Wind Farm Simulator; Time-dependent wind energy calculations

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Overview

- What is Wind Farm Simulator (WFS)?
- What is needed to run WFS?
- Layout optimization
- Example from WFS results at Smøla
  - Wind shear module
  - TI influence on the production
  - Density influence on the production
  - Influence of turbine operation
  - Optimizing of maintenance

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What is Wind Farm Simulator?

- WFS is developed in a cooperation project with Statkraft, University of Oslo and Kjeller Vindteknikk as involved partners
- WFS is a time dependent methodology to estimate the wind farm production. This means that the production is estimated for each turbine at each defined time stamp.
- Applications
  - Pre construction Energy Yield Assessment
  - Post construction follow-up of wind farm production, calculation of lost production
  - Optimizing of O&M (Operation and Maintenance)
  - Production forecasting
  - Down-rating/curtailment

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What is needed to run WFS?

- Time series of wind speed, turbulence, wind shear (voluntary), air density (voluntary) and operational status (voluntary)
  - Historical time series in wind farm energy yield estimates and production analyses
  - Forecasted time series in power forecasting and planning of O&M
- Coordinates and heights for turbines and met mast
- Conversion ratios between the met mast and turbines (for wind speed and possibly turbulence)
- Turbine power- and c_t curve

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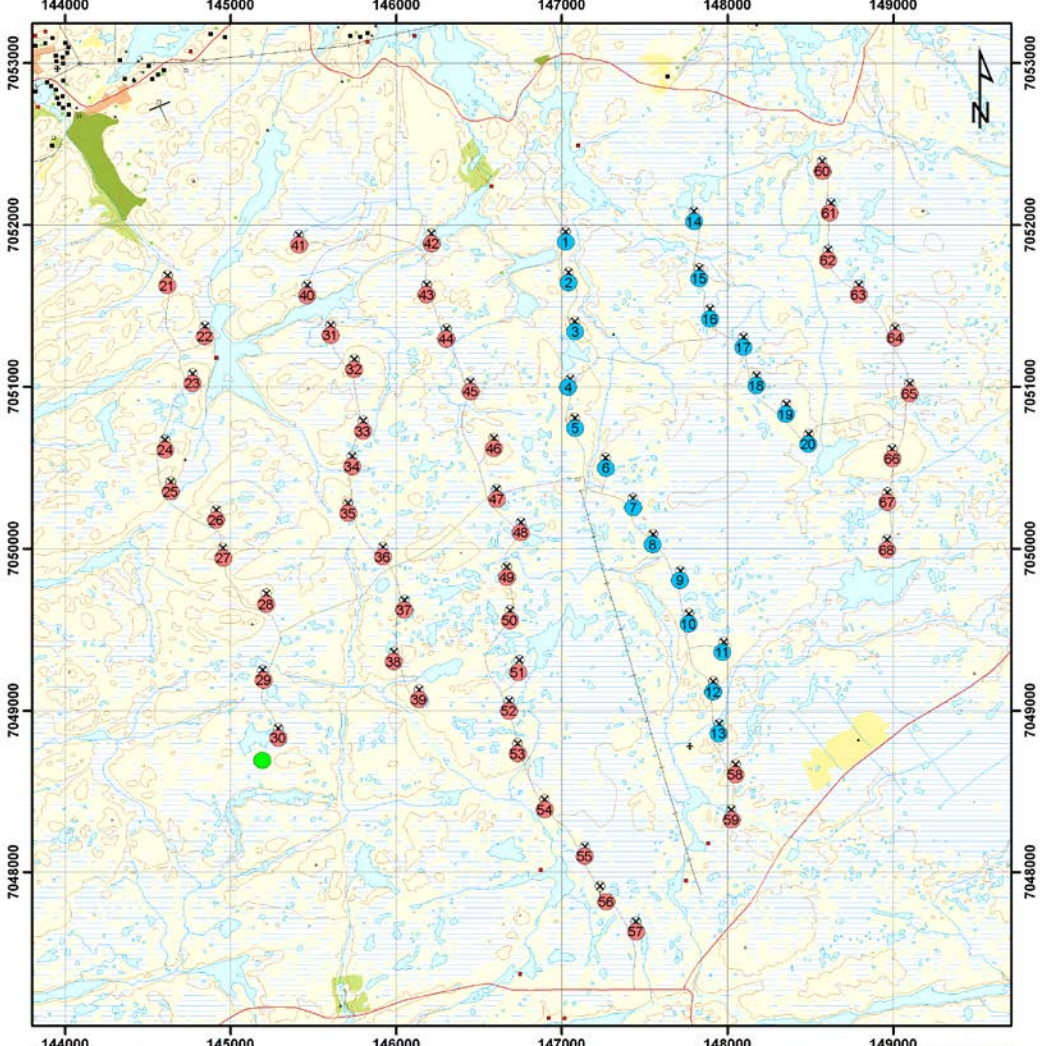
Layout optimization

- Annual wind statistics:
  - Typically directions of 30º
    → Production influence of small turbine movements becomes inaccurate
- Time dependent calculations:
  - Typically 5º accuracy of direction measurements
    → Production influence of small turbine movements becomes more accurate using a wake model representing the true wake. In WFS Dynamical Wake Meandering model is implemented in addition to the more simple Jensen model

Example from Smøla



Legend

- Smøla 1
- Smøla 2
- Meteorological mast

0 0.25 0.5 1 km

Statkraft - Smøla			
Figure/Drawing Title: Layout and meteorological mast			
File Name: K:\Statkraft\Smola		Rev: 0	
By: OU	Date: 02/07/12	Checked: ES	Date: 02/07/12
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Datum: WGS84		Projection: UTM Zone 33	

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Statkraft

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Wind shear module

- Implemented module calculates the wind shear based on "1D Gryning wind profile model" (Gryning et al., 2007).
- Input data: "Boundary layer height, friction velocity and vertical heat fluxes"
- Improved estimate of the total wind shear coefficient α between 30 m and 70 m:

Parameter	Observations	Gryning	WRF	WAsP
Wind shear annual mean	0.21	0.21	0.14	0.14

- Minor influence on the estimated annual production using rotor equivalent wind speed

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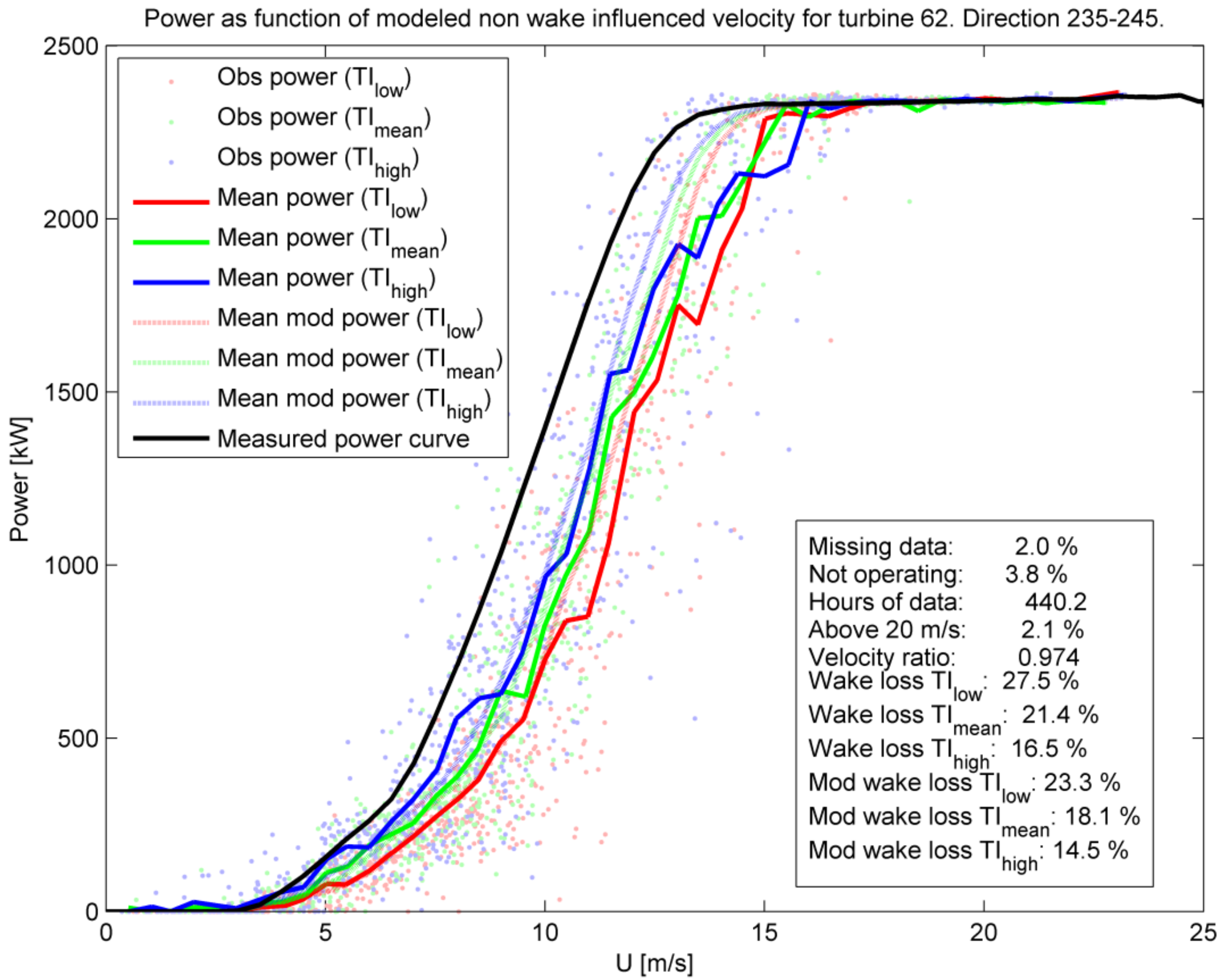
TI dependence of turbine in wake



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TI dependence all turbines

	Wake loss [%] TI_{Low}	Wake loss [%] TI_{Mean}	Wake loss [%] TI_{High}
Measured wake loss	14.6	10.6	7.9
Modelled wake loss with time-dependent approach	10.2	8.6	7.3
Modelled wake loss WAsP (turbulence dependent WDC)	10.2	8.2	6.5
Mean TI of group [%]	7.3	10.2	14.3

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Production density dependence

Mnd	Mean temp [^{0}C]	Prod error
Jan	2.1	-0.5 %
Feb	3.2	-0.8 %
Mar	1.6	-0.2 %
Apr	5.7	-0.5 %
May	8.2	-0.6 %
Jun	11.6	0.9 %
Jul	14.2	3.3 %
Aug	12.3	1.3 %
Sep	9.2	0.4 %
Oct	7.6	-0.4 %
Nov	3.7	-0.5 %
Dec	3.4	-0.7 %

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Influence of operational status

- The production loss caused by down time is directly estimated for the period.
- The production gain of down wind turbines caused by missing wake is directly estimated for the period.

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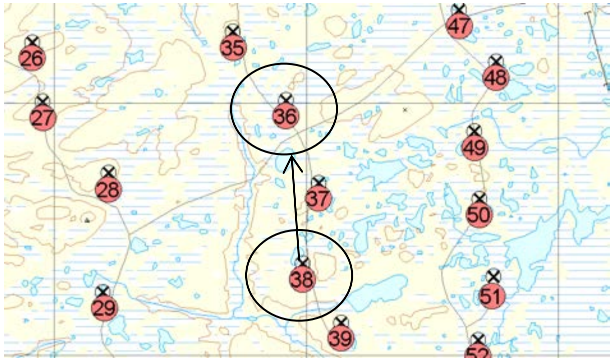

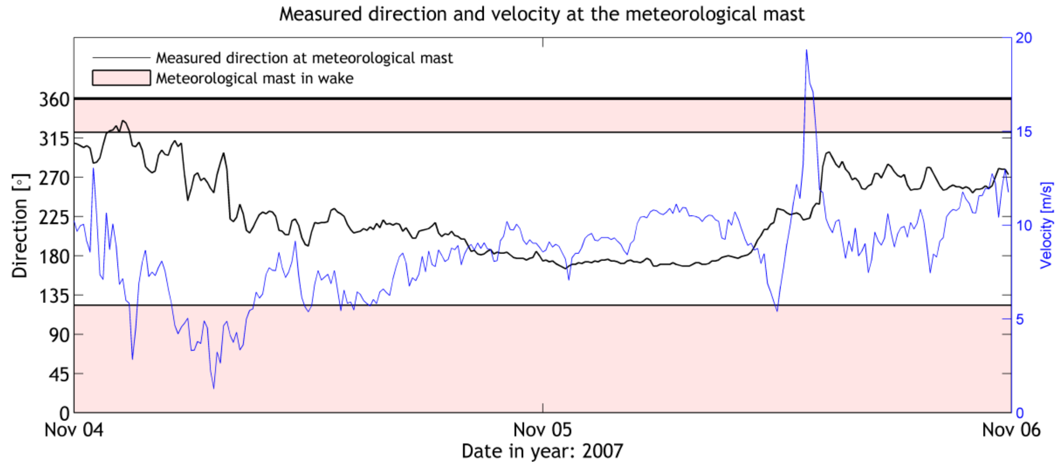

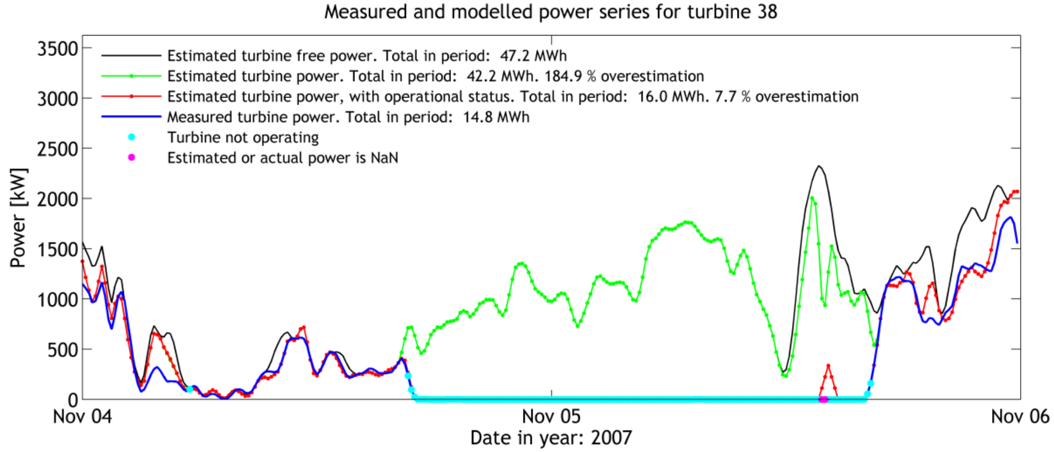

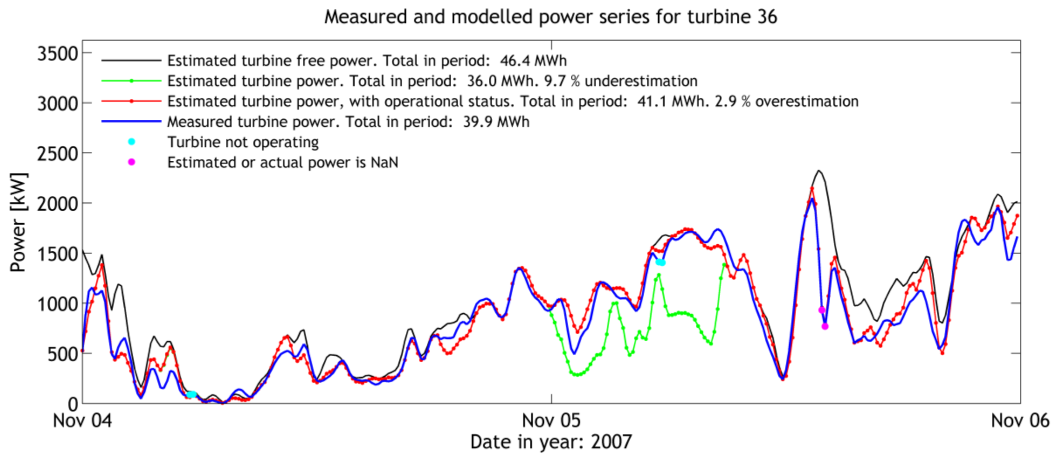

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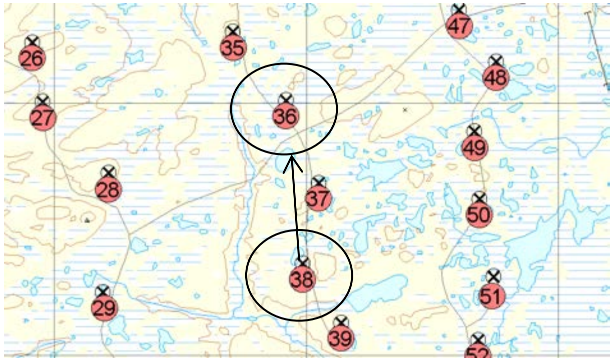
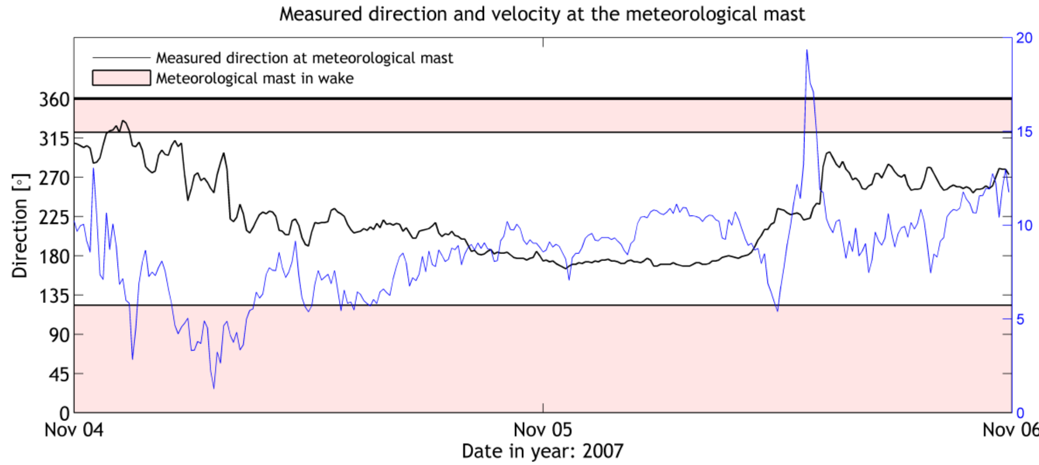
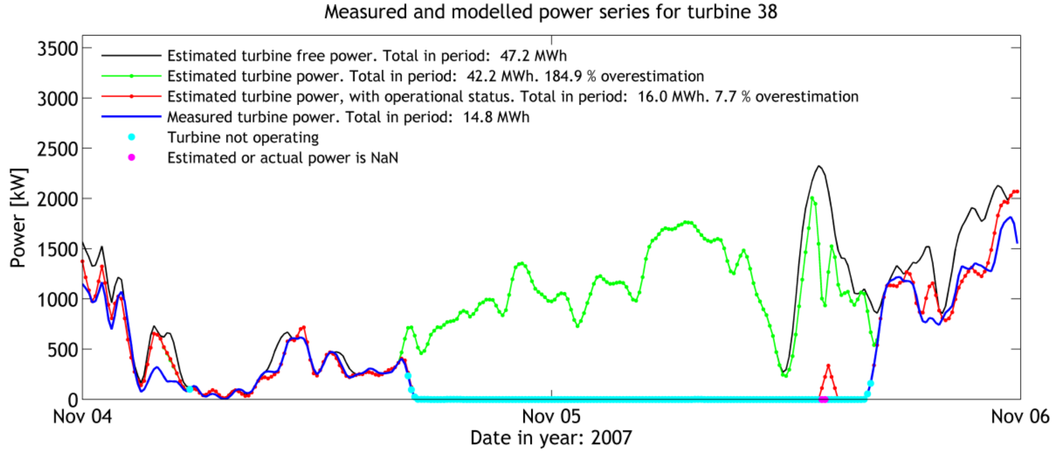
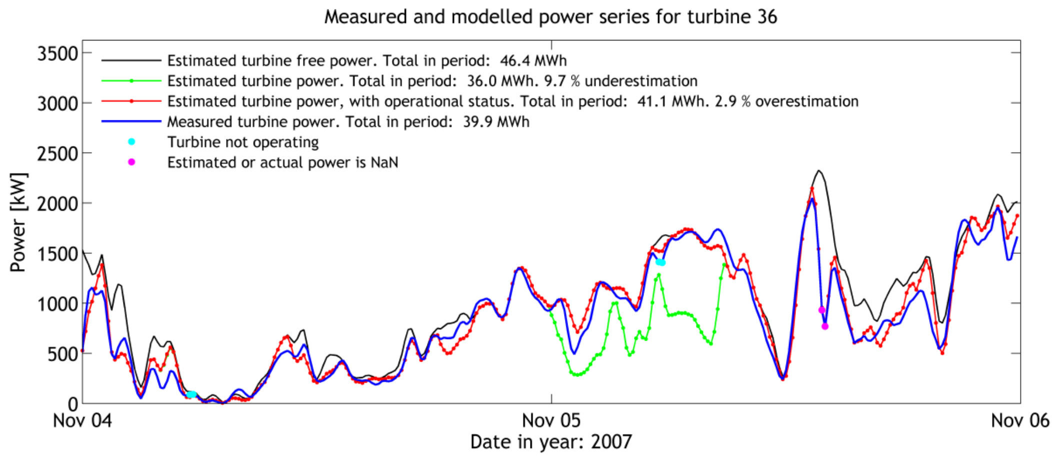






Production loss:
26.2 MWh



Production gain:
5.1 MWh
(20 % of prod loss)

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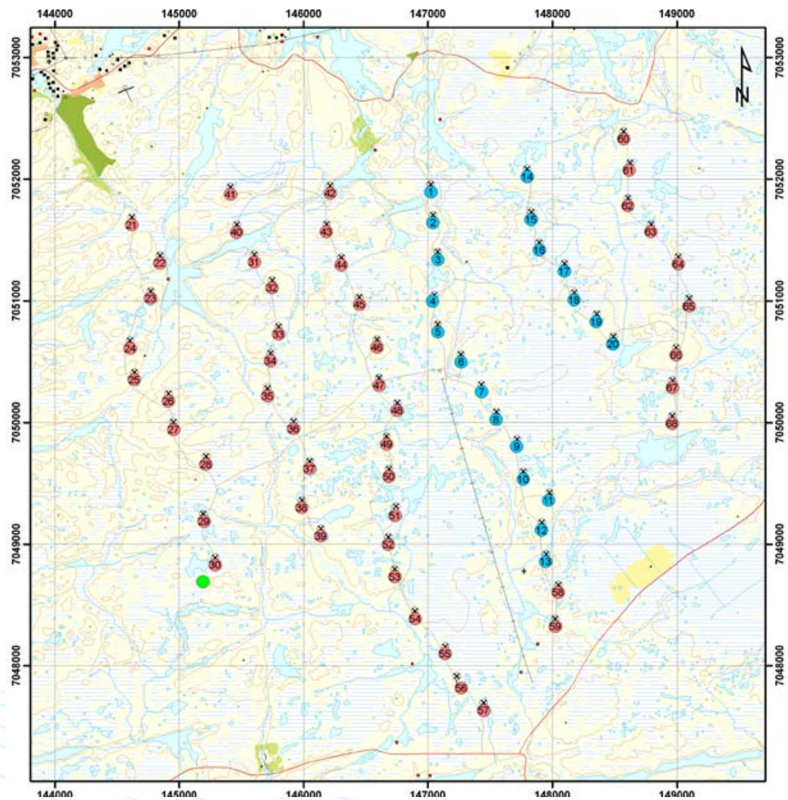
Optimizing of Maintenance

- Maintenance scenario:
  - All the turbines of Smøla 1 (turbine 1-20) needs maintenance, but only one (or a few) turbine(s) can be shut down at a time.
  - Evaluate which turbines to shut down in the period from 8-16 the following two days.



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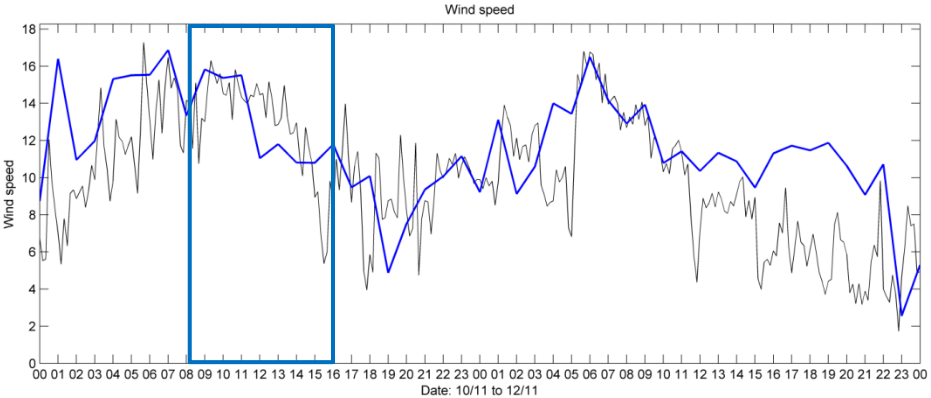
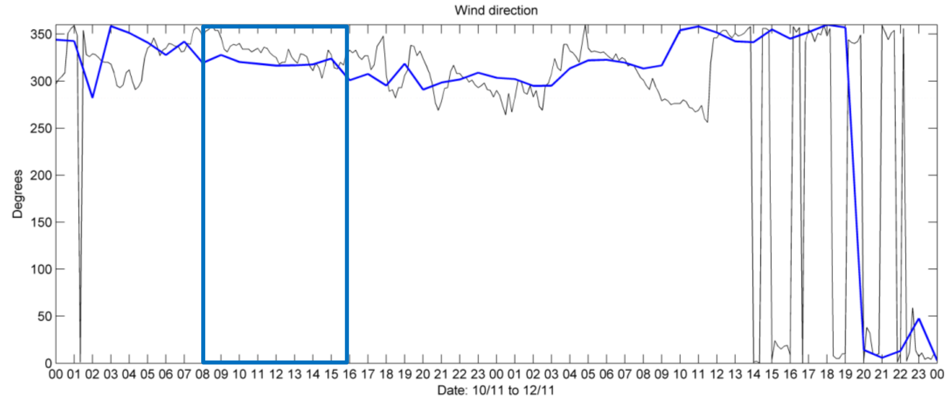
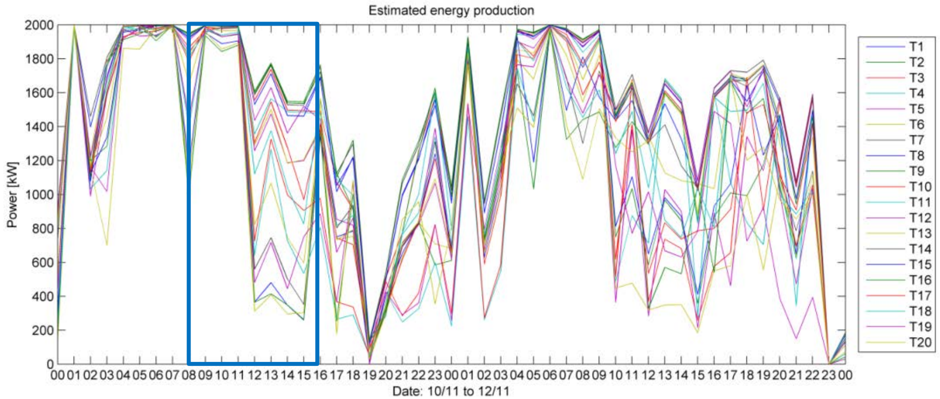
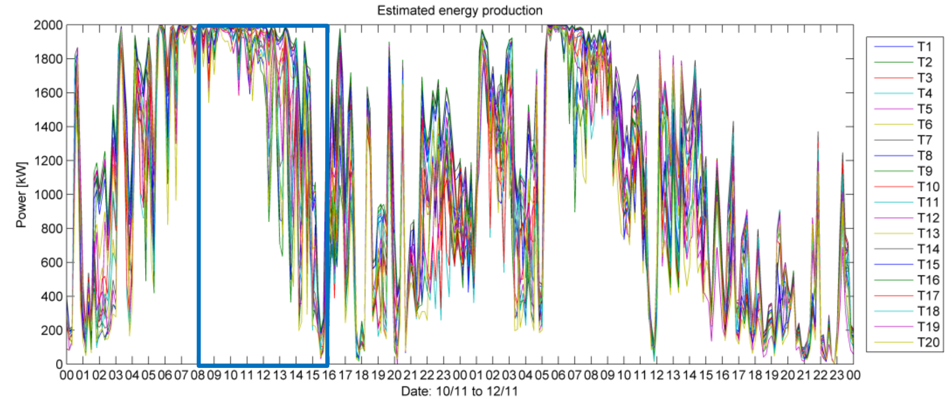




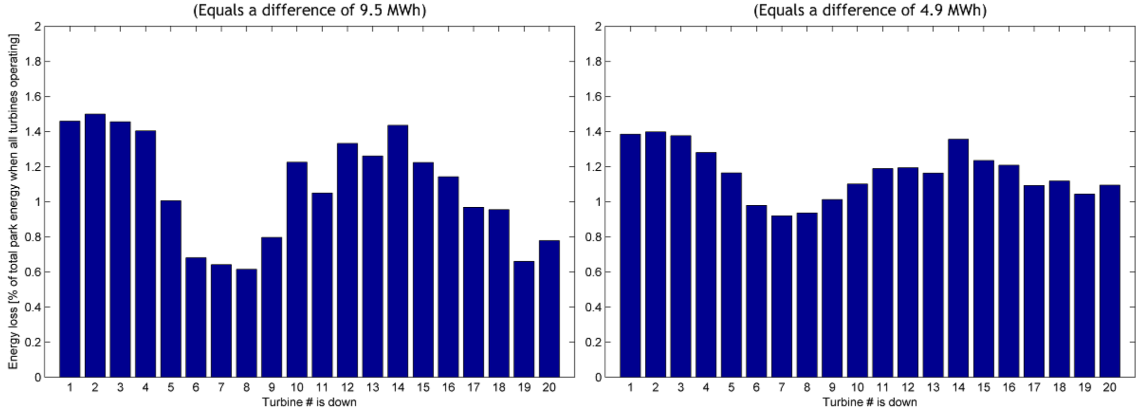




10-Nov-2007 08:00:00 to 10-Nov-2007 16:00:00

Min production (1055.3 MWh) when turbine 2 down
Max production (1064.7 MWh) when turbine 8 down
(Equals a difference of 9.5 MWh)

Min production (1004.7 MWh) when turbine 2 down
Max production (1009.6 MWh) when turbine 7 down
(Equals a difference of 4.9 MWh)



Maintenance example 10-12th November 2007

Summary

- Wind Farm Simulator (WFS)

- Resolved time dependent variations
- Currently taking time dependence in TI (through wakes), wind shear, operational status and density into account.
- Used for optimization of planned maintenance
- Can be used in layout optimization

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