periods which cannot be reconciled to the most comparable GAAP financial measure are calculated in a manner which is consistent with the accounting policies applied in Shell plc's consolidated financial statements.

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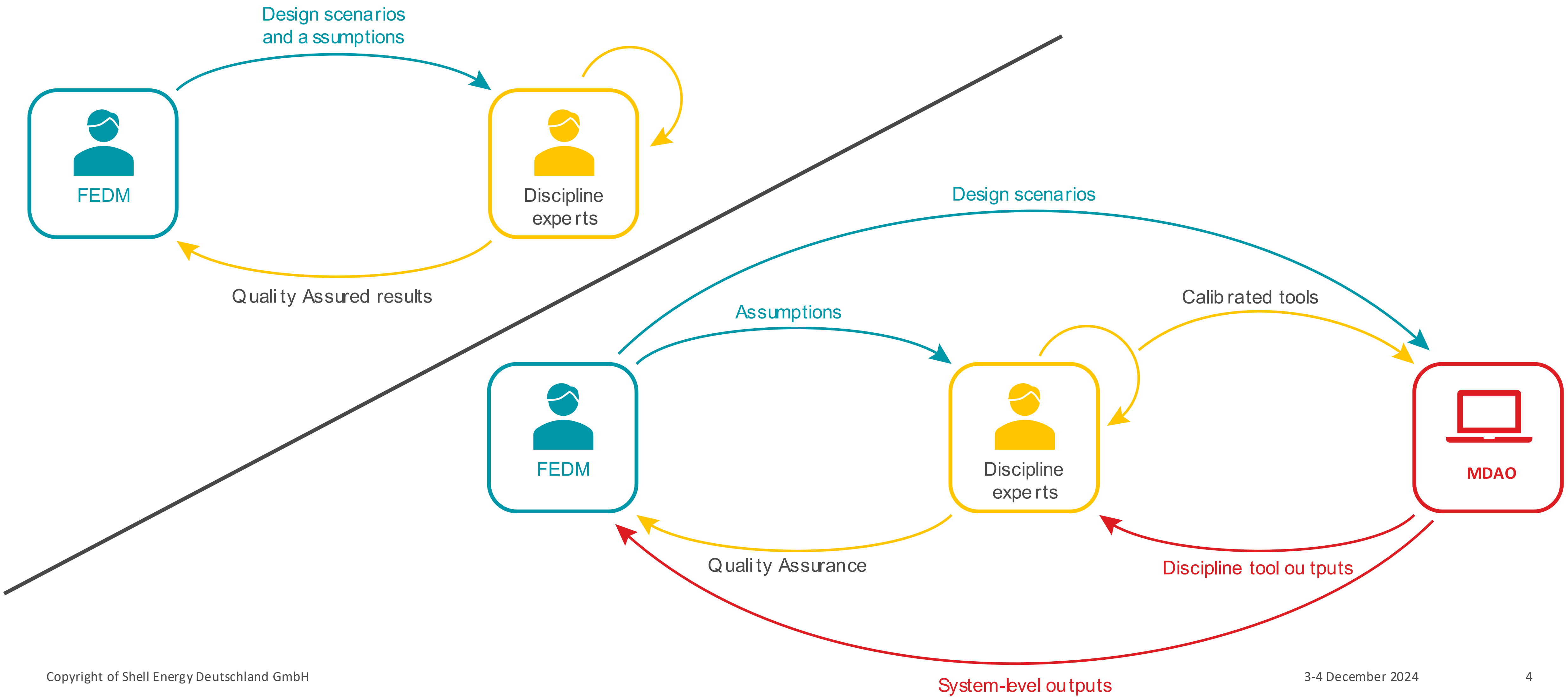
Five topics
for the price of one
%

Holistic Optimisation of Offshore wind farms

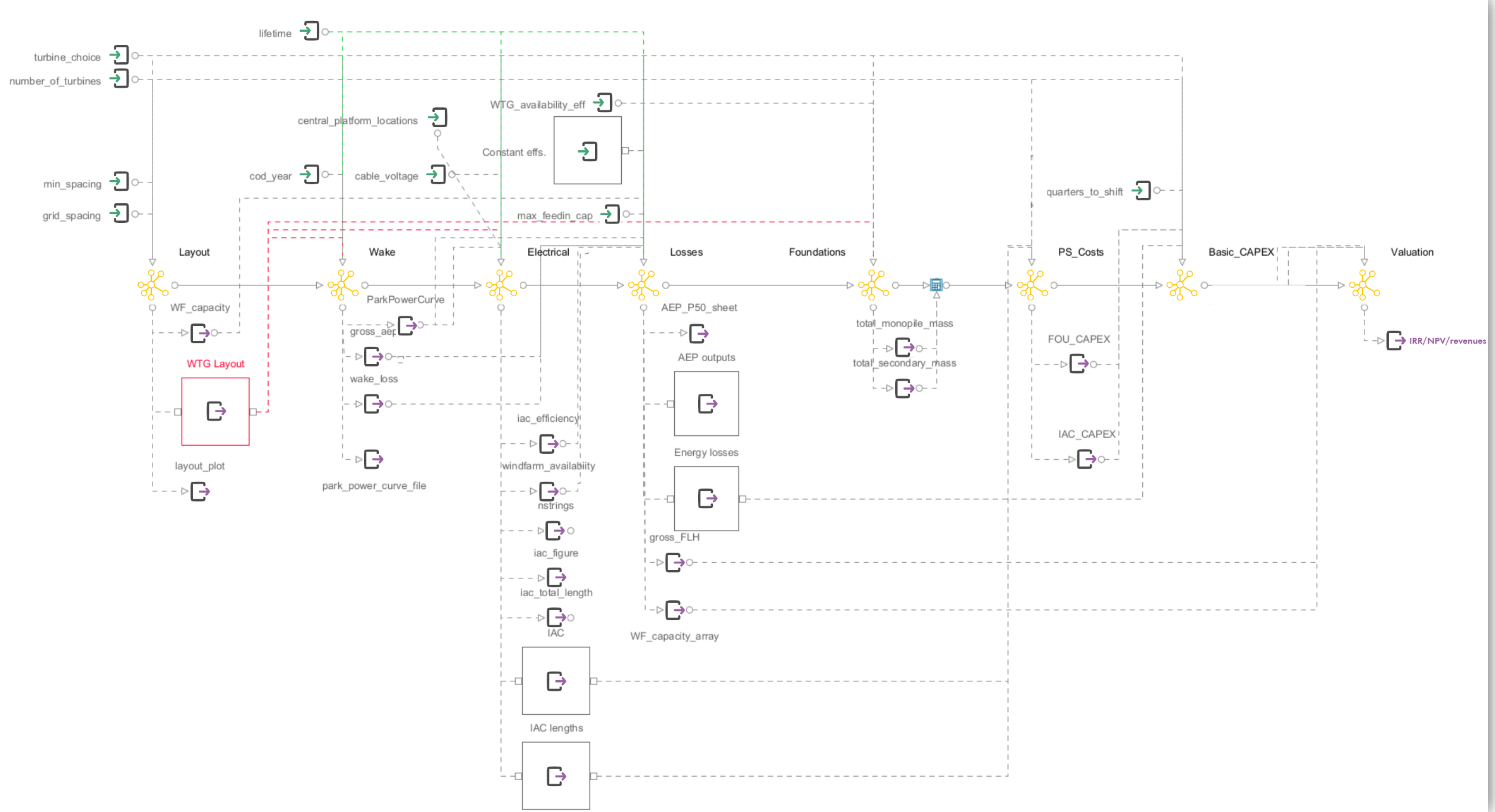
P.J. Stanley and Sebastian Sanchez Perez-Moreno



One MDAO framework to solve many trade-offs e.g.:

- Installation: duration vs costs vs preservation vs early revenues vs late cash out
- Layout: Energy yield vs costs
- Lifetime: revenue vs O&M + CAPEX
- WTG: Costs (incl. foundations) vs yield
- Installed capacity: costs vs yield (incl. curtailment losses)
- Electrical system: revenue losses vs CAPEX + OPEX

LCOE, IRR, NPV,
and other metrics to optimise



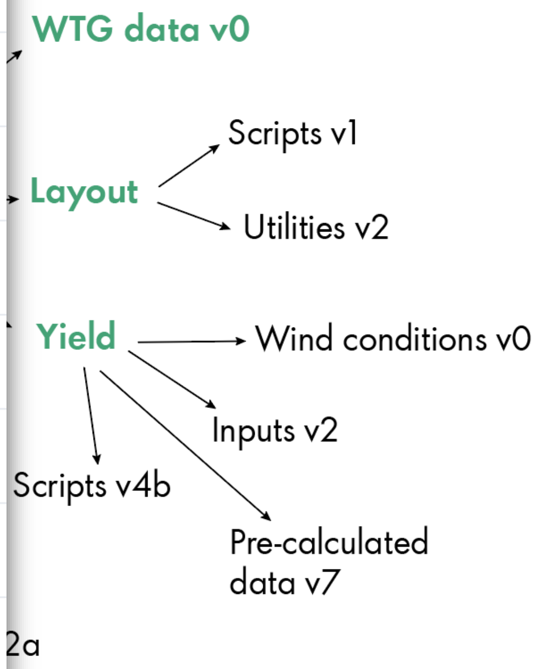
lifetime
turbine_choice
number_of_turbines
WTG_availability_eff
central_platform_locations
Constant effs.
min_spacing
cod_year
cable_voltage
quarters_to_shift
grid_spacing
max_feedin_cap
Layout
Wake
Electrical
Losses
Foundations
PS_Costs
Basic_CAPEX
Valuation
WF_capacity
ParkPowerCurve
AEP_P50_sheet
total_monopile_mass
gross_aep
AEP outputs
FOU_CAPEX
IRR/NPV/revenues
total_secondary_mass
WTG Layout
wake_loss
iac_efficiency
IAC_CAPEX
Energy losses
layout_plot
windfarm_availability
park_power_curve_file
nstrings
gross_FLH
iac_figure
iac_total_length
IAC
WF_capacity_array
IAC lengths

Front end – Dem

- Web-based
- Trigger design studie
  - Driver/DOE
  - System scope
  - Assumptions
  - Data
  - Design variables
- Traceability:
  - Which tools, data,
    what results
  - Database of mode
  - Tool version contr
- Data visualisation
  - Interactive charts
  - Share dashboards

NAME	TYPE	VALUE	LOWER BOUND	UPPER BOUND	STEP
WTG availability (-)	P	0.94	0	1	0
WTG transformer efficiency (-)	P	0.995	0	1	0
IAC voltage (kV)	P	66	33	132	33
COD Year (Year)	V		2030	2033	1
Grid spacing (Rotor Diameters)	P		0.95	1.05	0
Operational lifetime (Years)	P		15	35	1
Maximum grid capacity (MW)	P	1500	1000	1500	0
Minimum spacing (Rotor Diameters)	P	3	2.85	3.15	0
Number of turbines (-)	V		63	115	1
Onshore and offshore transfor... (-)	P	0.99	0	1	0
Quarters to shift FID (-)	P	0	0	20	1
Turbine model	V		0	2	1
Wind farm consumption efficie... (-)	P	0.9993	0	1	0

Continuous
Discrete Ordered
Discrete Unordered
Constant

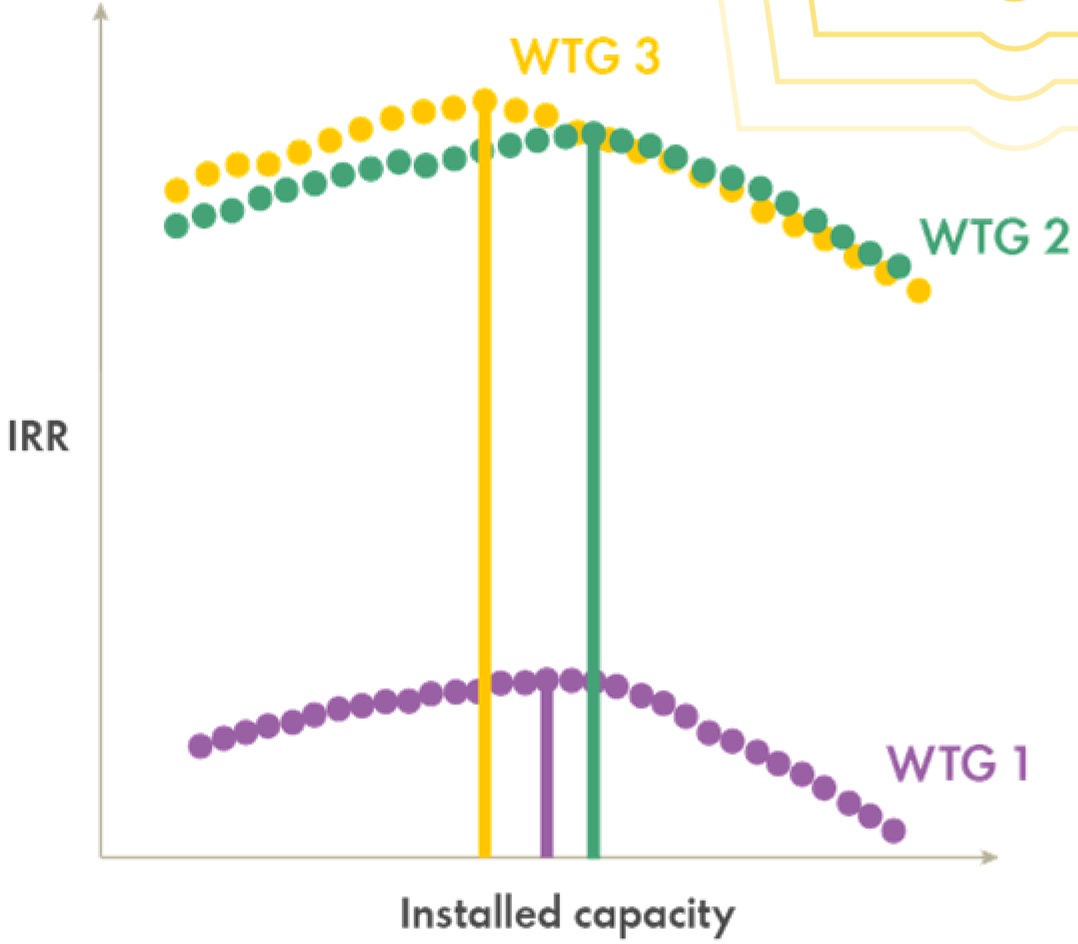


Manual work: weeks (and less scenarios)

- Mid/high fidelity: 10 minutes per scenario
- Mid/low-fidelity: 3 minutes per scenario
- Surrogate models: sub-second per scenario

Optimise under uncertainty

- Find optimum for many what-if scenarios (cost assumptions, external constraints, etc.)



SUDOCO: Loads surrogate model for yaw-misaligned operation

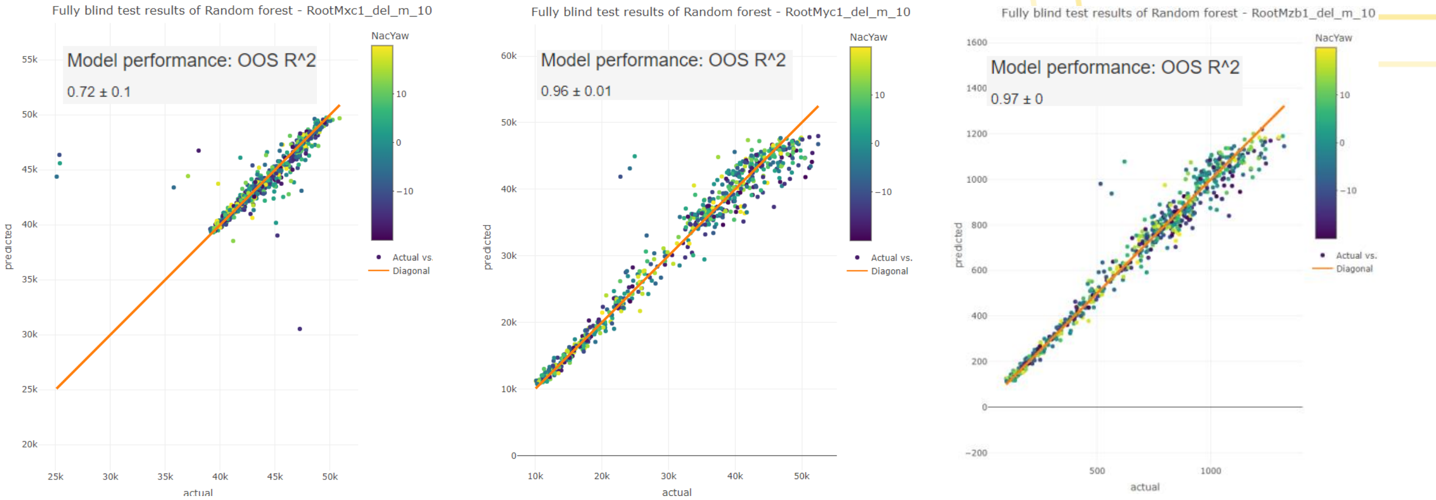
Kelsey Shaler

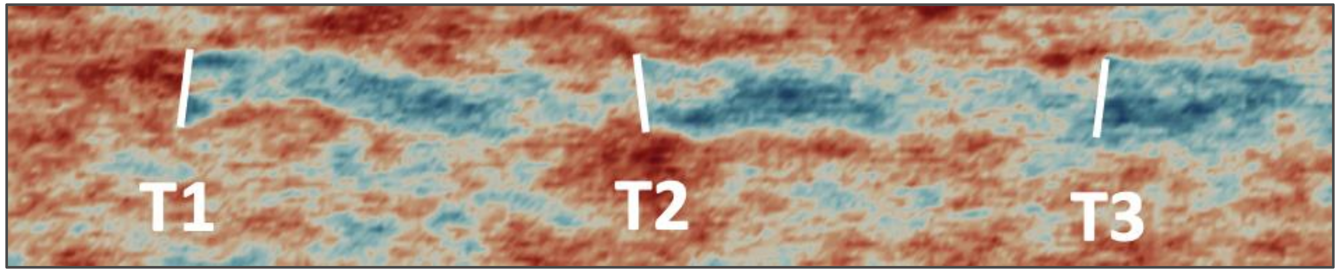
Simulation set-up

- IEA 22-MW reference turbine
- Synthetic turbulence w/ Kaimal Spectrum
- 10-minute simulations
- 12 seeds per simulation
- 500 inflow conditions, 6.000 FAST.Farm simulations of a 3-turbine array, netting 18.000 unique rotor timeseries.

Quantity of Interest	Components	
Generator power	N/A	
Rotor speed	N/A	
Rotor torque	N/A	
Rotor thrust	N/A	
Blade Pitch	N/A	
Blade-root moments	**Total bending**	**Pitching**
Low-speed shaft moments	**Total bending**	
Tower-top moments	**Total bending**	**Yaw**
Tower-base moments	**Total bending**	**Yaw**

Preliminary results





For details on surrogate generation process, see following publication: https://www.nrel.gov/docs/fy22osti/82524.pdf

DELs to estimate turbine health and component degradation.

Maximize profit through operations: Value Optimization

Erika Echavarria

Maximizing profit: maximizing value at low cost

$$LCOE = \frac{CapEx \, * FCR \, - OpEx}{AEP}$$

- Increase AEP
- Reduce CapEx & OpEx

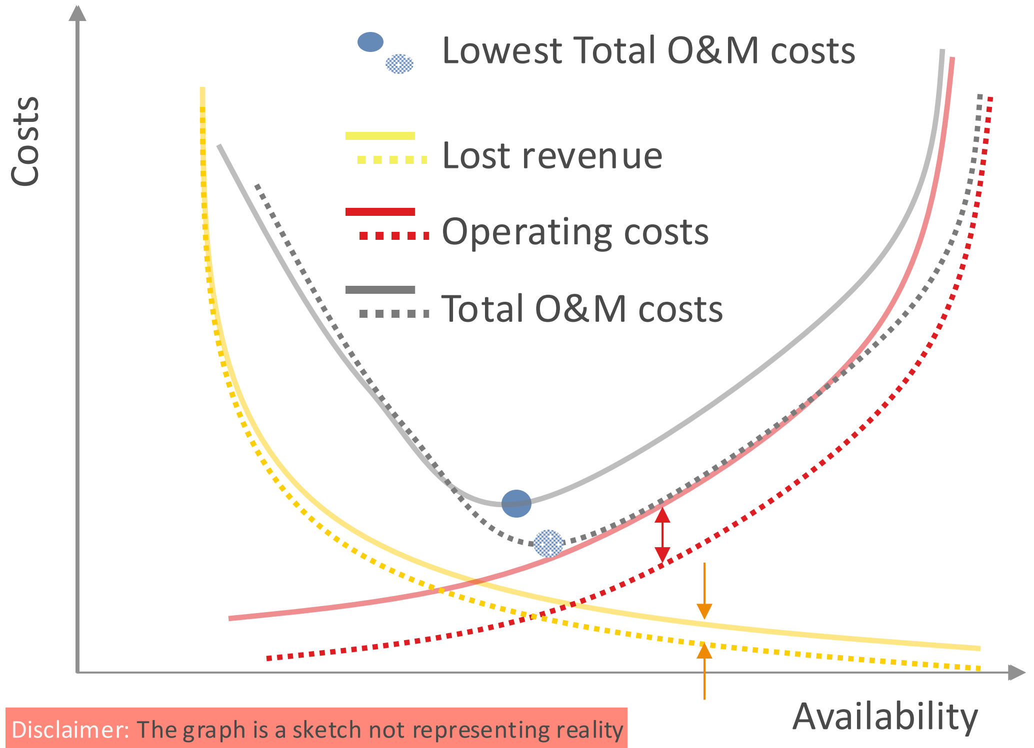
Strategies

Energy Price vs Cost of Energy (incl. opportunity costs):

- Contracting (strategy, make the vision concrete)
- Forecasting (wind, production, electricity price)
- Asset integrity (Predictive Maintenance, Digital Twin)
- Digitalization (Visualization, access to information)
- Technology (means of lowering the curves)

Reduce LCOE through O&M:

- Bring the curve down of total O&M costs.
- Find the optimal trade-off between lost revenue and the cost of reaching availability.



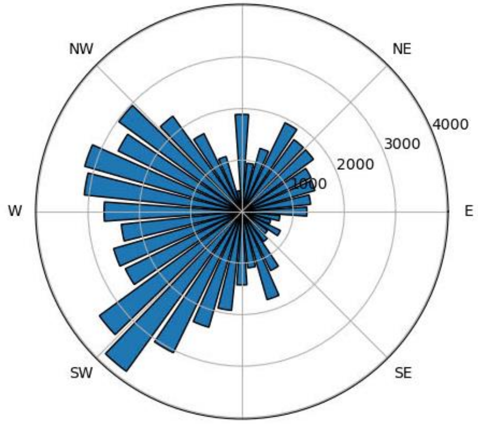
Disclaimer: The graph is a sketch not representing reality or using actual numbers to calculate it.

PJ

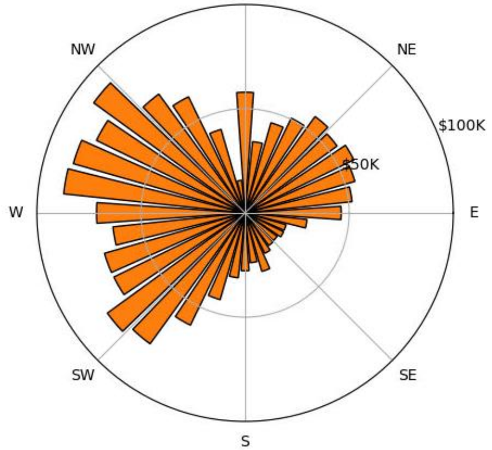
Revenue-based layout/wind farm design

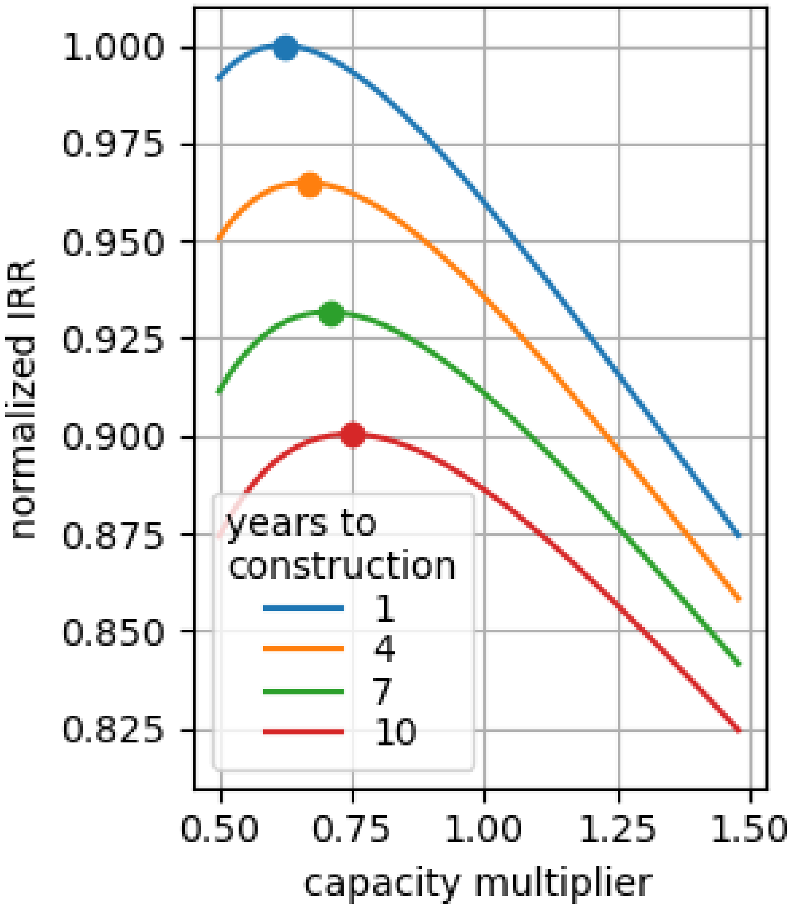
P.J. Stanley

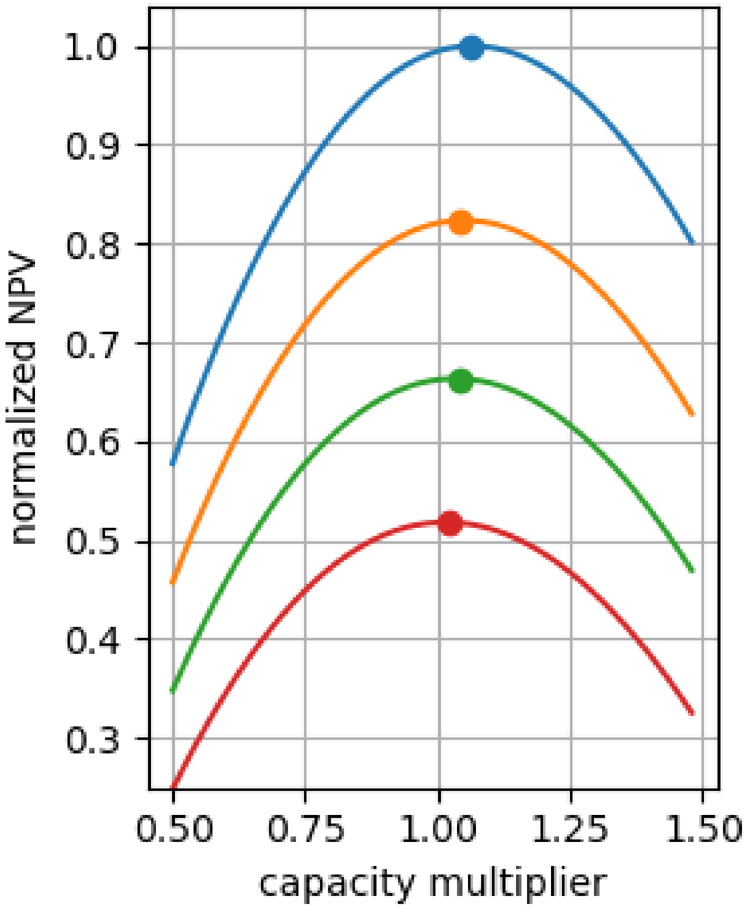
Directional energy potential



Directional revenue potential







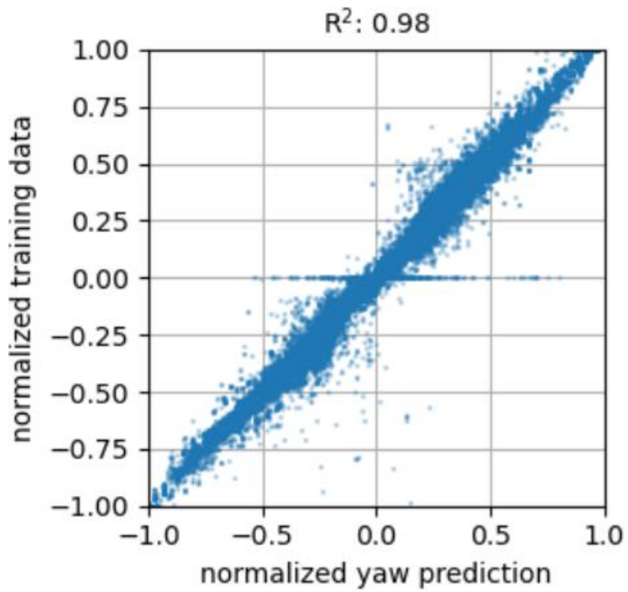
doi:10.1088/1742-6596/2767/8/082011

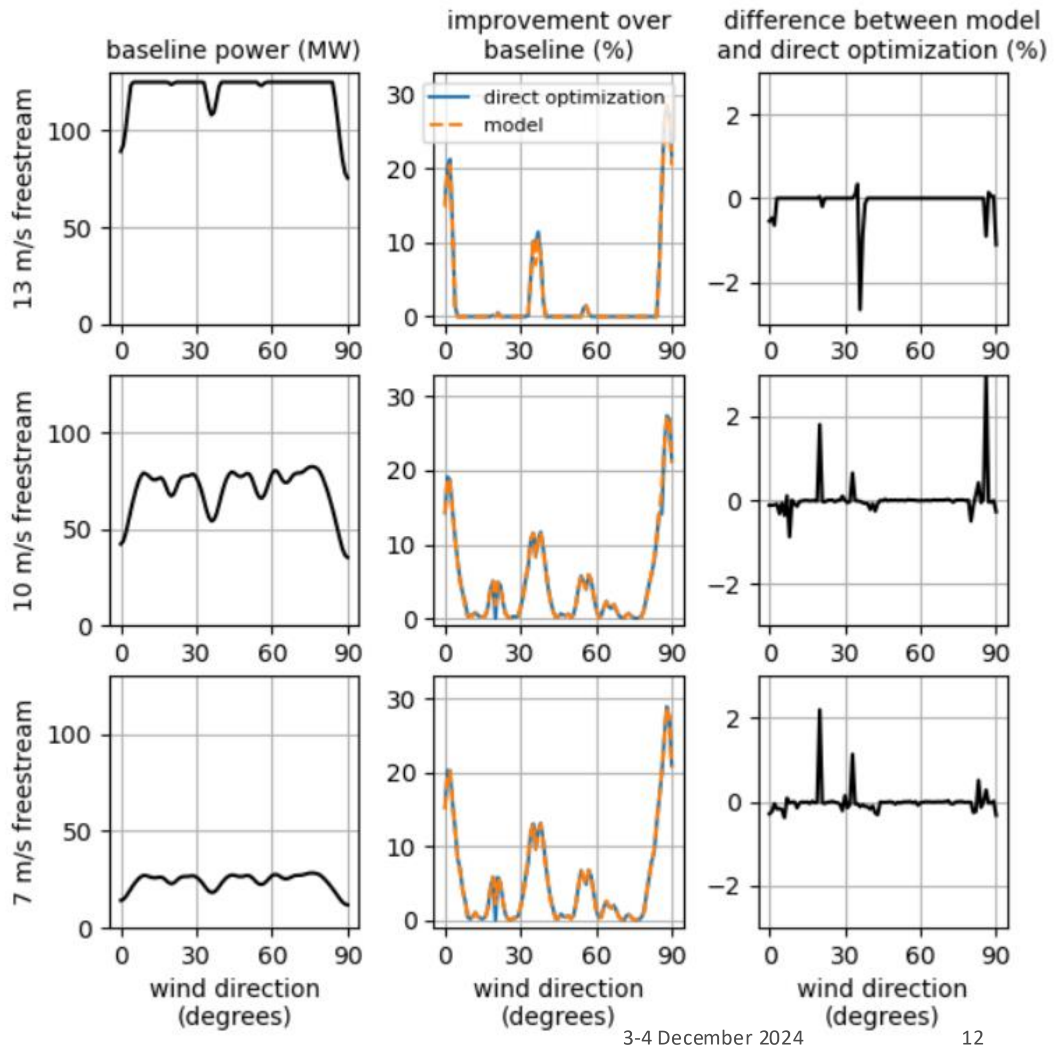
Enabling layout optimization with yaw control co-design

P.J. Stanley

Machine learning to rapidly predict turbine yaw angles for wake steering

Andrew P. J. Stanley, Tim Mulder, Bart Doekemeijer, and Jasper Kreeft





Q&A

Thank you!

System Development: Start Integrated to Stay Integrated