OFFSHORE WIND ENERGY DEVELOPMENT IN THE ADRIATIC SEA: THE P.O.W.E.R.E.D. PROJECT AS PLANNING POLICY

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Wind resource, energy and uncertainty

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Organization:
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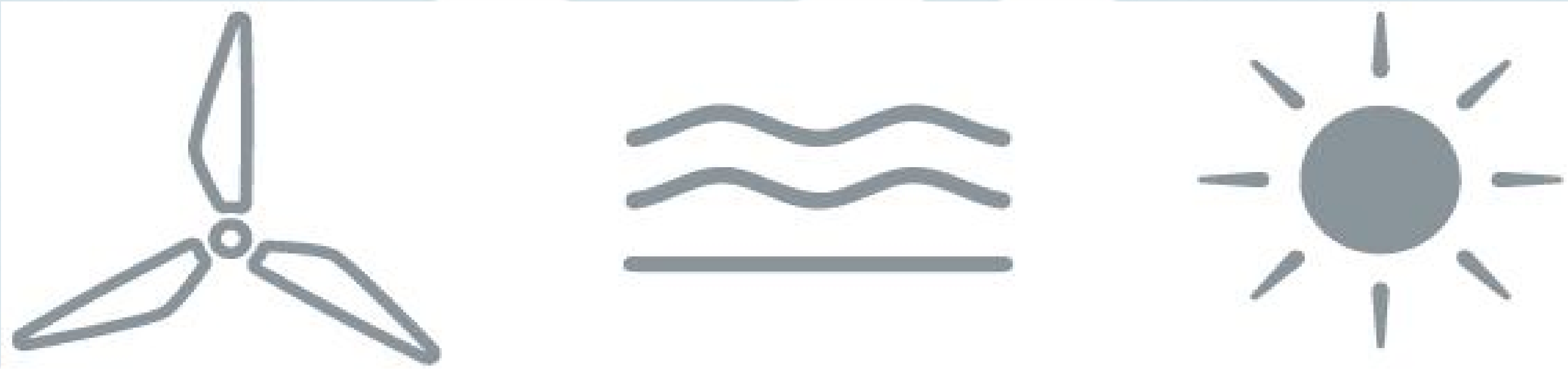
GL Garrad Hassan: experts in renewable energy



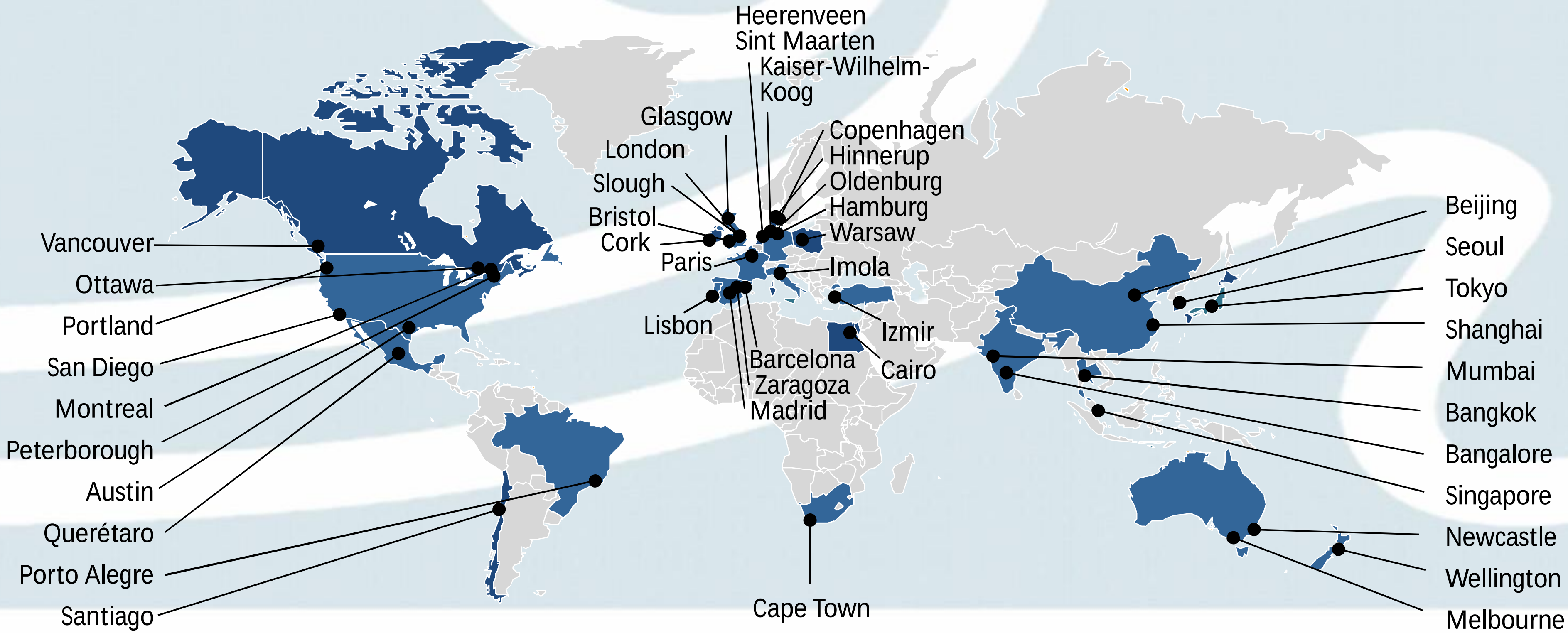
Onshore & Offshore Wind

Wave & Tidal

Solar PV & CSP

LOCAL UNDERSTANDING FORMS A GLOBAL PERSPECTIVE

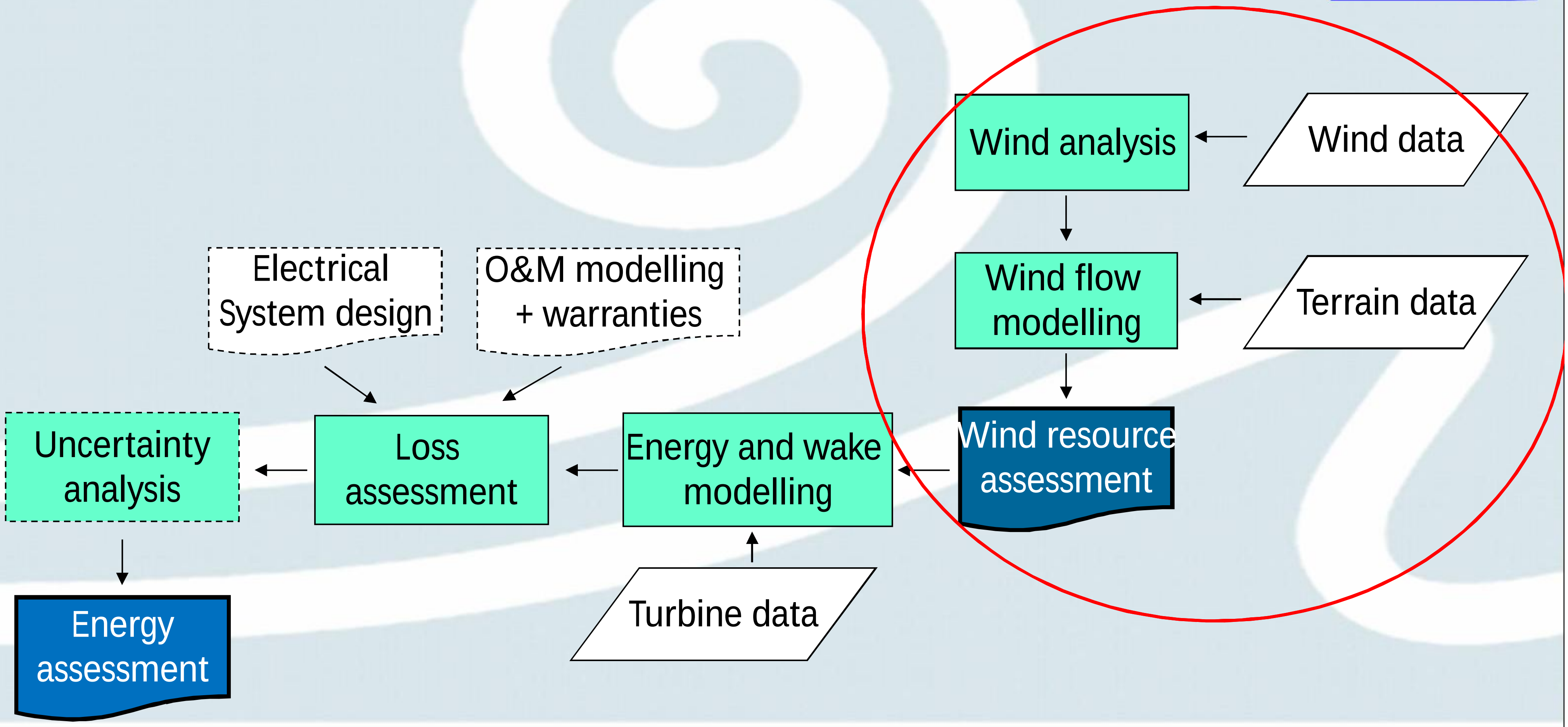
Approximately 1000 staff, in 44 locations, across 26 countries



PROVIDING LIFECYCLE SUPPORT TO ALL STAKEHOLDERS

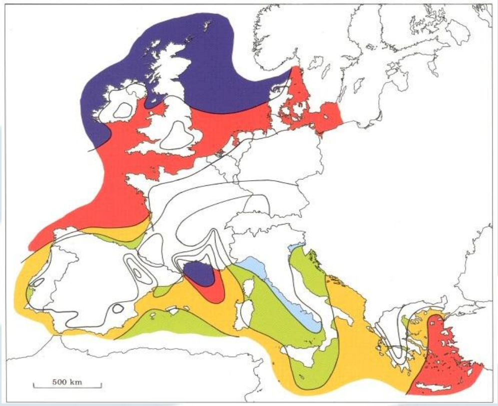
- Project Developers
- Owners and Operators
- Investors
- Manufacturers
- Governments and NGOs

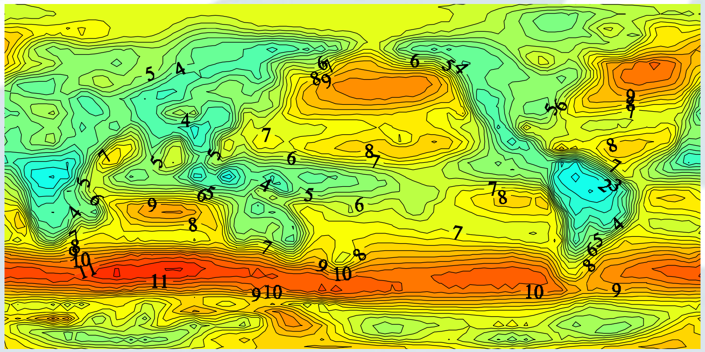
WIND RESOURCE, ENERGY AND UNCERTAINTY: PROCESS OVERVIEW



WIND RESOURCE

1. Published Studies
2. Re-analysis data
3. Coastal meteorological stations
4. Offshore meteorological stations
5. Offshore masts





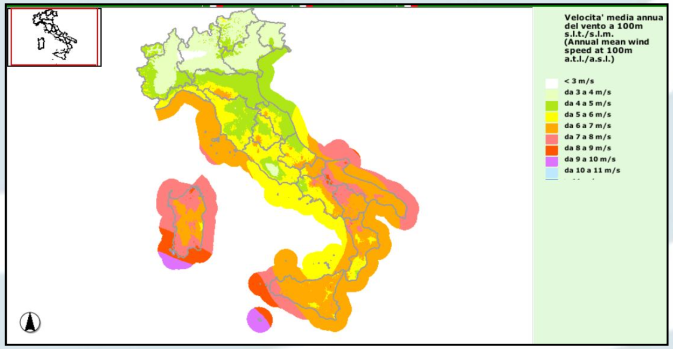
WIND DATA: PUBLISHED STUDIES

1. Risø – European Wind Atlas

http://www.windatlas.dk/europe/oceanmap.html

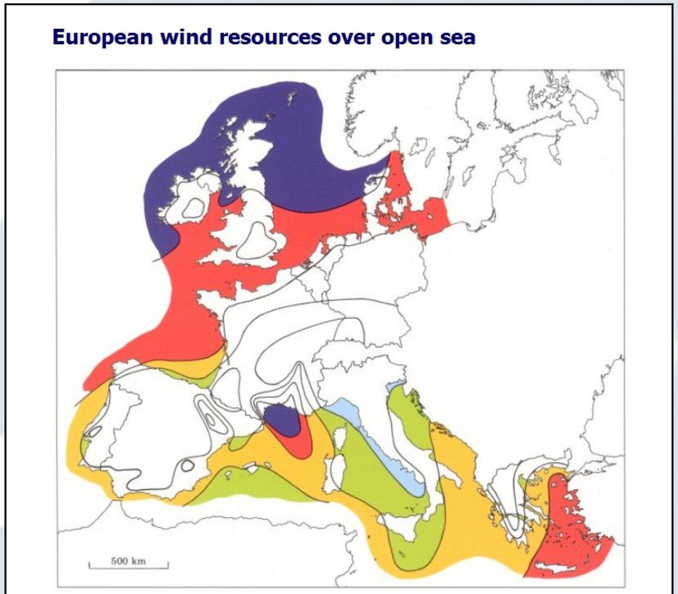
2. RSE - Interactive Wind Atlas

http://atlanteeolico.rse-web.it/viewer.htm



- ✓ Quick, cheap and easy
- ✓ Wide spatial coverage

- × Limited accuracy
- × Low resolution



Wind resources over open sea (more than 10 km offshore) for five standard heights

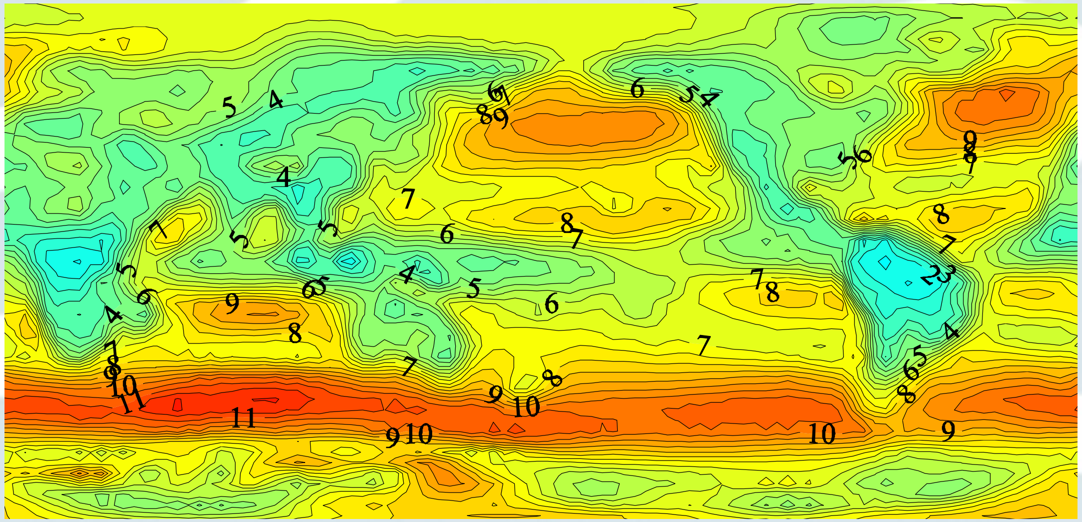
	10 m		25 m		50 m		100 m		200 m	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

WIND DATA: RE-ANALYSIS

1. Derived from a massive range of meteorological measurements
2. Input data used to run hind cast model and assimilated onto a grid
3. Up to 50 years of time series data available

✓ Freely available
✓ Covers whole globe

× Limited accuracy
× Low resolution



WIND DATA: OFFSHORE MEASUREMENTS

Anemometry installed offshore, near the site

e.g. Oil/gas installations, offshore met stations, neighbouring site mast

- ✓ Real (traceable) measurements
- ✓ Offshore environment

× × Distortion by platform structure

WIND DATA: OFFSHORE MEASUREMENTS

1. Buoy-mounted cup anemometry at 10m ASL
2. Mass ≈ 4 tonnes
3. Available on lease basis

- ✓ Onsite measurements
- ✓ Cheaper than mast

- × Vertical extrapolation still required
- × Significant cost

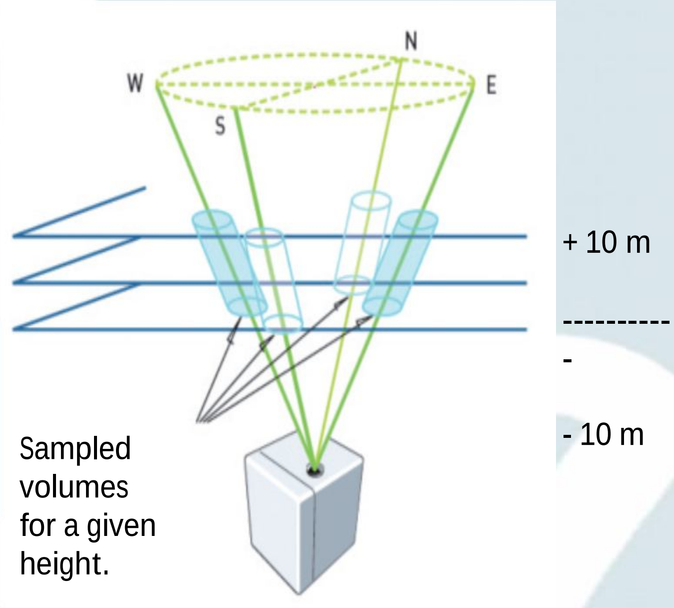
WIND DATA: REMOTE SENSING BY LIDAR

(Light Detection And Ranging)

1. Measurements at up to 200 m height
2. Usually based on fixed platforms;
3. New options for floating LIDAR

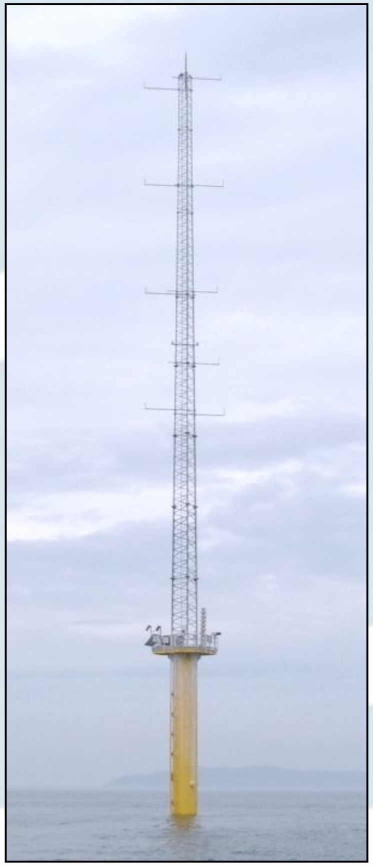
✓ Cost (if deployed on existing structure)
✓ Measurement of wind shear

× Sensitivity to meteorological phenomena
× High power consumption (~200W)
× Not industry standard (yet)
× Validation campaign required
× Lack of redundancy



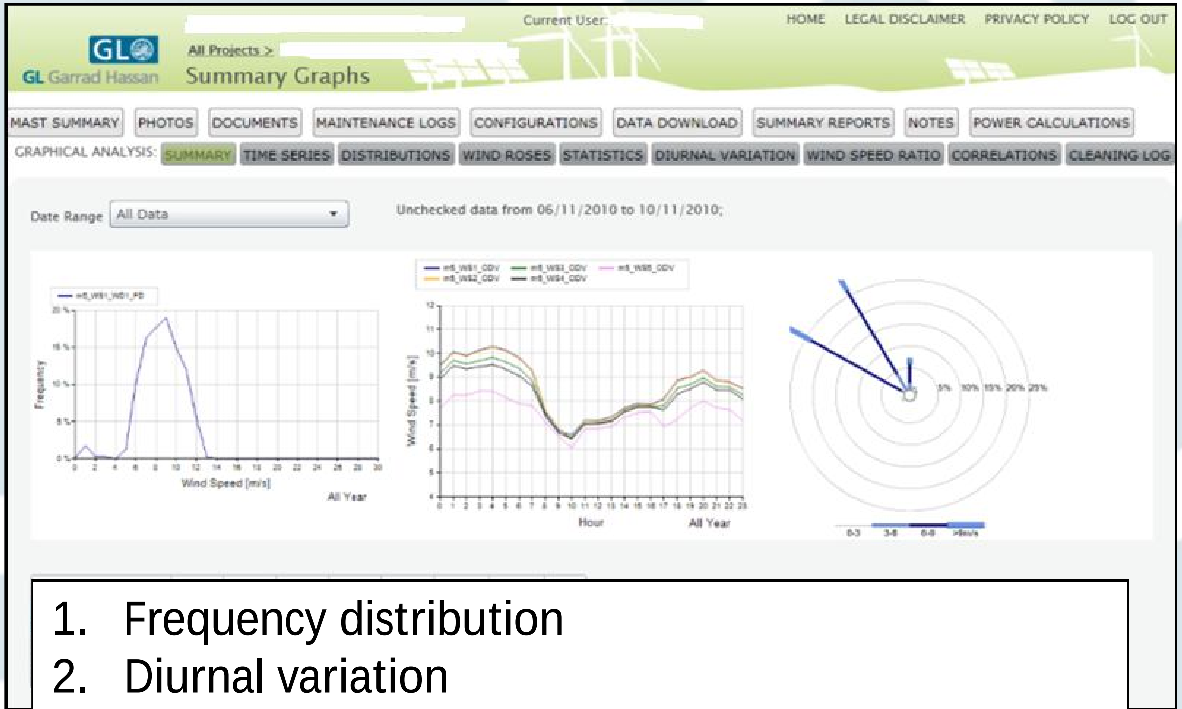
WIND DATA: ONSITE MAST

1. Typical arrangement: lattice tower mounted on steel monopile
2. High quality instrumentation
3. Redundancy in measurements
4. At least 12 months



- ✓ Onsite measurements
- ✓ Best accuracy
- ✓ Reduced reliance on models
- × High cost

WIND MONITORING AND DATA PROCESSING



1. Frequency distribution
2. Diurnal variation
3. Wind rose

1. Compile wind speed / direction statistics
2. Correlate with long term reference data
3. Long term wind regime
4. Wind speed and direction frequency distribution at the mast

WIND FLOW MODELLING

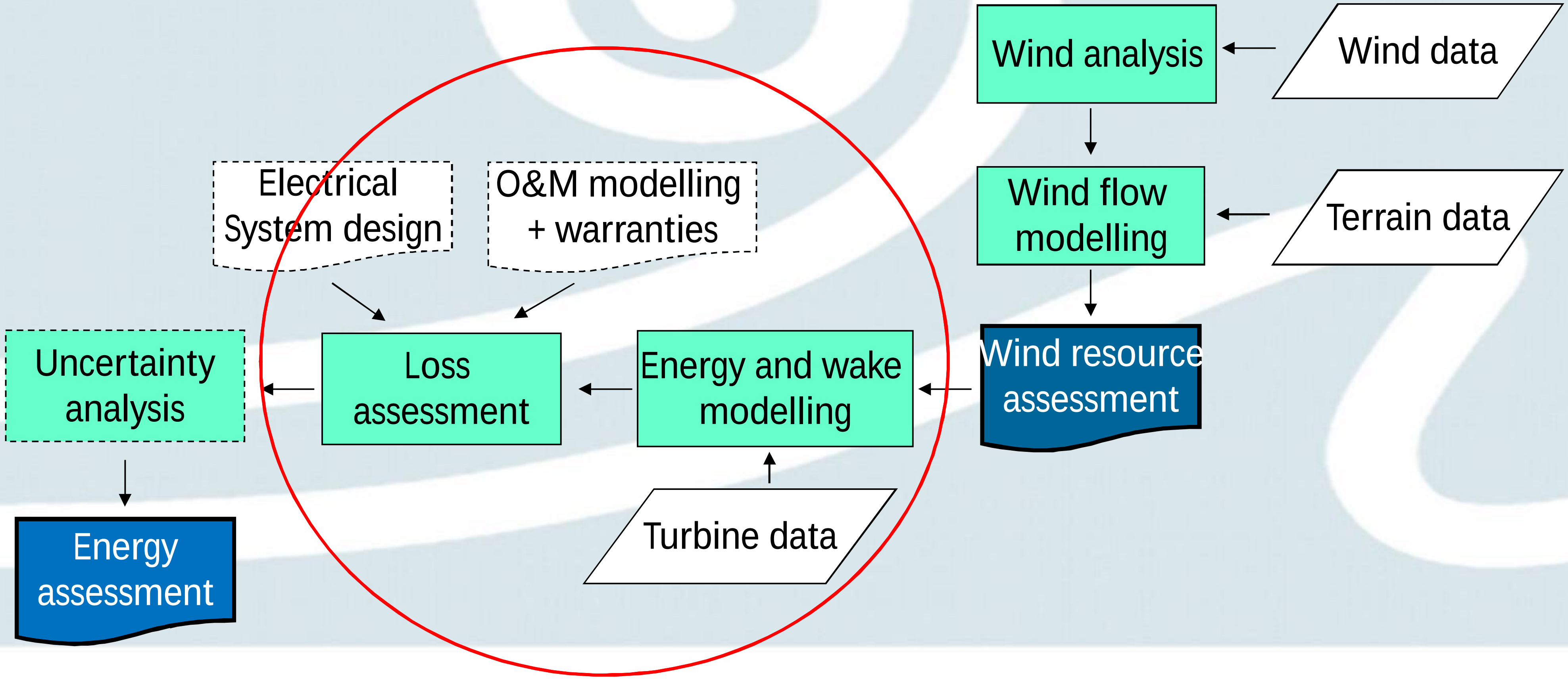
1. Input
- Wind speed and direction frequency distribution at mast
- Location and roughness areas of land

2. Options
- Area of interest
- Height (hub height of turbines)
- Resolution

3. Tools
- WAsP = Wind Atlas Analysis & Application Program
- CFD models

4. Outputs
- Wind speed and direction frequency distribution at hub height over project

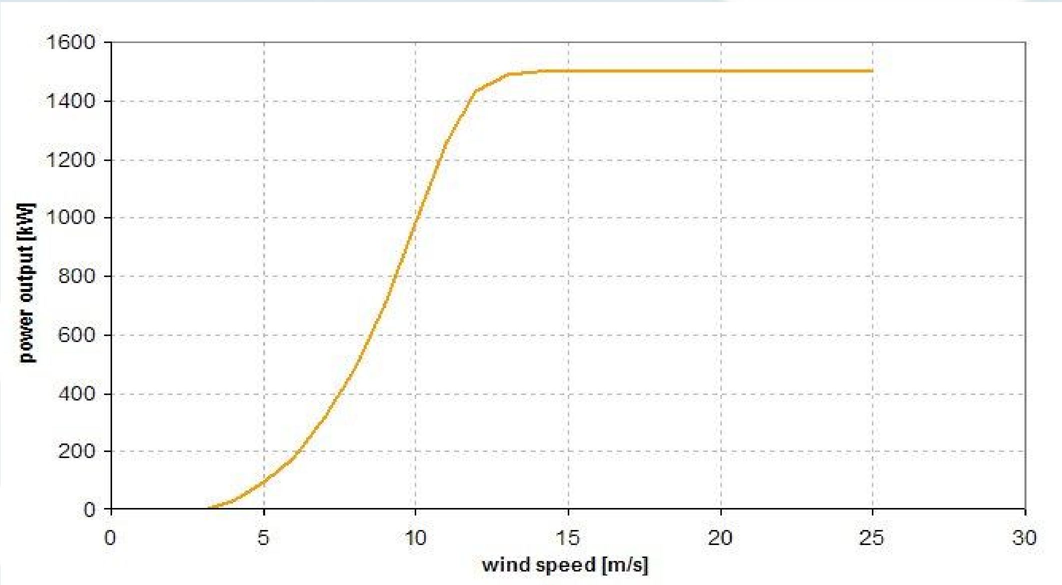
WIND RESOURCE, ENERGY AND UNCERTAINTY: PROCESS OVERVIEW



ENERGY PRODUCTION

For a single turbine

Ideal annual output = ΣΣ { Power curve (U) x Wind probability (U,Θ)}



	5.8	3.8	4.8	4.8	6.9	6.8	9.3	11.9	11.9	11.
1	4	17	16	29	18	23	10	8	9	7
2	27	24	31	46	26	31	25	13	18	17
3	39	51	59	60	57	43	45	27	36	33
4	55	75	52	58	68	64	58	43	38	41
5	82	91	72	61	71	66	57	49	61	49
6	90	88	56	78	79	72	68	53	64	59
7	92	111	80	91	75	106	75	67	78	76
8	77	88	71	83	76	88	85	75	68	84
9	93	72	87	62	63	60	72	64	66	64
10	75	67	99	78	69	70	70	65	80	80
11	63	65	86	65	46	60	61	67	64	65
12	56	55	64	60	61	61	61	77	73	75
13	42	51	58	46	35	49	49	77	57	57
14	38	52	42	50	52	50	46	52	61	63
15	27	36	40	26	40	34	40	52	46	43
16	30	17	27	24	26	21	35	35	41	35
17	26	16	20	27	26	28	23	31	35	35
18	18	10	15	16	35	20	26	38	27	26
19	16	4	6	11	20	15	22	23	20	15
20	16	0	2	10	15	10	19	17	16	16
21	11	2	6	6	16	11	9	16	9	16
22	7	4	3	6	10	6	11	12	10	9
23	7	0	5	1	6	3	9	6	6	14
24	2	4	3	5	4	3	4	9	6	10
25	1	1	0	0	1	3	4	5	4	5
26	3	0	1	0	1	1	6	8	0	1

But there are important losses... $E_{farm} = E_o \cdot \eta_{topo} \cdot \eta_{array} \cdot \eta_{elec} \cdot \eta_{avail} \cdot \eta_{other}$

ENERGY PREDICTION – OVERALL NET YIELD

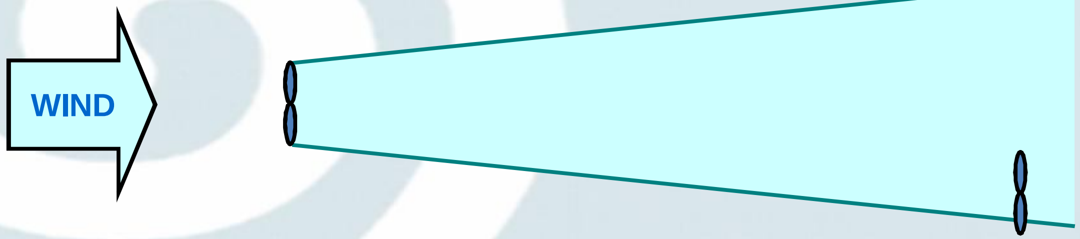
Major losses to be considered

1. Wakes: internal and external
2. Electrical system losses
3. Availability

And more minor losses

1. Environmental
2. Utility downtime

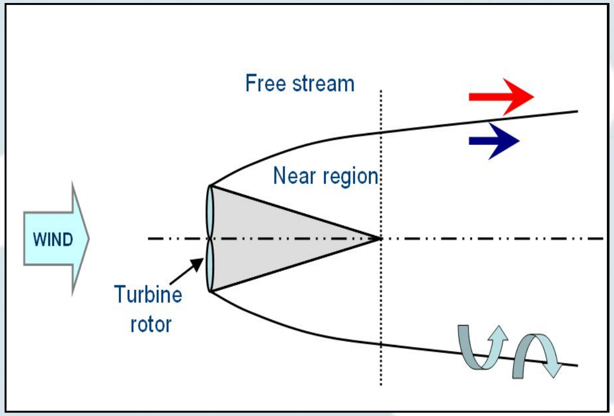
WAKES IN OFFSHORE WIND FARMS



1. Wake effects cause
   - Reduced wind speeds → losses in energy production
   - Higher turbulence → increased fatigue loading

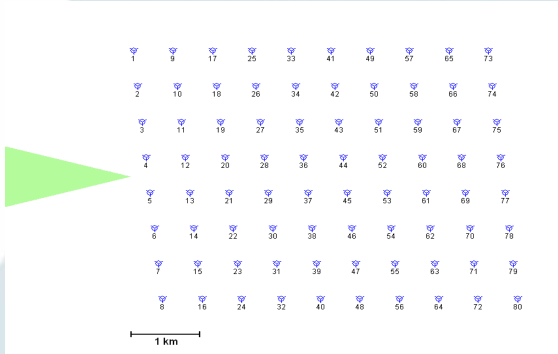
2. Offshore, wake losses are generally higher than onshore
   - Low ambient turbulence (5-10%) → slow wake recovery

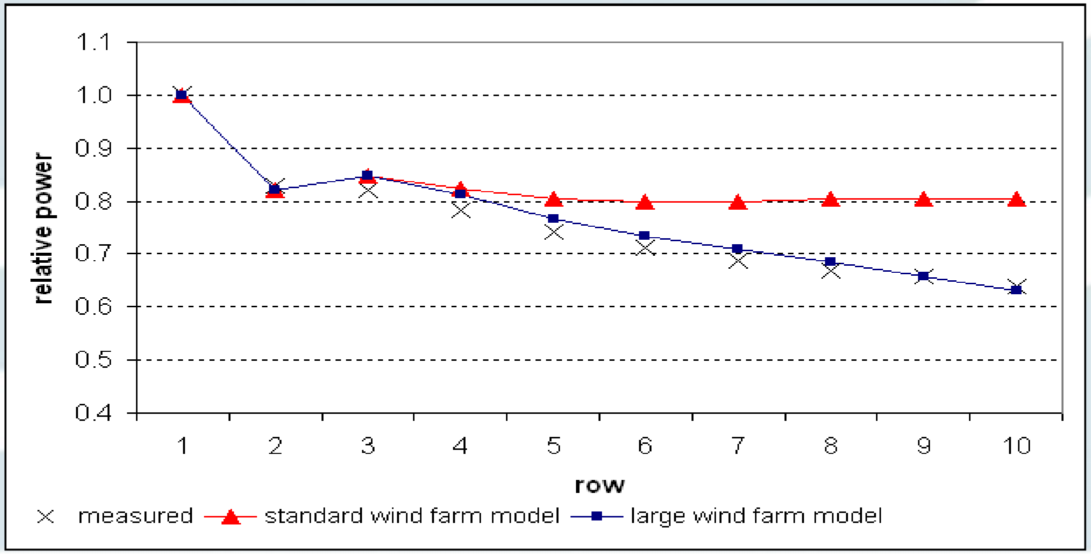
3. Established commercial wake models
   - PARK (Jensen)
   - Eddy Viscosity (Ainslie)
   - Specific off-shore models



ENERGY PREDICTION OF LARGE WIND FARMS
DEEP ARRAY EFFECTS

Standard wind and wake modelling under-predicts the array losses in very large wind farms offshore





Using GLGH WindFarmer software

Standard wake model under-predicts the array losses

Enhanced model addresses “deep array” effects

LAYOUT OPTIMISATION

1. To minimise wake effects

Maximise spacing in dominant wind direction

As large spacing as possible, but

- may have limited sea-space
- electrical cabling is more costly

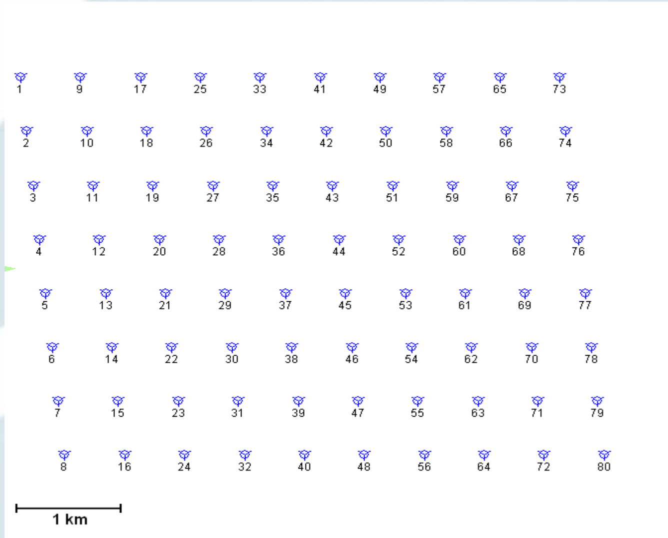
2. Regular arrays favoured initially

- Easier to plan
- Easier to navigate

But can they give minimum array effects?

3. Typically

- 7 D x 5 D in existing wind farms
- May see >10 D if more sea-space
- Minimum spacing 6 x 4 D (for fatigue reasons)



OPTIMISATION TOOLS

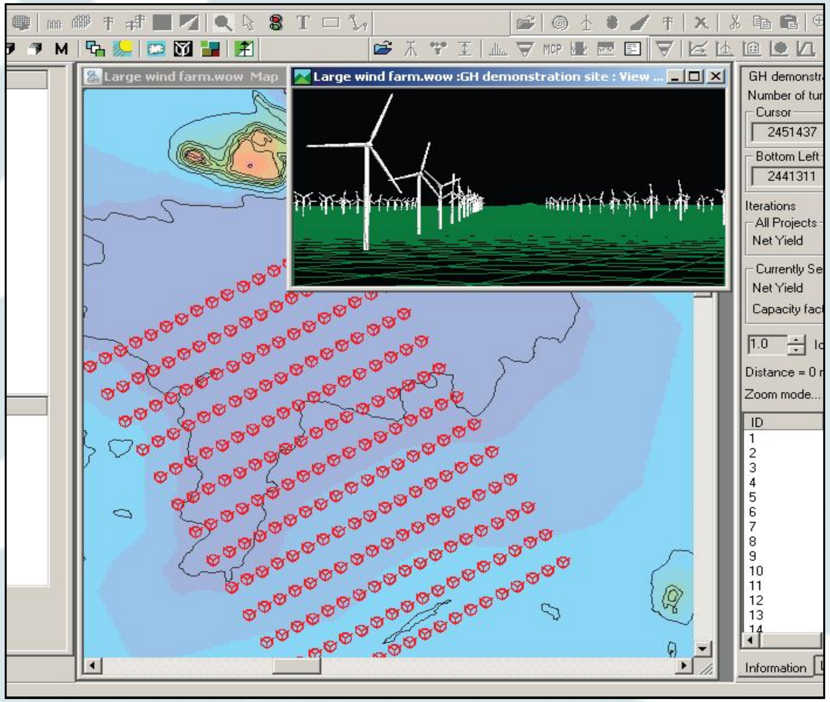
In GLGH WindFarmer

Optimiser

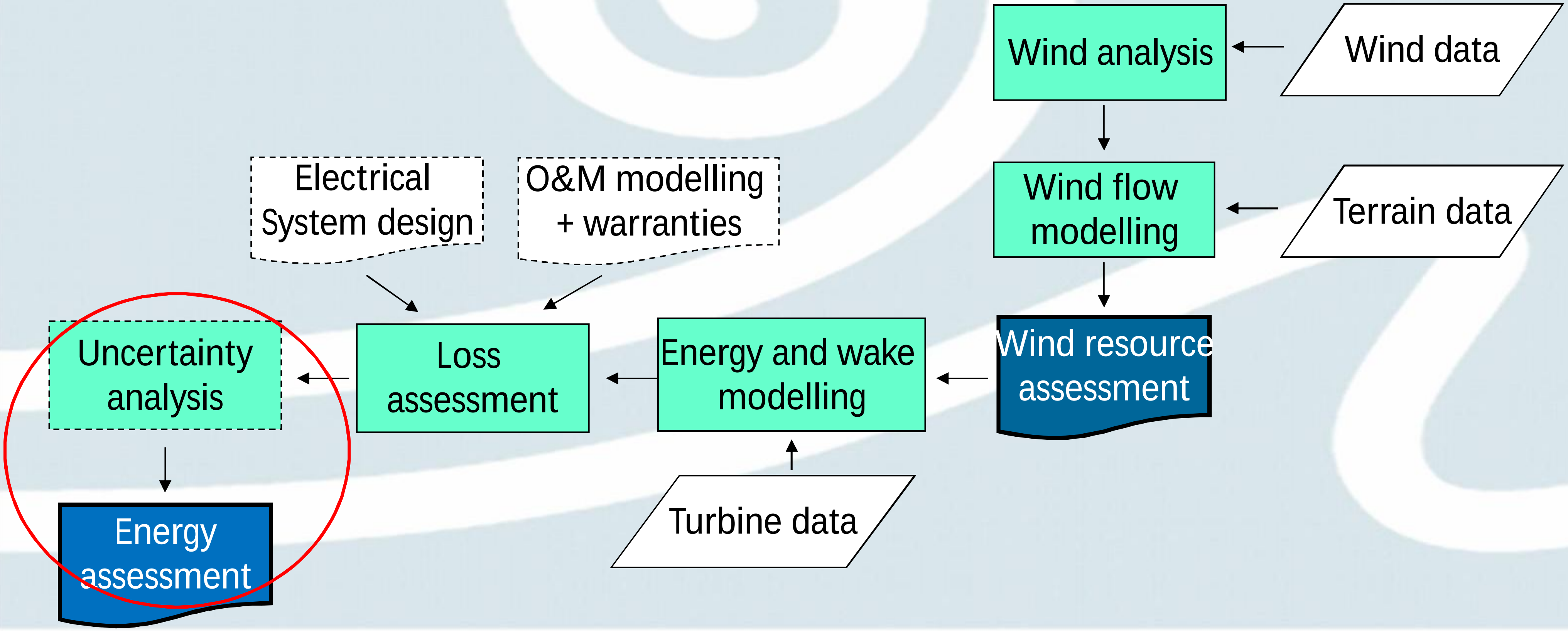
1. Maximises overall energy production
2. Takes into account
- Wind variation over site
- Wind rose
- Array effects
- Boundaries and buffer zones
3. Optional: environmental constraints

Symmetrical optimiser

1. Maximises overall energy production
2. Forces turbines to adopt symmetrical layout
3. Finds the best spacings along 2 axes
4. Finds the best orientation and angle between the axes



WIND RESOURCE, ENERGY AND UNCERTAINTY



UNCERTAINTY ANALYSIS

Annual energy production is central estimate

Sources of uncertainty:

1. Instrument accuracy;
2. Measurement period;
3. Wind data correlations;
4. Consistency of reference sources;
5. Wake modelling.

For some, the uncertainty will be calculated as the standard error, others are estimated

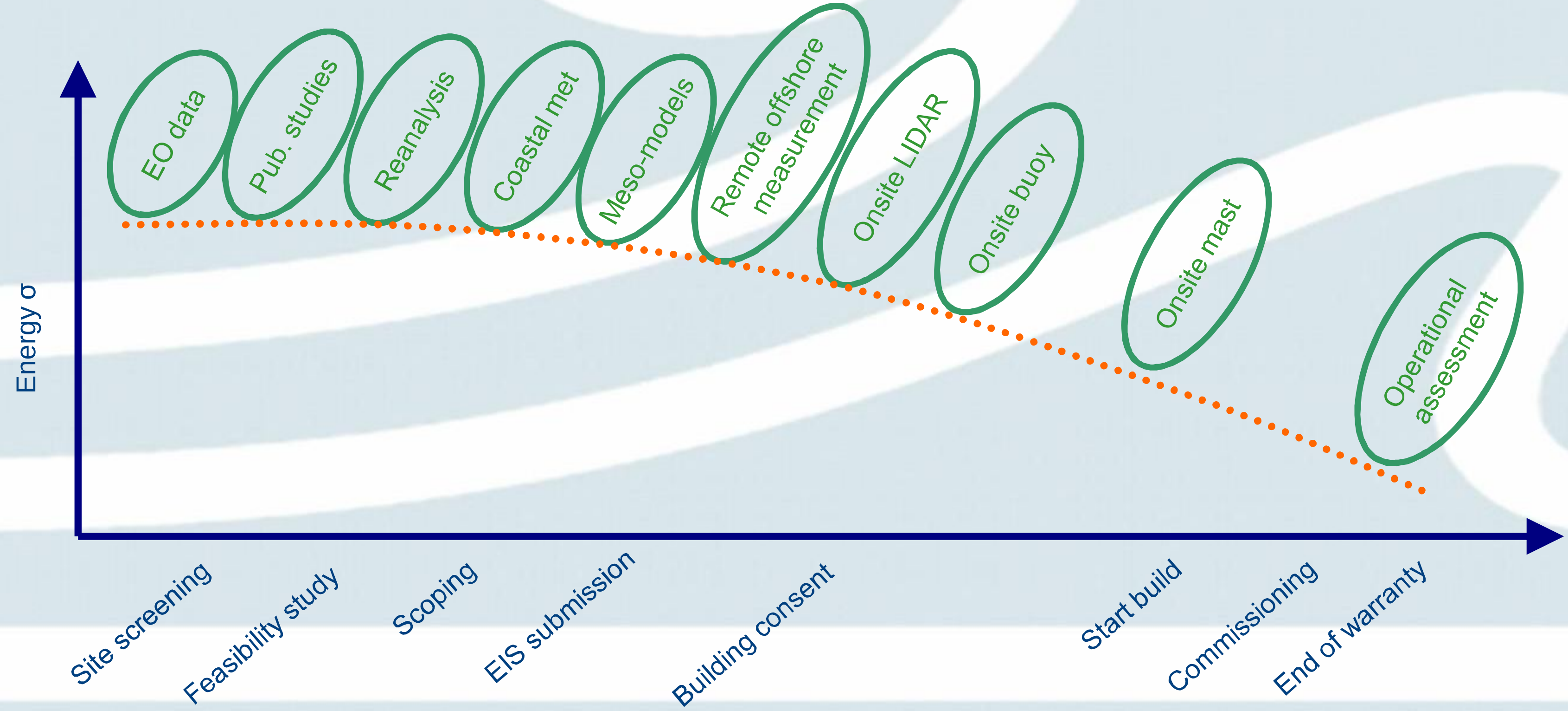
Apply energy sensitivity to convert **wind speed** uncertainties to **energy** uncertainties

Sources of uncertainty are combined assuming they are independent processes

$$S = SQRT(A^2 + B^2 + C^2 + \ldots)$$

OBJECTIVE OF WIND AND ENERGY ASSESSMENT THROUGHOUT DEVELOPMENT

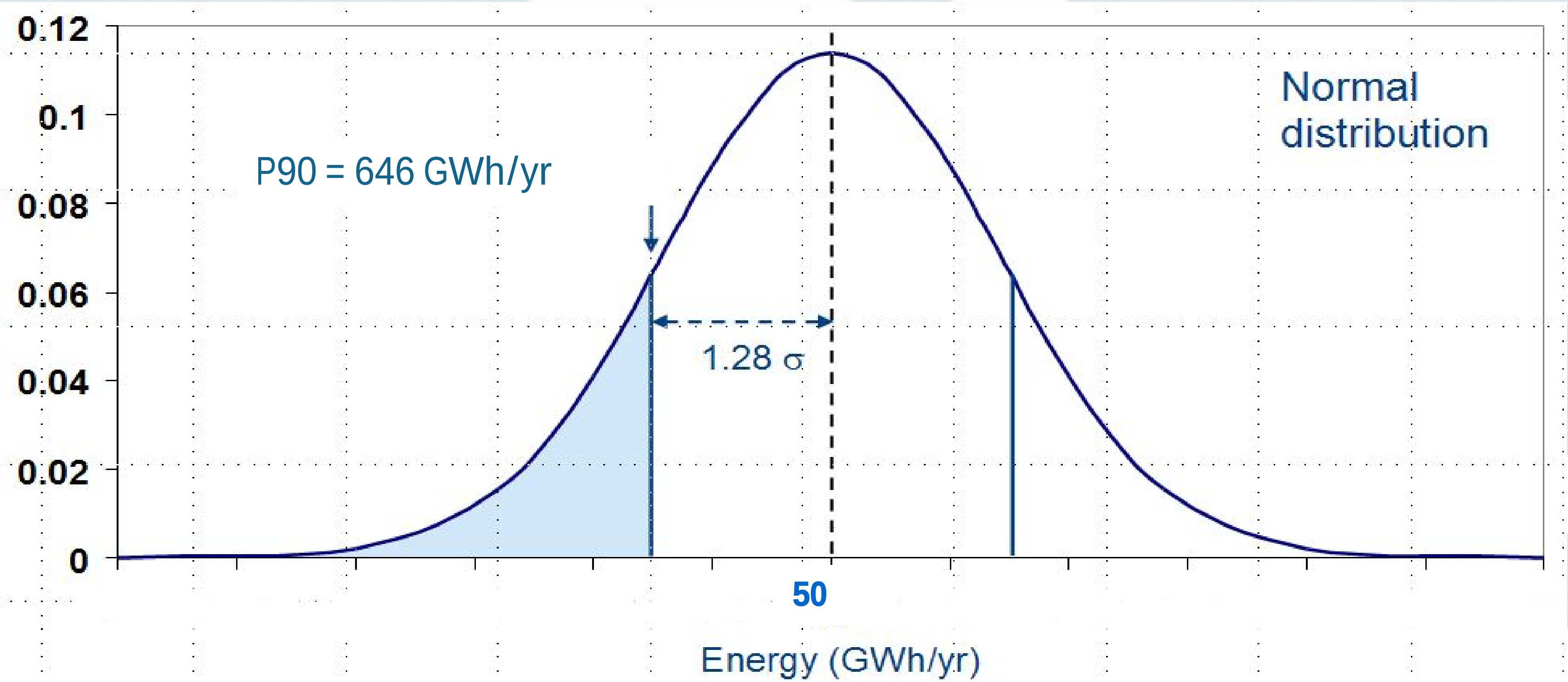
" to **reduce** energy prediction **uncertainty**...
...to an **appropriate level** at each development stage"



EXAMPLE OF UNCERTAINTY

In any one year of production, probability distribution

Mean of distribution = 800 GWh/annum
Standard deviation of distribution, **σ** = 120 GWh/annum



EXAMPLE OF CONFIDENCE LIMITS

Mean of distribution = 800 GWh/annum
Standard deviation of distribution, σ = 120 GWh/annum

P50 – Annual net energy production which has a 50% chance of being exceeded

P90 – Annual net energy production which has a 90% change of being exceeded

P90/P50 – Useful normalised value to compare uncertainty of different wind farms

Probability of exceedance, %	A = no. of σ below central	Energy GWh/yr
50	0	800.0
75	0.6745	719.0
90	1.2816	646.0
95	1.6449	603.0

CONCLUSIONS

Maximising the energy yield in the design of the wind farm:

1. Wake analysis;
2. Energy assessment;
3. Large wind farm array effects;
4. Layout optimisation;

Reducing the uncertainties in the energy prediction:

1. Wind measurement - quality monitoring and certified design equipment, best practice guidelines;
2. Long-term data set available;
3. Specific wake modelling.

THANK YOU!

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