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TOPFARM - philosophy, results and outlook

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TOPFARM – philosophy, results and outlook…

G.C. Larsen, H.Aa. Madsen, T.J. Larsen, P.-E. Réthoré, P. Fuglsang, N. Troldborg, T. Buhl, …

Outline

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- Vision/philosophy
- The TOPFARM project
- The wake “engine”
- The optimization “engine”
- Results
  - The objective function
  - Middelgrunden
- Conclusion
- Outlook

Introduction

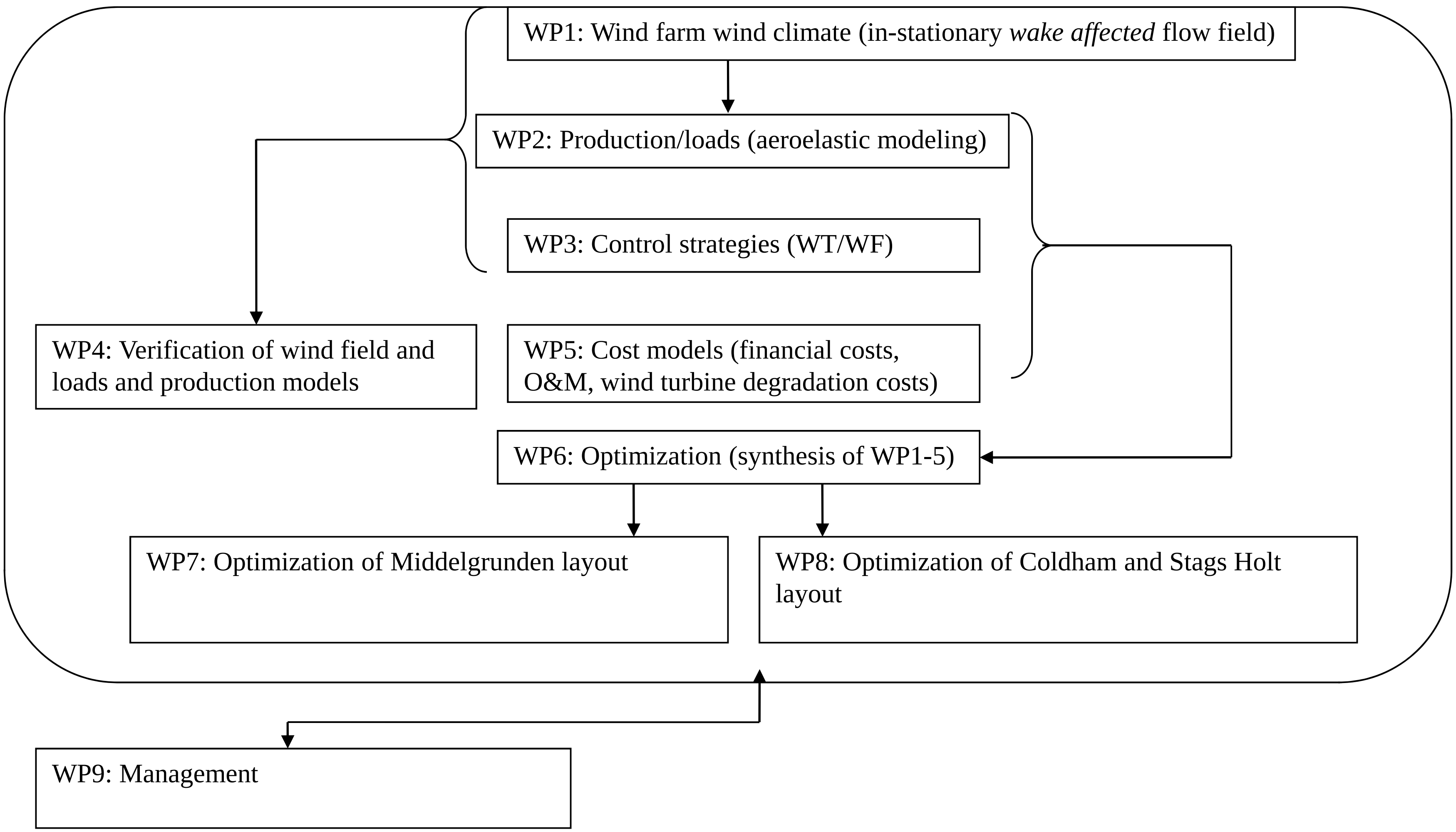
- TOPFARM acronym for: NEXT GENERATION DESIGN TOOL FOR OPTIMISATION OF WIND FARM TOPOLOGY AND OPERATION
- The EU TOPFARM project addresses optimisation of wind farm topology and control strategy based on aeroelastic modelling of *loads* as well as of *power* production
- Partners: Risø-DTU (coordinator); MEK-DTU; Cambridge Environmental Research Consultants ltd; DONG ENERGY; Garrad Hassan and Partners ltd.; Teknikgruppen AB; Universidad Politécnica de Madrid; Germanischer Lloyd Industrial Services GmbH; and Vestas Wind Systems A/S

Vision/Philosophy

- **Vision:** A “complete” wind farm topology optimization taking into account
  - *Loading*- and *production* aspects in a realistic and coherent framework
  - Financial costs (foundation, grid infrastructure, ...)

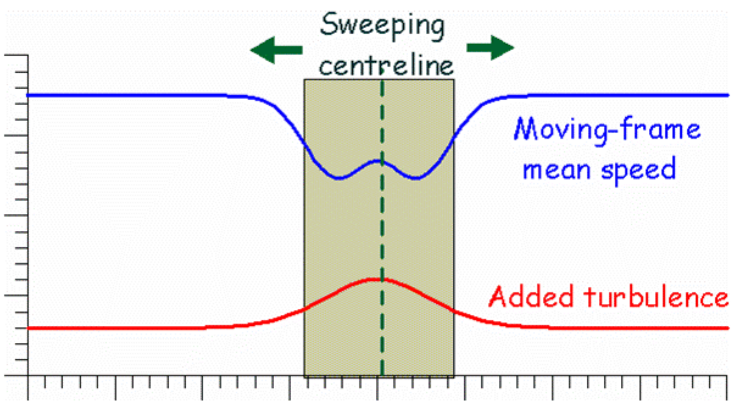
  ... and subjected to various constraints (area, spacing,...)
- **Philosophy:** The optimal wind farm layout reflects the *optimal economical performance* as seen over the lifetime of the wind farm

The TOPFARM project

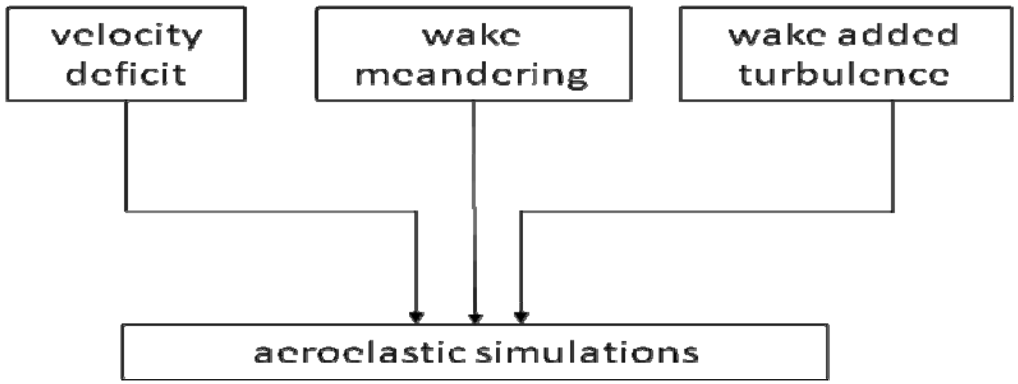


The wake ”engine” (1)

- The dynamic wake meandering (DWM) model (“poor mans LES”) is an efficient model providing a realistic description of wake affected flow fields within wind farms
- The core of the DWM model is a *split in scales* in the wake flow field, with *large turbulent scales* being responsible for stochastic wake meandering (passive tracer analogy), and *small scales* being responsible for wake attenuation and expansion in the meandering frame of reference as caused by turbulent mixing (… LES sub-scale analogy)



The wake ”engine” (2)



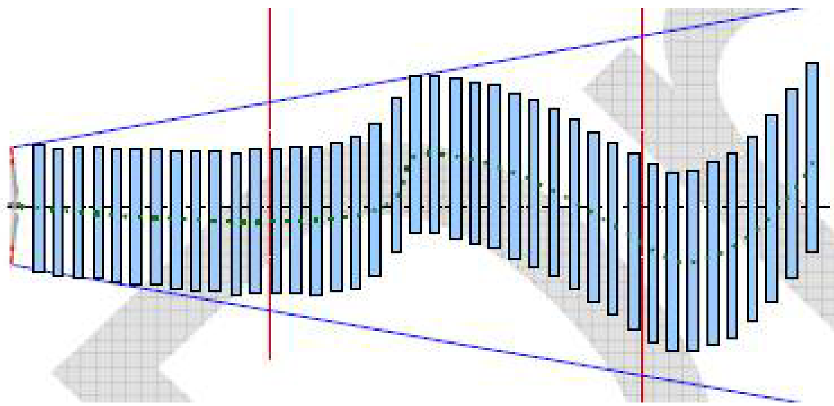
DWM main ingredients (1):

- The *quasi-steady wake deficit* … is the wake deficit formulated in the moving (meandering) frame of reference (*wake expansion and attenuation* as function of downstream position included … BEM + NS-BLE)
- Self-generated *wake turbulence ...* includes contributions from mechanically generated turbulence (wake shear), as well as from the blade bound vorticity (*inhomogeneous; reduced length scale* compared to ABL)

The wake ”engine” (3)

DWM main ingredients (2):

- *Wake* down-stream transportation (meandering) by passive tracer analogy (... LES large-scale analogy)
- A sequence of *“deficit-releases”* is considered ... and described in space and time

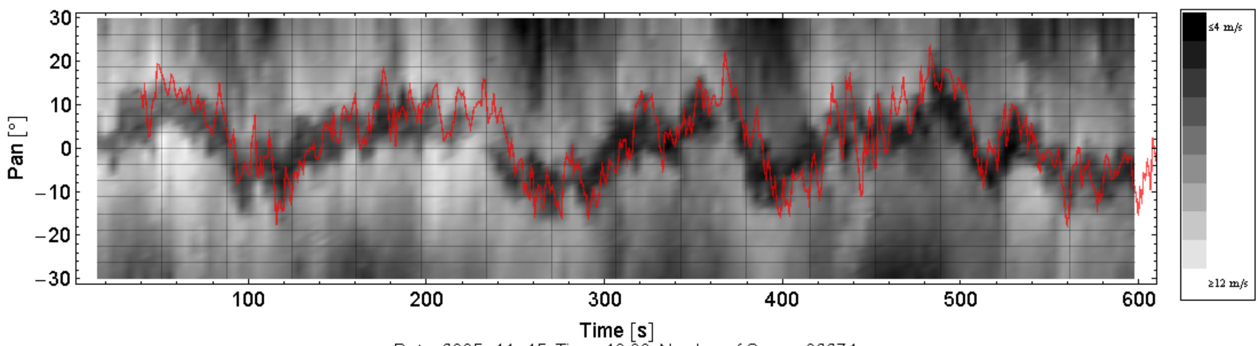


The wake "engine" (4)

- Does it work? ... a full-scale verification (based on LiDAR measurements)

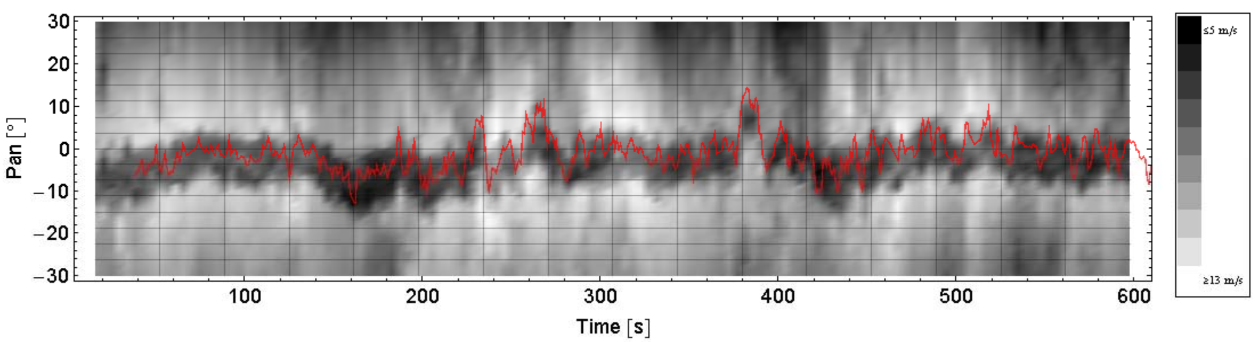
Date 2005–11–15 Time 21:20 Number of Scans 78501

LiDAR				Turbine				Met.Mast							
WS [m/s]				Yaw [°]				WS [m/s]				WD [°]			
Mean	Min	Max	StdDev	Mean	Min	Max	StdDev	Mean	Min	Max	StdDev	Mean	Min	Max	StdDev
7.76	3.07	13.10	1.56	279.0	258.0	296.0	5.6	8.74	5.43	12.40	1.37	277.0	265.0	289.0	6.0



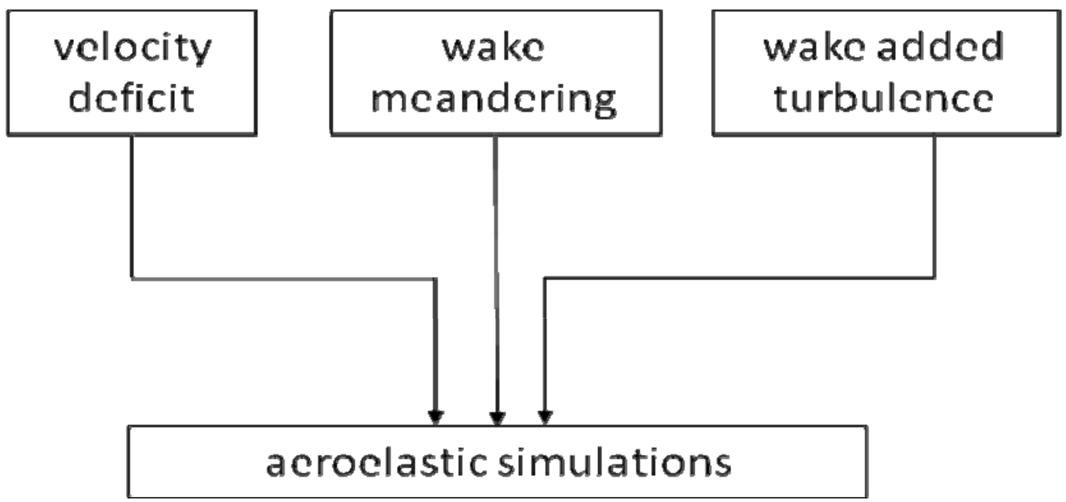
Date 2005–11–15 Time 18:00 Number of Scans 82274

LiDAR				Turbine				Met.Mast							
WS [m/s]				Yaw [°]				WS [m/s]				WD [°]			
Mean	Min	Max	StdDev	Mean	Min	Max	StdDev	Mean	Min	Max	StdDev	Mean	Min	Max	StdDev
9.54	4.59	14.50	1.59	294.0	283.0	310.0	4.1	11.30	7.66	13.90	1.22	295.0	295.0	296.0	0.1



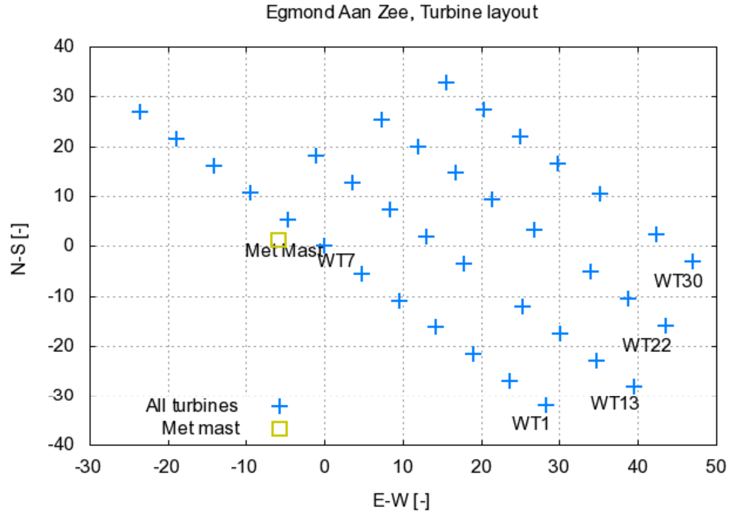
The optimization ”engine” (1)

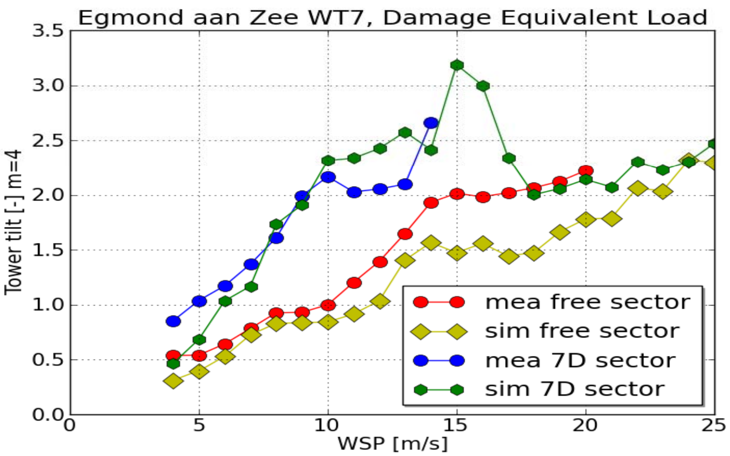
- Dynamic wake meandering (DWM) model (“poor mans LES”) – WP1 – combined with aeroelastic simulations of the individual turbines – WP2, WP3

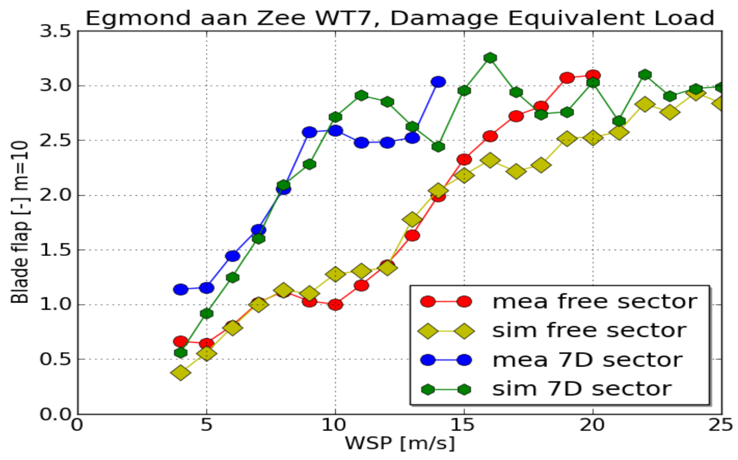


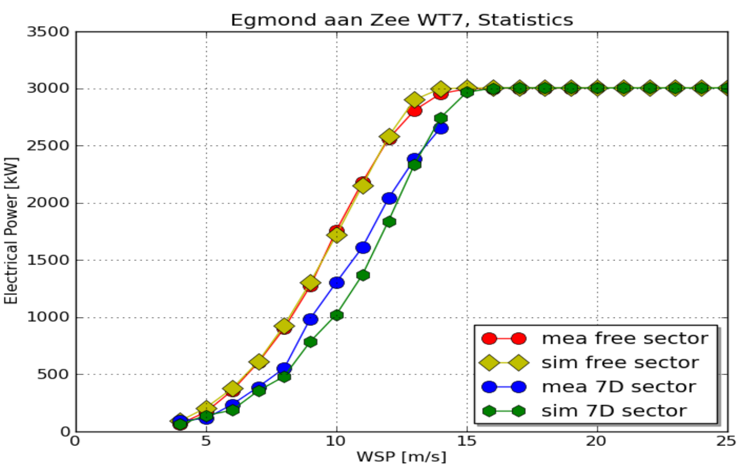
The optimization "engine" (2)

- Does it work? ... a full-scale verification (based on WT7)









Results/objective function (1)

- Only variable costs (i.e. costs depending on the wind farm topology) are included in the objective function (OF)
- OF formulated as a financial balance expressing the difference between the wind farm income (power production (WP)) and the wind farm expenses (i.e. O&M expenses (CM), cost of turbine fatigue load degradation (CD), and financial expenses (C) – in this case including grid costs (CG) and foundation costs (CF))

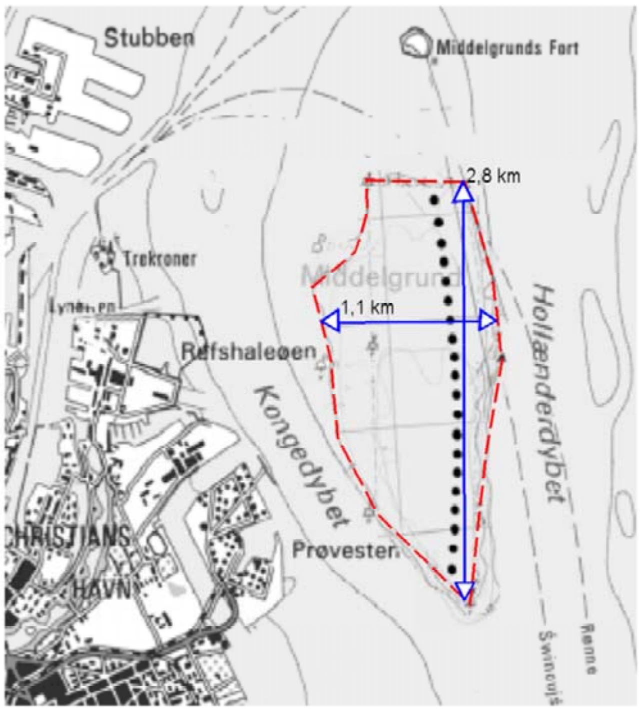
$$FB = WP_n - C\left(1 + \left(\frac{r_{c1} - r_i}{N_L}\right)\right)^{XN_L},$$

$$WP_n = WP - CD - CM \quad ,$$

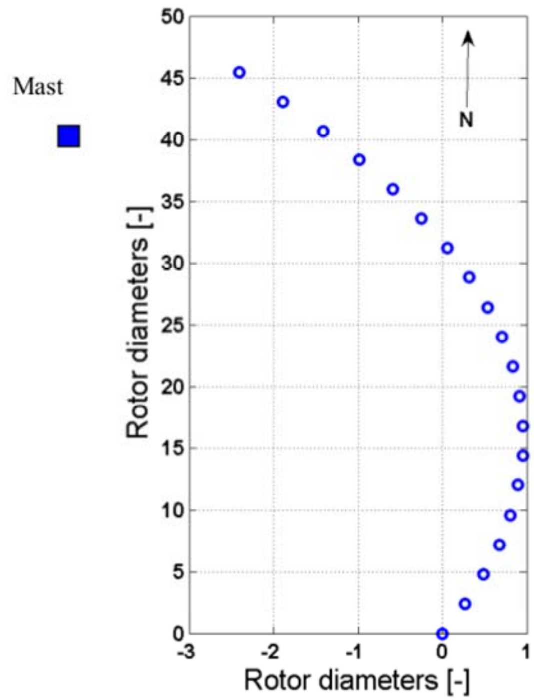
Results/objective function (2)

- All operating costs (i.e. *CD* and *CM*) refer to year Zero …. with the implicit assumption that the development of these expenses over time follows the inflation rate, and that the inflation rate is the natural choice for the discounting factor transforming these running costs to *net present value*.
- We have also referred the value of the wind farm power production over the wind farm lifetime, *WP*, to year Zero.

Results/Middelgrunden (1)



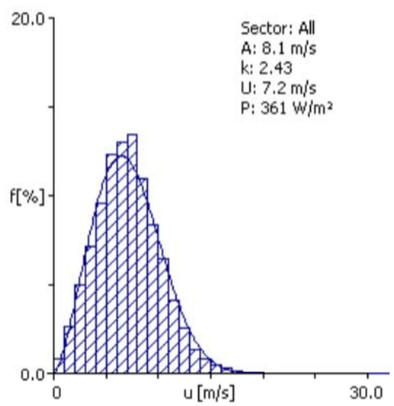
Allowed wind turbine region

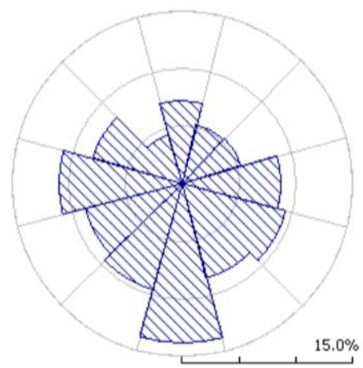


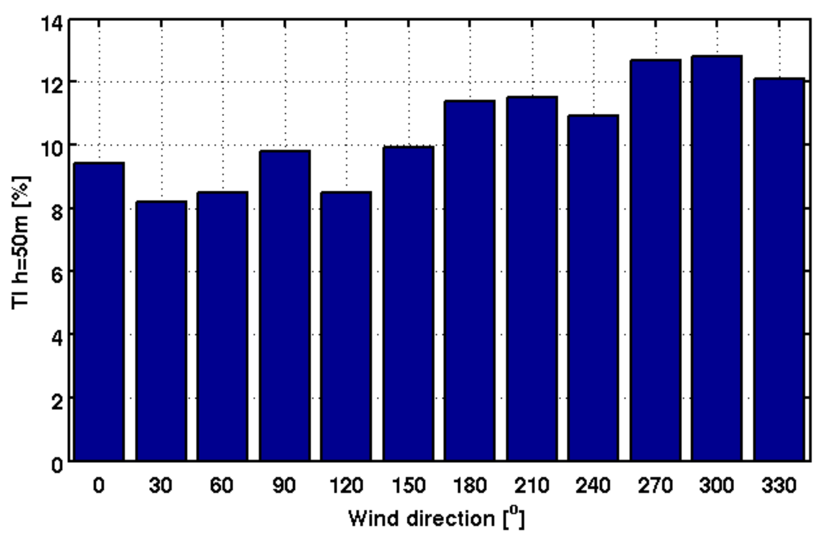
Middelgrunden layout

Results/Middelgrunden (2)

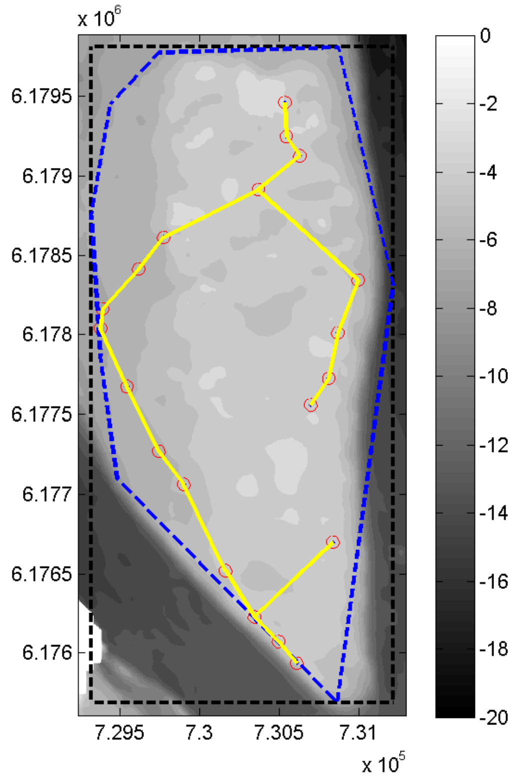
- Ambient wind climate:

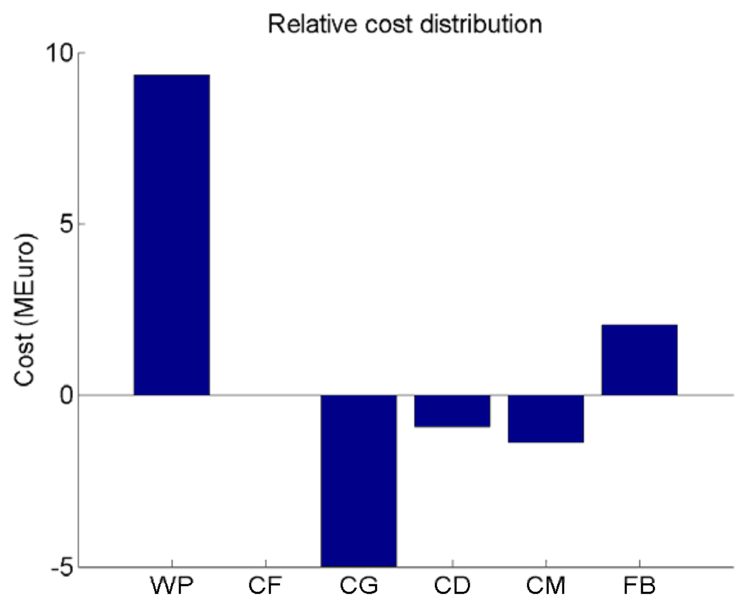






Results/Middelgrunden (3)





Optimum wind farm layout (left) and financial balance cost distribution relative to baseline design (right).

Results/Middelgrunden (4)

- The baseline layout was based on visual considerations
- The optimized solution is fundamentally different from the baseline layout ... the resulting layout makes use of the entire feasible domain, and the turbines are not placed in a regular pattern
- The foundation costs have not been increased, because the turbines have been placed at shallow water
- The major changes involve energy production and electrical grid costs ... both were increased
- A total improvement of the financial balance of 2.1 M€ was achieved compared to the baseline layout

Conclusion(s)

- A new optimization platform has been developed that allow for wind farm topology optimization in the sense that the *optimal economical performance,* as seen over the lifetime of the wind farm, is achieved
- This is done by:
  - Taking into account both loading (i.e. degradation) and production of the individual turbines in the wind farm in a realistic and coherent framework .... and by
  - Including financial costs (foundation, grid infrastructure, etc.) in the optimization problem
- The performance of the platform has been demonstrated for an off-shore example site

Outlook

- (Possible) future model extensions:
  - Inclusion of atmospheric stability effects (… important for production; cf. L. Jensen & R. Barthelmie)
  - Full DWM based optimization (presently only the closest upstream turbine is considered load generating) ... improved accuracy
  - Parallization of the code … improved computational speed
  - Aeroelastic computations in the frequency domain … improved computational speed
  - Cheapest rather than shortest cabling between turbines
  - Inclusion of extreme load aspects
  - Eddy viscosity model consistent with the DWM split in scales … improved description of the wake deficit