



Meventus
Your partner in wind



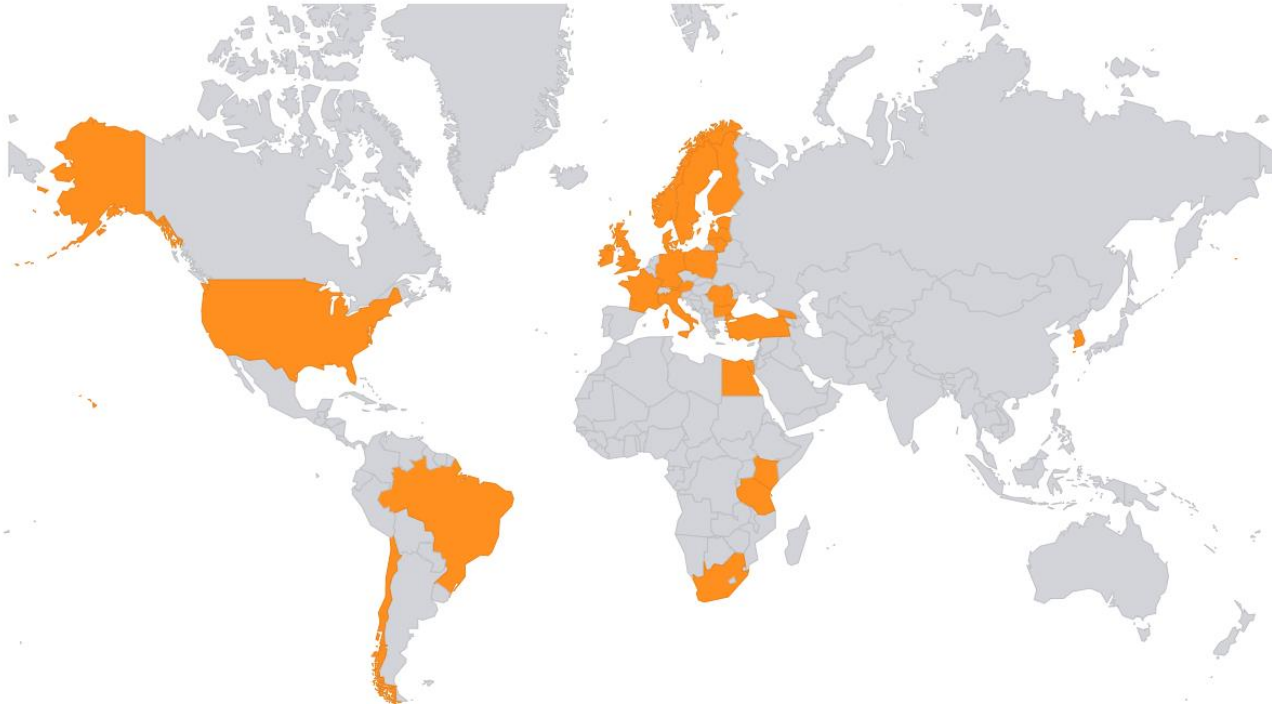
WINDSIM FLOWRES AND WINDPRO – IMPROVING EFFICIENCY
AND RESULTS

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ABOUT MEVENTUS

Our Experience Worldwide



- Offices in Norway, Sweden, Denmark
- Windsim users since 2007
- More than 110 Windsim flow models and 6,000 GW of projects assessed
- Over 3,800 MW of turbines procured

AGENDA

- Industry status - impact on analysts
- FLOWRES impact on our procedures
- Resource files vs. time based approach
- Some examples and sensitivity
- Wind/Production Index of Existing Parks in Norway

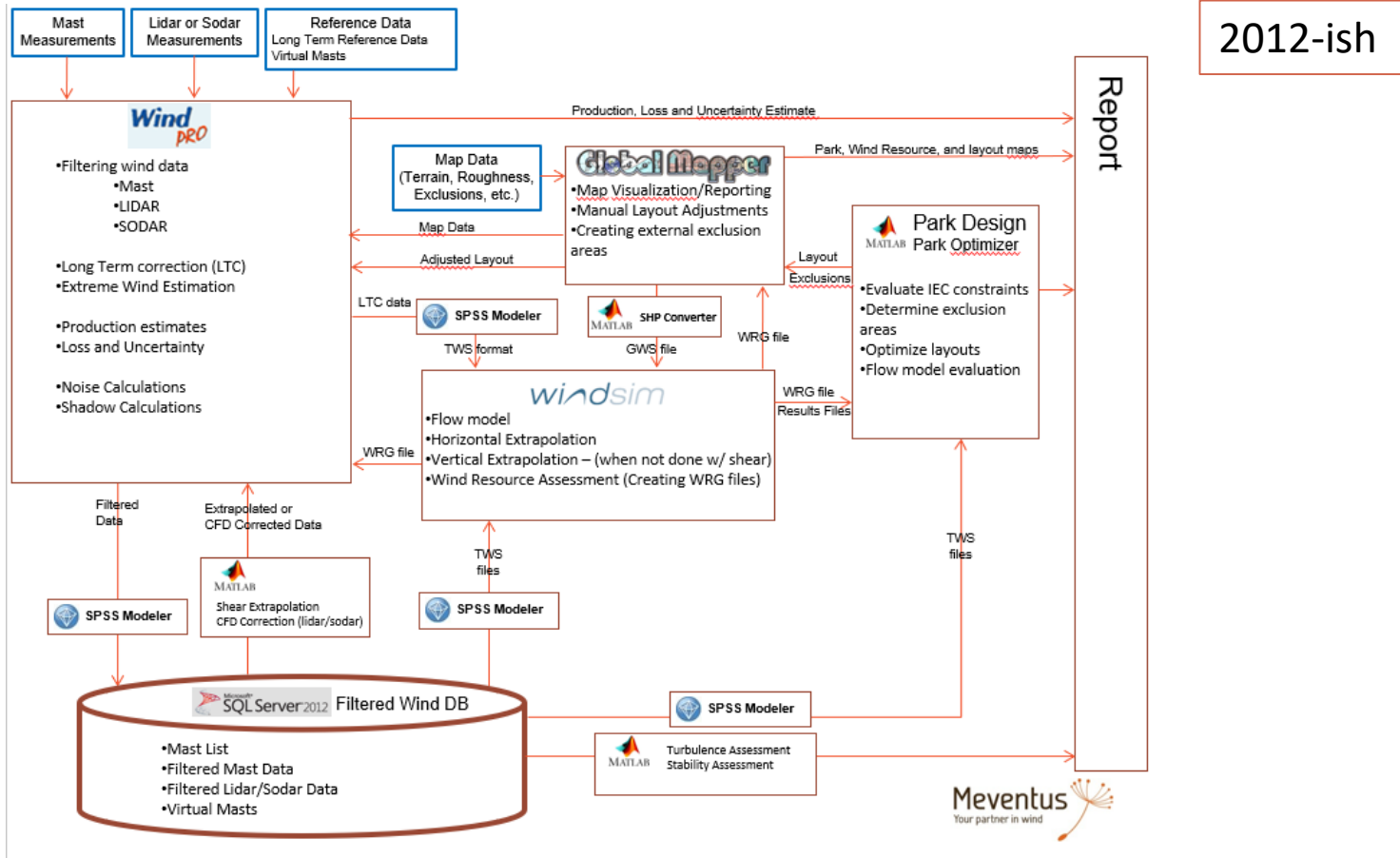
INDUSTRY STATUS – IMPACT ON ANALYSIS

- Scandinavian market is very active right now
 - Wind power is profitable now without subsidies!
 - Procurement of mature projects to reach the 2020 Green Certificate deadline
 - Greenfield activities for new projects, large interest of foreign investors
- Turbines are getting bigger
- Terrain and wind conditions at project sites are getting more complex
- Turbine manufacturers that are too conservative don't get «short-listed» in procurement processes
 - Class I site = Class II turbine with some form of curtailment
 - Wind Sector Management
 - Active control algorithms (Power Speed Adaptor(PSA), Adaptive Control Strategy (ACS))
- How do you assess a turbine suitability and potential energy yield, and impact of curtailment in the best and most efficient manner?

“ENSEMBLE APPROACH”

- Wind Industry’s favorite buzzword – “Ensemble Approach”
- Combining the best features of different software platforms and methods to achieve a desired result
- Important to keep up to date with new software features so you don’t miss out on new functionality in software – Go to User’s Meetings!
- Like many, Meventus has used Windsim and WindPRO together for many years
- Windsim FLOWRES has unlocked potential to improve efficiency and accuracy in many ways

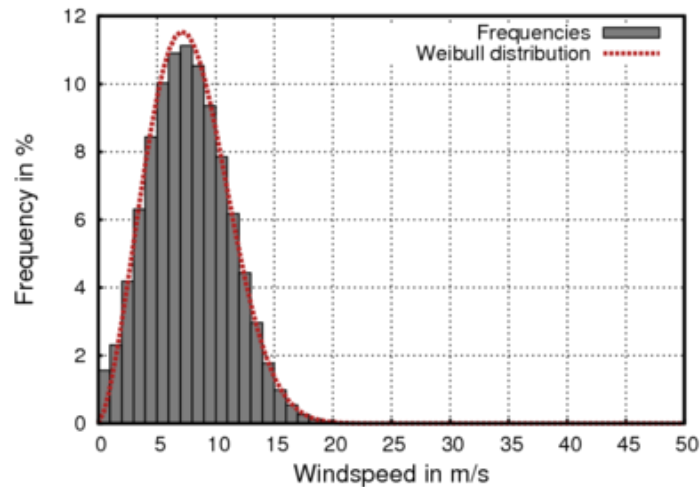
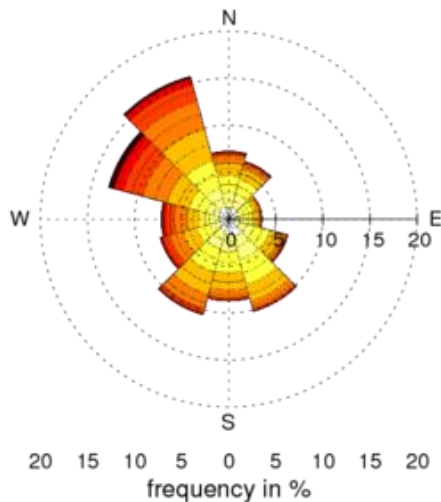
EXAMPLE ANALYSIS PROCESS – THEN...



- Lots of exports / format conversions / special scripts / imports between different software
- Key Windsim generated result = Wind Resource File

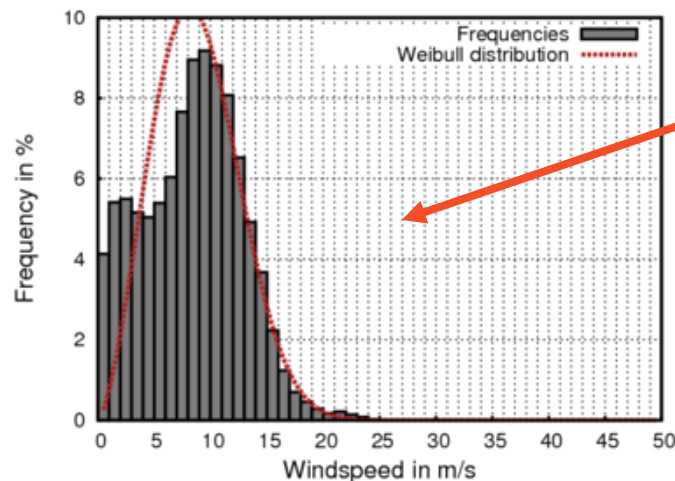
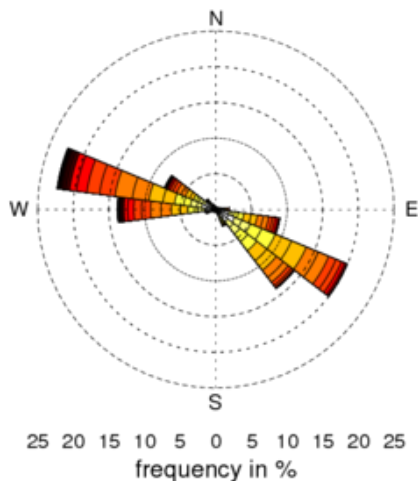
WIND RESOURCE FILES

- Key Windsim generated result
- Benefits
 - Industry Standard
 - Quick energy calculations
- Disadvantages
 - Assumes Weibull fits are representative of the site



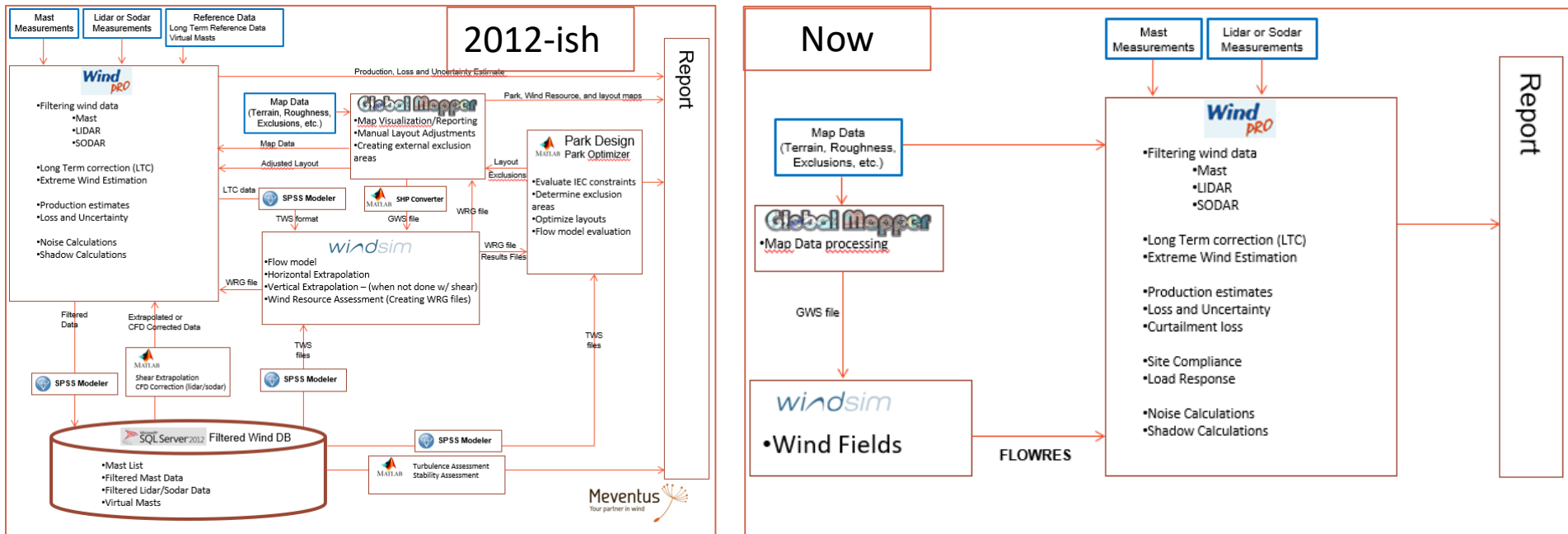
WIND RESOURCE FILES

- Key Windsim generated result
- Benefits
 - Industry Standard
 - Quick energy calculations
- Disadvantages
 - Assumes Weibull fits are representative of the site
 - No time information (time of day, season, etc)
 - How do you estimate diurnal/seasonal production for areas where the energy prices have large time variations?



What do you do when your Weibull fit looks like this?

EXAMPLE ANALYSIS PROCESS – THEN VS. NOW



- Key files is FLOWRES
- Limited need for exports / format conversions / special scripts / imports between different software
- **Most important benefit – enables use of many WindPRO's time series-based calculations using your Windsim model instead of being forced to use WAsP or direct measurements.**

BENEFITS OF FLOWRES / TIME-BASED CALCULATIONS

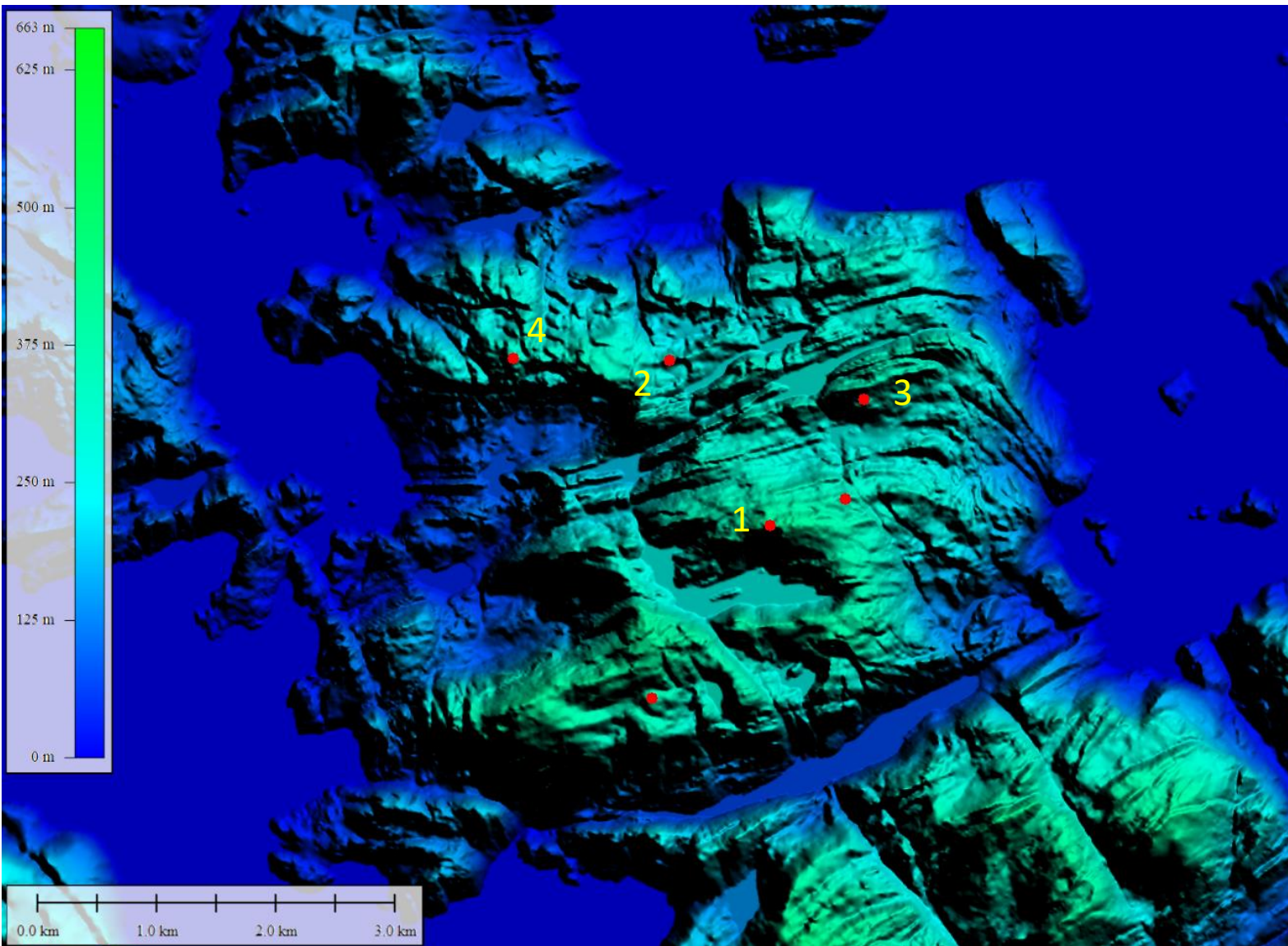
- Time-based production time series
 - Can assess diurnal and seasonal patterns related to energy prices, grid constraints, etc.
 - More accurate 24/12 production profiles
 - Improved wake loss assessment
- Allows for more dynamic assessment of sector management / active control algorithms (PSA / ACS) which are active under a different combination of conditions present
- Site Compliance and Load Response based on Windsim model instead of WAsP or direct measurements
- Atmospheric Stability Conditions
 - Production time series based on stability condition for each time-step instead of sector
- Seasonal Roughness Conditions
 - Production time series based on seasonal roughness in regions where roughness conditions change considerable over season or time (deciduous forest in winter, or active deforestation)

ATMOSPHERIC STABILITY TIME SERIES

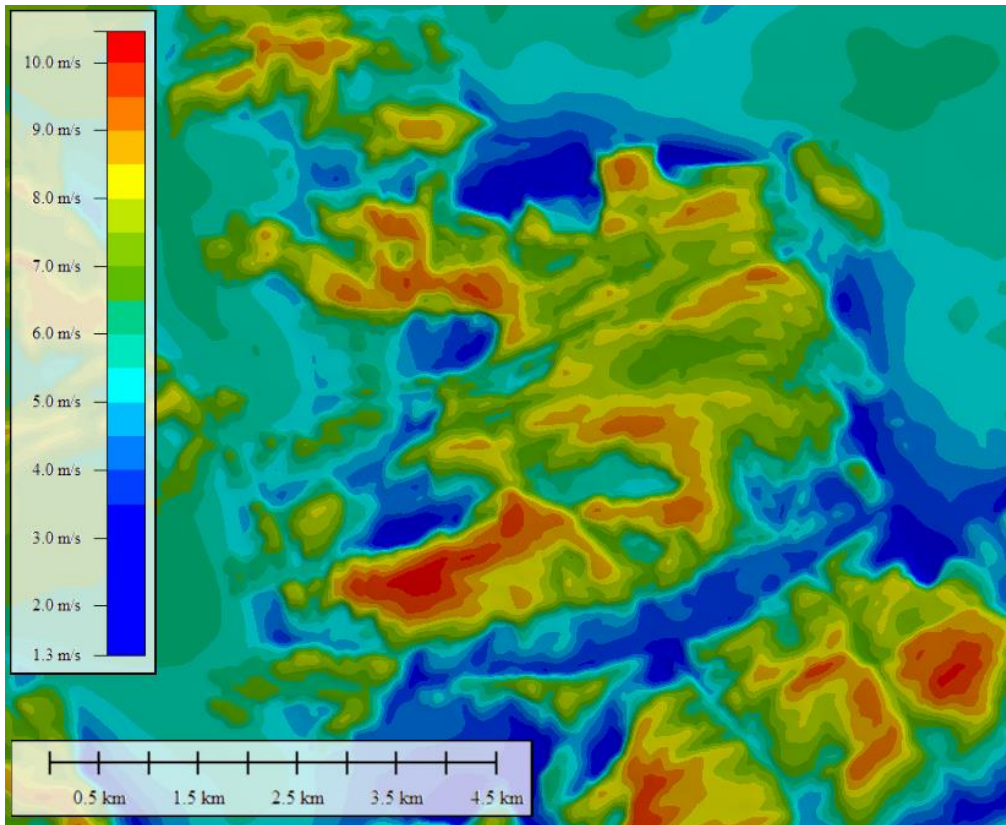
Date-time	Power [MW] - Neutral	Power [MW] - Stable	Power [MW] - Unstable	Assessed Timestamp Stability Condition	Compiled Time Series
01.01.2000 00:00	130.007	120.91	127.41	Neutral	130.01
01.01.2000 01:00	107.6067	100.07	105.45	Neutral	107.61
01.01.2000 02:00	129.26	120.21	126.67	Stable	120.21
01.01.2000 03:00	129.59	120.52	127.00	Stable	120.52
01.01.2000 04:00	129.64	120.57	127.05	Stable	120.57
01.01.2000 05:00	130.07	120.97	127.47	Stable	120.97
01.01.2000 06:00	126.45	117.60	123.93	Stable	117.60
01.01.2000 07:00	130.08	120.97	127.48	Stable	120.97
01.01.2000 08:00	129.61	120.53	127.01	Stable	120.53
01.01.2000 09:00	121.22	112.73	118.79	Stable	112.73
01.01.2000 10:00	129.63	120.56	127.04	Stable	120.56
01.01.2000 11:00	37.44	34.82	36.69	Unstable	36.69
01.01.2000 12:00	89.71	83.43	87.92	Unstable	87.92
01.01.2000 13:00	64.85	60.31	63.55	Unstable	63.55
01.01.2000 14:00	128.63	119.62	126.06	Unstable	126.06
01.01.2000 15:00	47.30	43.99	46.35	Unstable	46.35
01.01.2000 16:00	11.55	10.74	11.32	Unstable	11.32

- Run a production time series for each Stability condition modeled
- Evaluate stability at each time step based on Mesoscale or other available data
- Select the resulting value per time-step instead of trying to determine how often a sector experiences different stability conditions
- Similar approach can be used for seasonal roughness changes

EXAMPLE PROJECT – NORWAY



EXAMPLE PROJECT – NORWAY OVERVIEW



- 6 masts between 50 and 80m height
 - Some masts measured < 1 year, not used for resource assessment or model verification
 - Wind conditions indicate Class I site
 - Many areas with MWS > 10 m/s
 - Areas with high turbulence
-
- Two example layouts, approximately 30 turbines
 - One with single hub height and single turbine type
 - One with mixed hub heights, different modes and wind sector management on more than half of the turbines

EXAMPLE PROJECT – WINDSIM MODEL

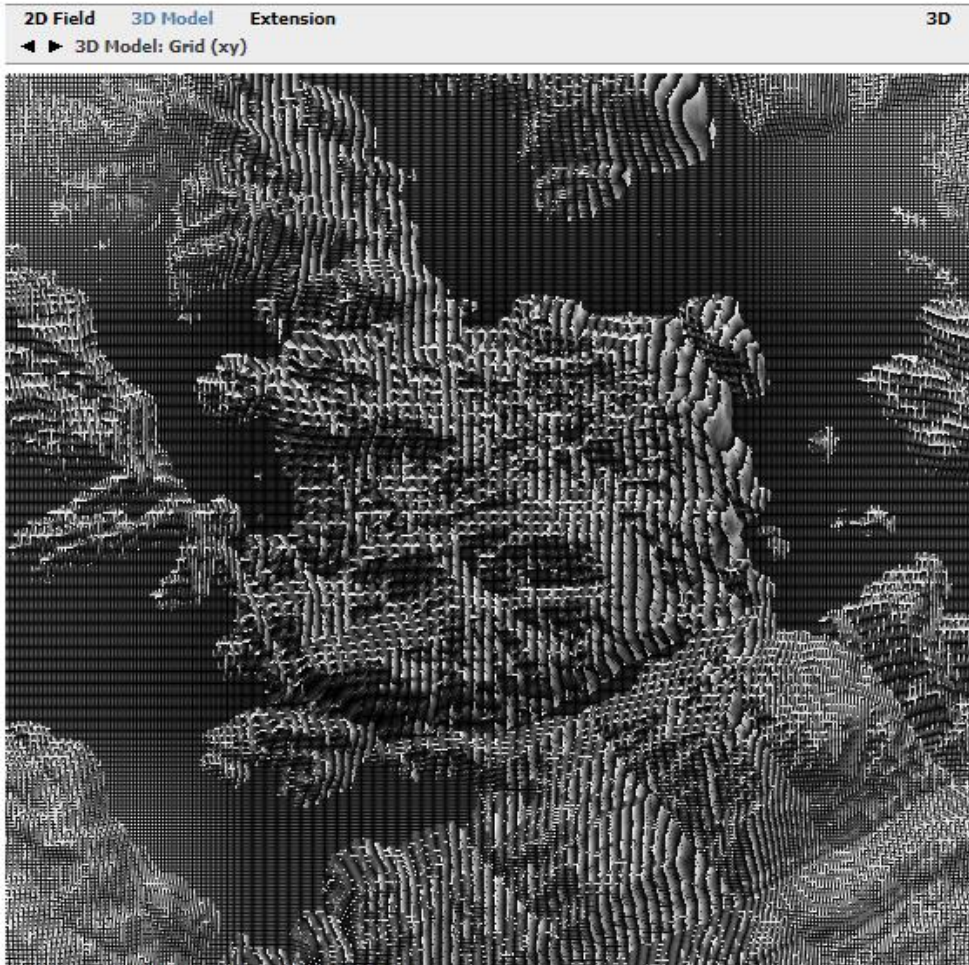


Fig 1. Digital terrain model - Grid (xy).

Body fitted co-ordinates (BFC) are used in grid generation. The above plot displays the resolution at ground level.

	x	y	z	total
Grid spacing, min - max (m)	25.0 - 59.5	25.0 - 59.5	Variable	-
Number of cells	382	342	31	4049964

Table 1. Grid data.

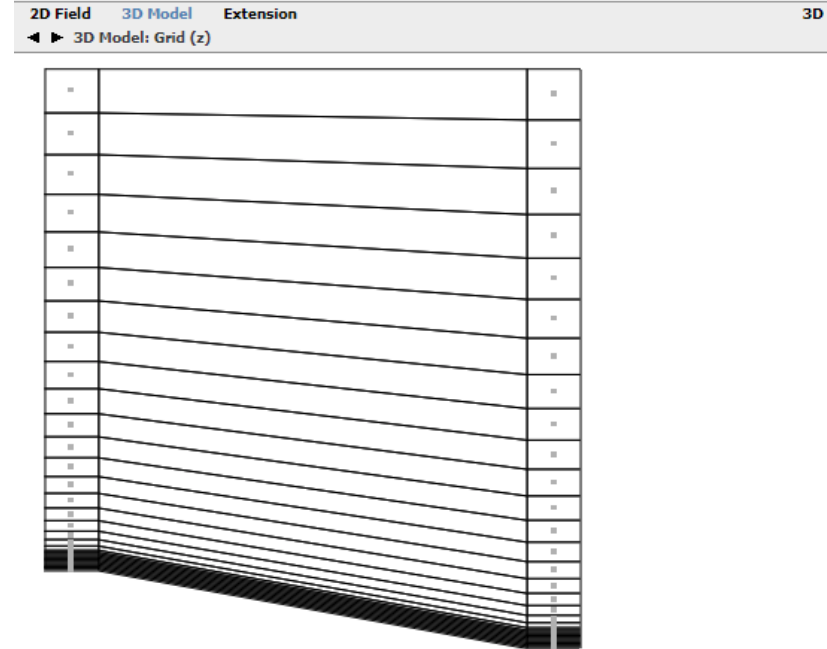


Fig 1. Digital terrain model - Grid (z).

The grid extends 3000.7 (m) above the point in the terrain with the highest elevation. The grid is refined towards the ground. The left and right columns display a schematic view of the distribution at the position with maximum and minimum elevation respectively. The nodes, where results from the simulations are available, are situated in the cell centers indicated by dots.

	1	2	3	4	5	6	7	8	9	10
z-dist. max (m)	5.5	16.5	27.5	38.5	49.5	60.5	71.5	82.5	93.5	104.5
z-dist. min (m)	5.5	16.5	27.5	38.5	49.5	60.5	71.5	82.5	93.5	104.5

Table 1. Distribution of the first 10 nodes in z-direction, relative to the ground, at the position with maximum and minimum elevation.

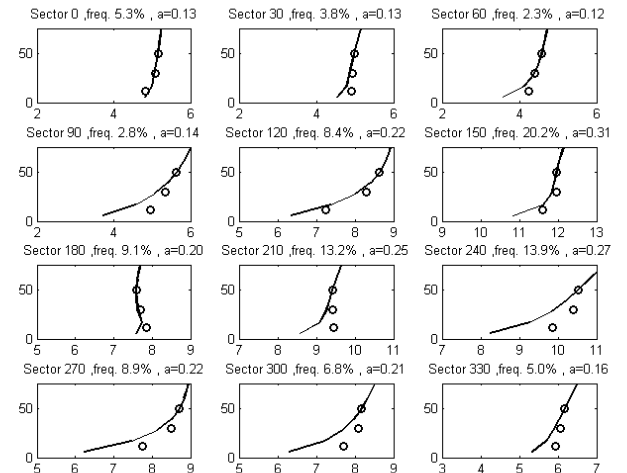
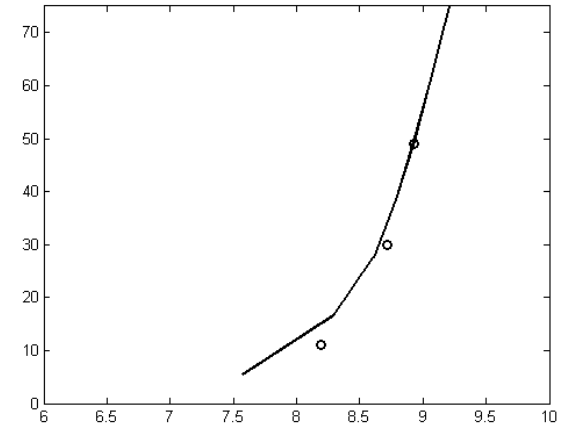
EXAMPLE PROJECT – MODEL VALIDATION

Model Cross Predictions

50m height				
	Mast 1	Mast 2	Mast 3	Mast 4
Mast 1		-3.69	-1.45	0.82
Mast 2	6.88		6.48	
Mast 3	1.48	-1.76		3.86
Mast 4	1.29		1.13	
80m height				
	Mast 2	Mast 3	Mast 4	
Mast 2		5.45		
Mast 3	-3.93		3.23	
Mast 4		0.11		

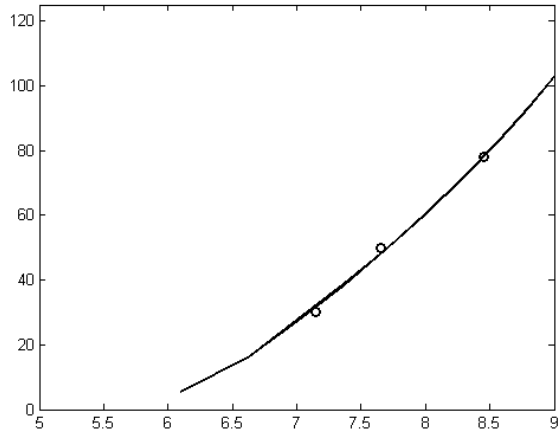
Modeled vs Measured shear

Mast 1

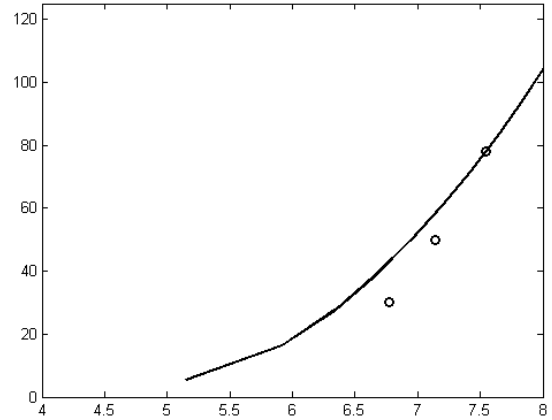


EXAMPLE PROJECT – MODEL VALIDATION

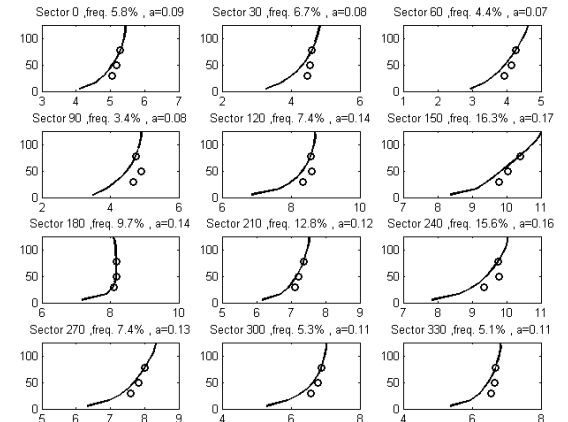
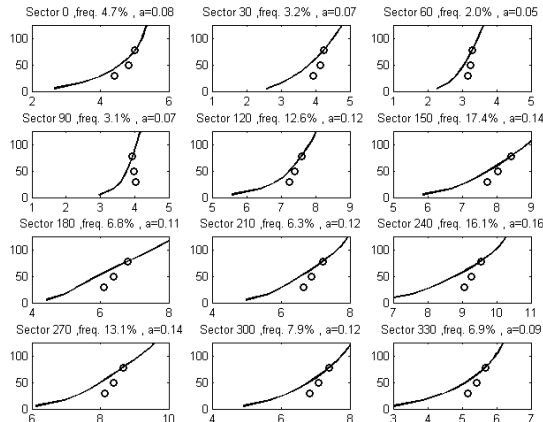
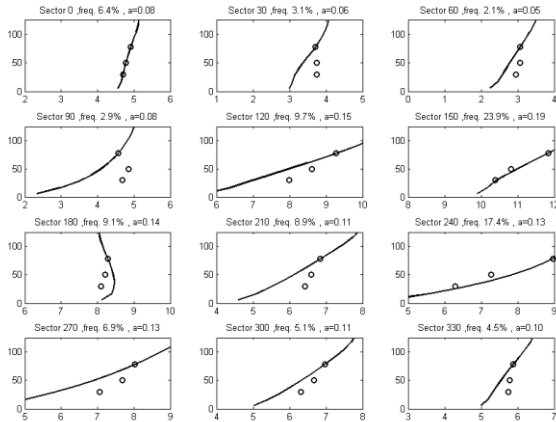
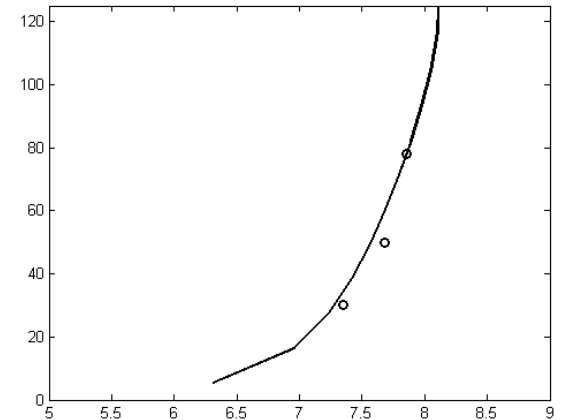
Mast 2



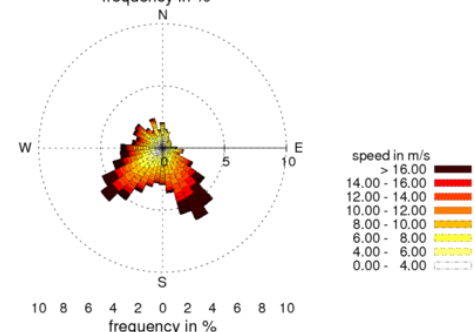
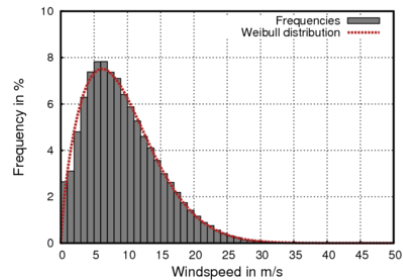
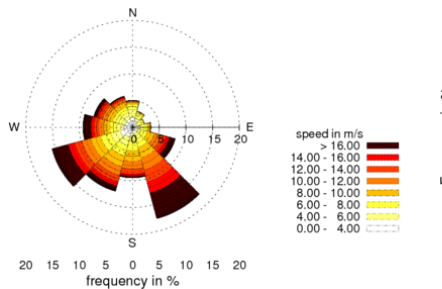
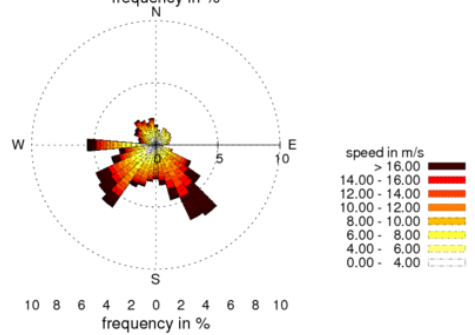
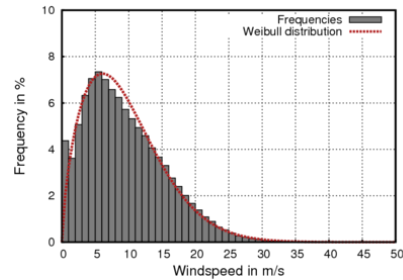
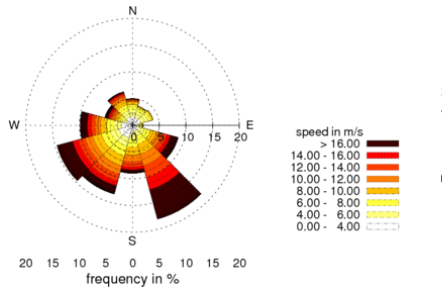
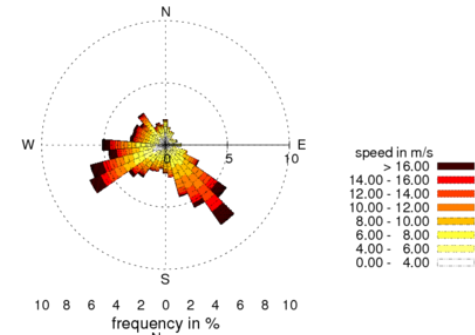
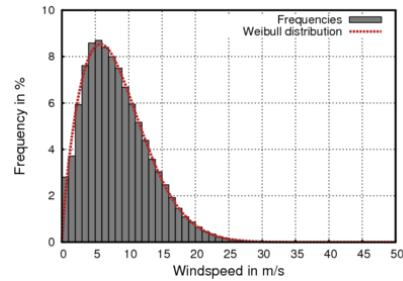
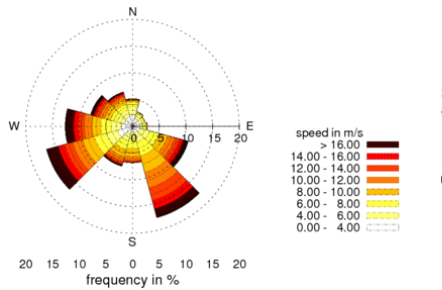
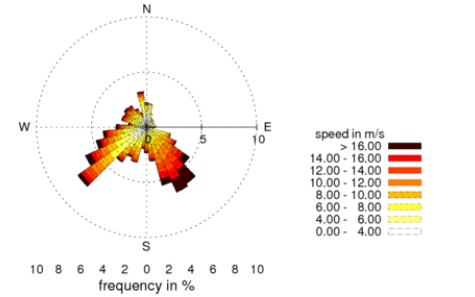
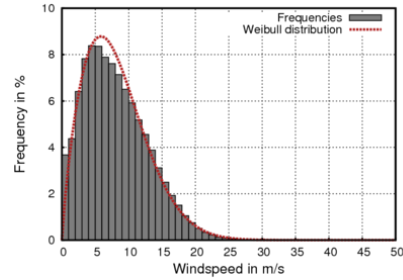
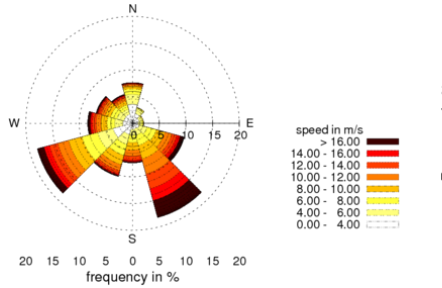
Mast 3



Mast 4



LTC DISTRIBUTIONS – 12 VS 36 SECTOR



EXAMPLE PROJECT – WRG VS TIME-BASED SENSITIVITY

Layout 1 - single hub height, single mode	Gross production (Normalized)	Wake Loss (%)	Production w Wake Loss (Normalized)
36 sector FLOWRES	100.00	7.72	100.00
36 sector WRG	100.52	7.47	100.79
12 sector WRG	98.96	7.59	99.09

Layout 2 - multiple hub heights, modes, curtailment	Gross production (Normalized)	Wake Loss (%)	Production w Wake Loss (Normalized)	Curtailment Loss (%)
36 sector FLOWRES	100.00	7.43	100.00	7.48
36 sector WRG	99.52	7.46	99.50	6.96

- Comparison of calculation performed using FLOWRES/Time series and WRG resulted in:
 - Differences of up to 0.8% of Net production (Gross – wake)
 - Wake loss differences up to 0.25%
 - Curtailment loss (WSM) difference of 0.5%
- Using a flow model with less sectoral resolution resulted in difference of 1.7% (36 vs 12 sector WRG)

WIND INDEX OF EXISTING PARKS IN NORWAY



Figur 1 - Oversikt over vindkraftverkene som er inkludert i analysen

WIND/ PRODUCTION INDEX PARKS IN NORWAY

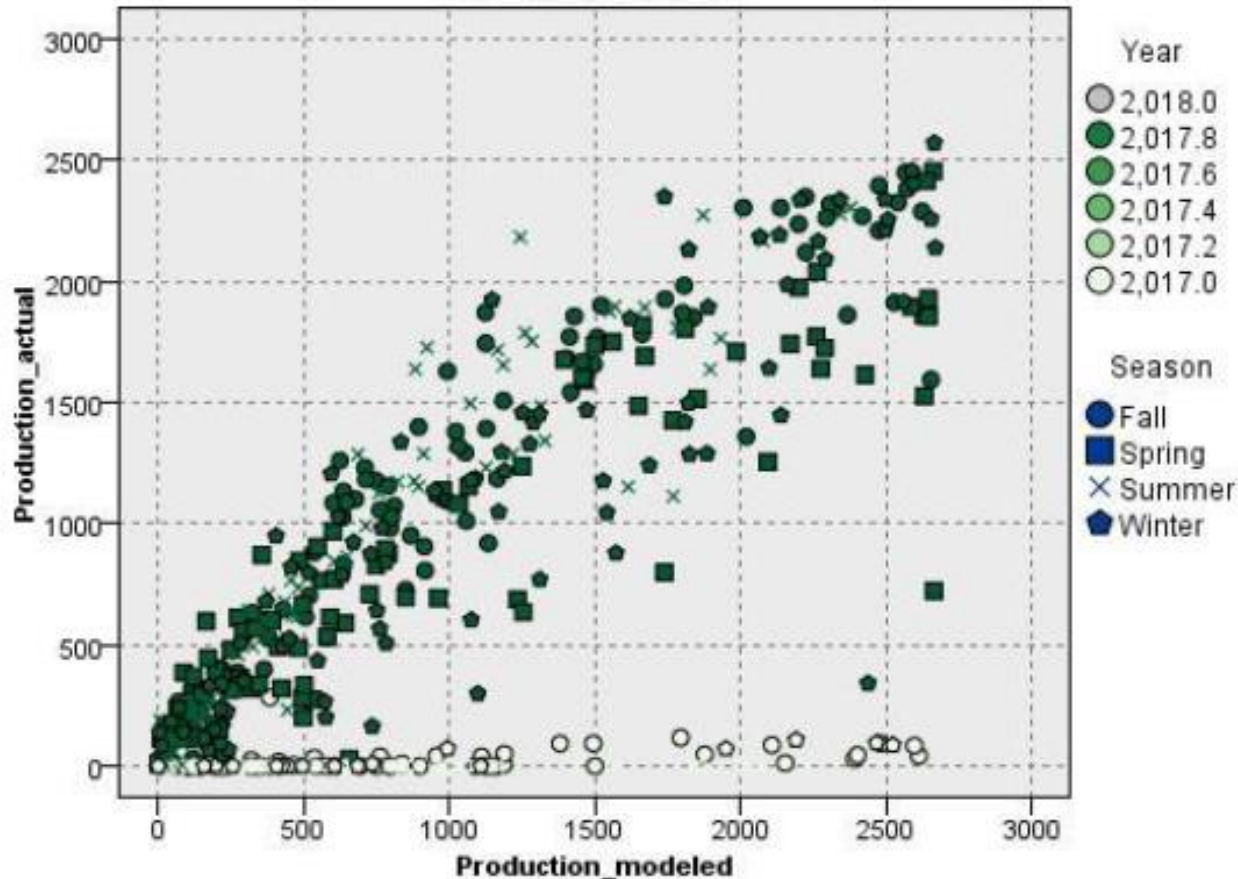
- 29 Operational Wind Farms in 2018, 19 more in 2019
- Modeled with Windsim and WAsP for small projects
- Synthetic time series to account for all wind speed, direction, and air density calculations (36 sector)
- Time based production calculation to make a park level “synthetic power curve” for each site
- This “synthetic power curve” became a lookup table for actual production based on speed and direction and air density in the WRF data
- Used WRF data as input - air density based on modeled temperature and pressure data
- Modeled results scaled against actual production data to adjust the WRF data to site specific conditions

airDensity	windDirection	windSpeed	power
1.375	50	1.000	0.000
1.375	50	1.200	0.000
1.375	50	1.400	0.000
1.375	50	1.600	0.000
1.375	50	1.800	0.000
1.375	50	2.000	0.000
1.375	50	2.200	0.000
1.375	50	2.400	0.000
1.375	50	2.600	23.400
1.375	50	2.800	90.300
1.375	50	3.000	243.000
1.375	50	3.200	570.700
1.375	50	3.400	999.200
1.375	50	3.600	1549.500
1.375	50	3.800	2177.700
1.375	50	4.000	2898.500
1.375	50	4.200	3706.800
1.375	50	4.400	4618.400
1.375	50	4.600	5634.500
1.375	50	4.800	6732.700

SCALING/VALIDATING THE MODELS

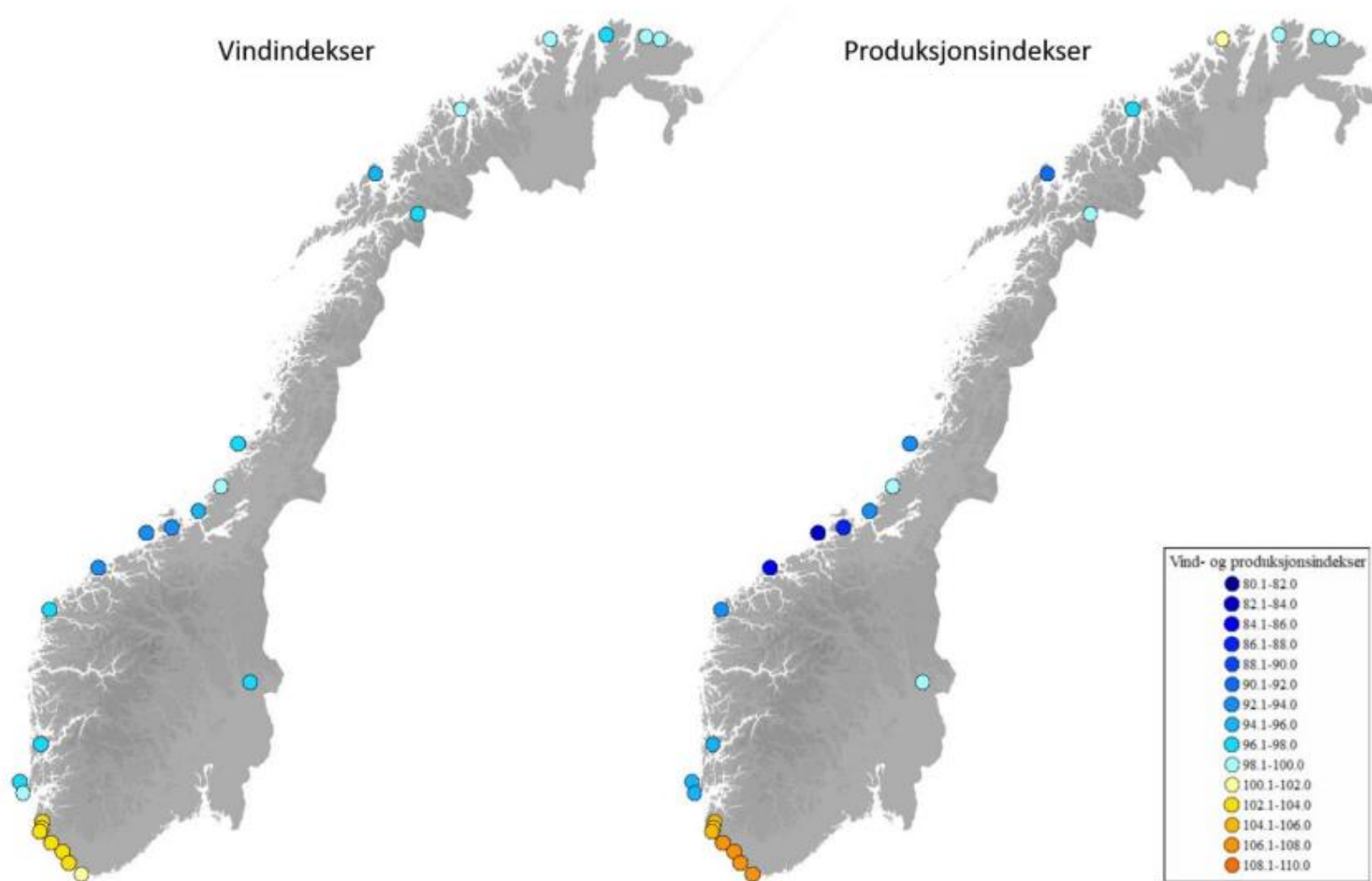
Egersund Daily Production (MWh/day)

Modeled vs Actual



- Hourly park level production data from Statnet at park level
- Summed on daily values. For scaling, outliers and winter data removed

WIND INDEX OF EXISTING PARKS IN NORWAY RESULTS



Figur 3 – Oversiktskart med beregnede indekser for samtlige norske vindparker som er inkludert i analysen

QUESTIONS?