EERA-DTOC: *How aerodynamic and electrical aspects come together in wind farm design*

G. Schepers, A van Garrel, E Wiggelinkhuizen, J. Pierik, E. Bot
(*ECN Wind Energy)*
Wei He (*Statoil Petroleum AS*)

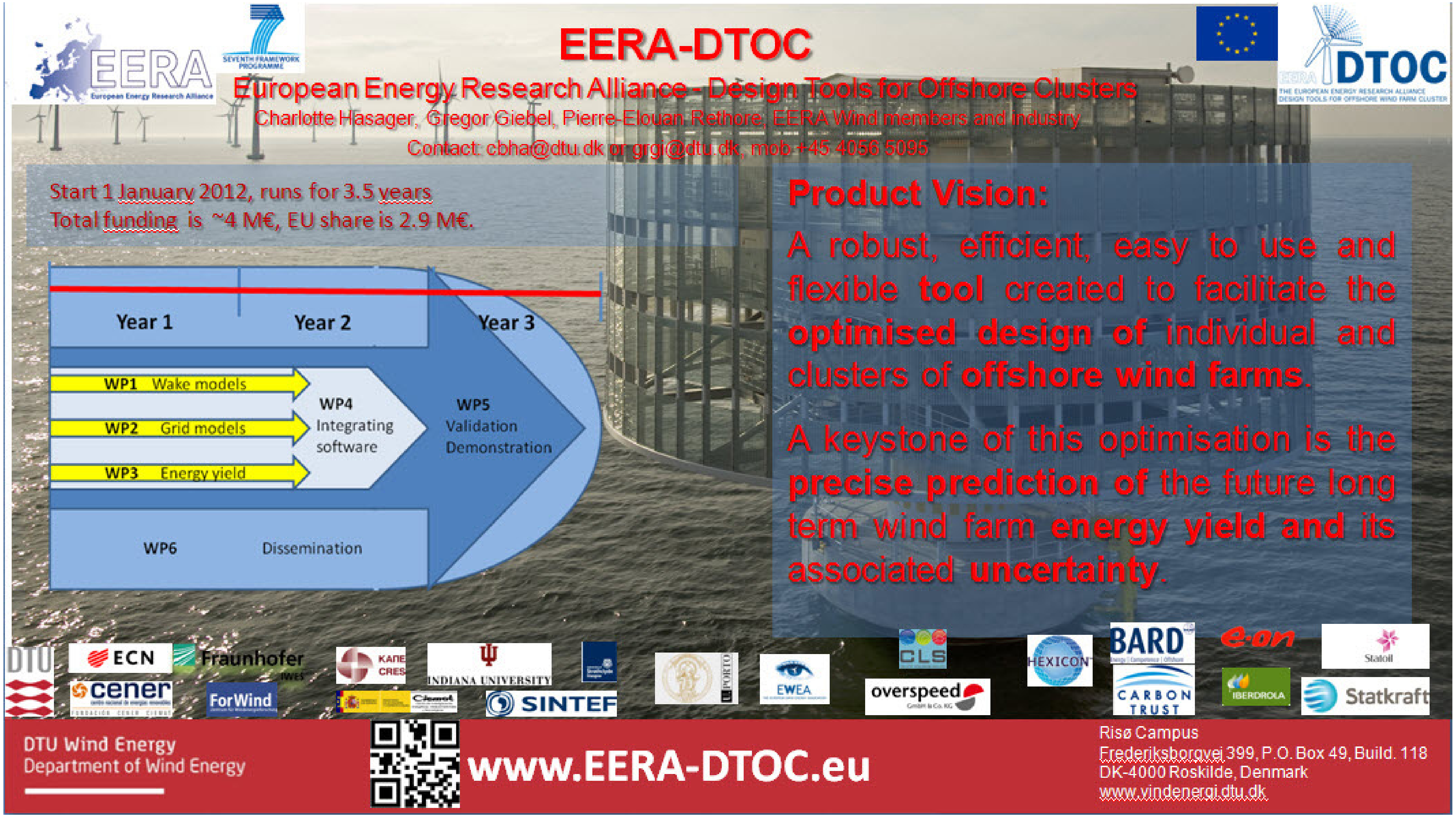
EERA DTOC
THE EUROPEAN ENERGY RESEARCH ALLIANCE
DESIGN TOOLS FOR OFFSHORE WIND FARM CLUSTER

Support by
FP7-ENERGY-2011-1/ n°282797
SEVENTH FRAMEWORK PROGRAMME

Contents

- *EERA-DTOC: Introduction*
- EERA-DTOC: Scenarios to be calculated
- EERA-DTOC: Results from a preliminary scenario calculated with ECN's tools FarmFlow and EEFARM

EERA-DTOC summary slide



EERA-DTOC main idea

- Use and bring together existing models from the partners
- Develop open interfaces between them
- Implement a shell to integrate
- Fine-tune the wake models using dedicated measurements
- Validate and demonstrate the final tool through likely scenarios

Contents

- EERA-DTOC: Introduction
- *EERA-DTOC: Scenarios to be calculated*
- EERA-DTOC: Results from a preliminary scenario calculated with ECN's tools FarmFlow and EEFARM

Scenarios

- Demonstration of INTEGRATED design tool to verify user requirements
- Measurement data are scarce and synchronous measurement data for wind farm clusters are fully missing
    - Tools will be demonstrated on basis of likely scenarios.
- Industry is heavily involved in the definition of scenarios

Scenarios

Scenarios:

1. **Base and near future scenario**
   - *Base scenario*: Single 500 MW wind farm with 6 MW turbines,
   - *Near future scenario*:
     - Carried out in steps
       1. Single 1GW wind farm with 10 MW turbines
       2. Adding other wind farms → cluster
2. **Far future** scenario:
   - Offshore wind farm clusters including innovations, e.g. floating turbines

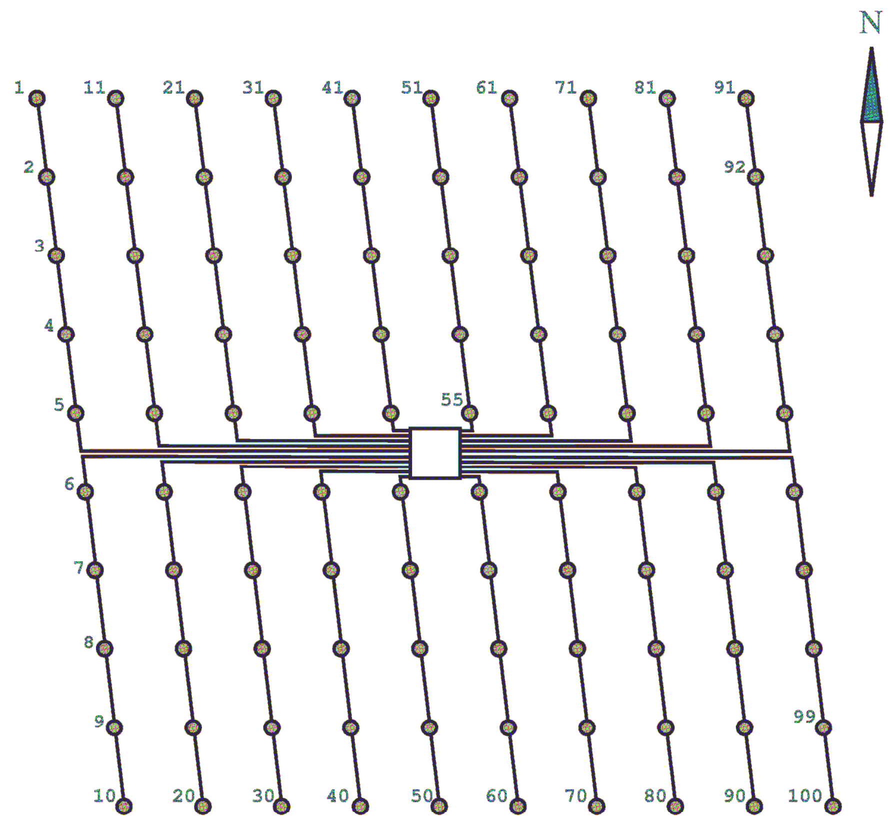
Scenario 1→2 reflects:

- A shift towards the future.
- Increasing complexity of the modeling problem
- A shift in target group:
  - Developers (base scenario)
  - Developers and strategic planners (far future scenario)

Present study focusses on near future scenario

EERA DTOC

- Single 1000 MW wind farm (other wind farms will be added at later stage to form a cluster)
- 100*10 MW turbines
  - Innwind.EU 10 MW reference turbine
- 20 parallel grid lines (66 kV) connecting 5 turbines to a central sub station
- North Sea wind climate
- Distance to shore: ~125 km
- Water depth: ~40 m

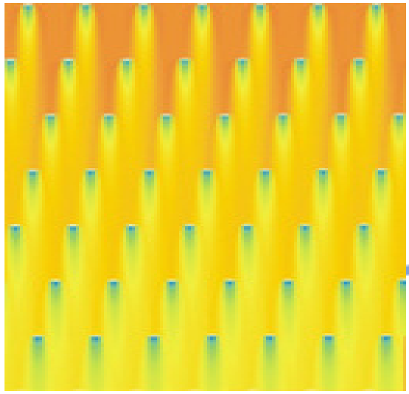


Contents

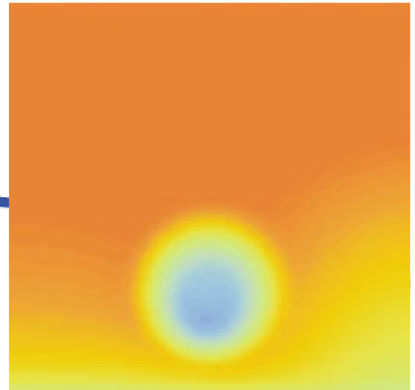
- EERA-DTOC: Introduction
- EERA-DTOC: Scenarios to be calculated
- *EERA-DTOC: Results from a preliminary scenario calculated with ECN's tools FarmFlow and EEFARM*

‘Preliminary’ scenario

- Eventually the scenarios will be calculated with the final EERA-DTOC tool
- ‘Preliminary’ scenario calculated with a combination of ECN’s aerodynamic (FarmFlow) and electrical tool (EEFARM)
  - Demonstrates value of INTEGRATED electrical-aerodynamic tool
  - Near future scenario, starting with 10D distance between the turbines (low aerodynamic losses versus high electrical losses and high costs for electrical infrastructure)
    - Decrease distance
      - Higher aerodynamic losses can be balanced versus lower electrical losses and lower costs for electrical infrastructure



What is FARMFLOW?

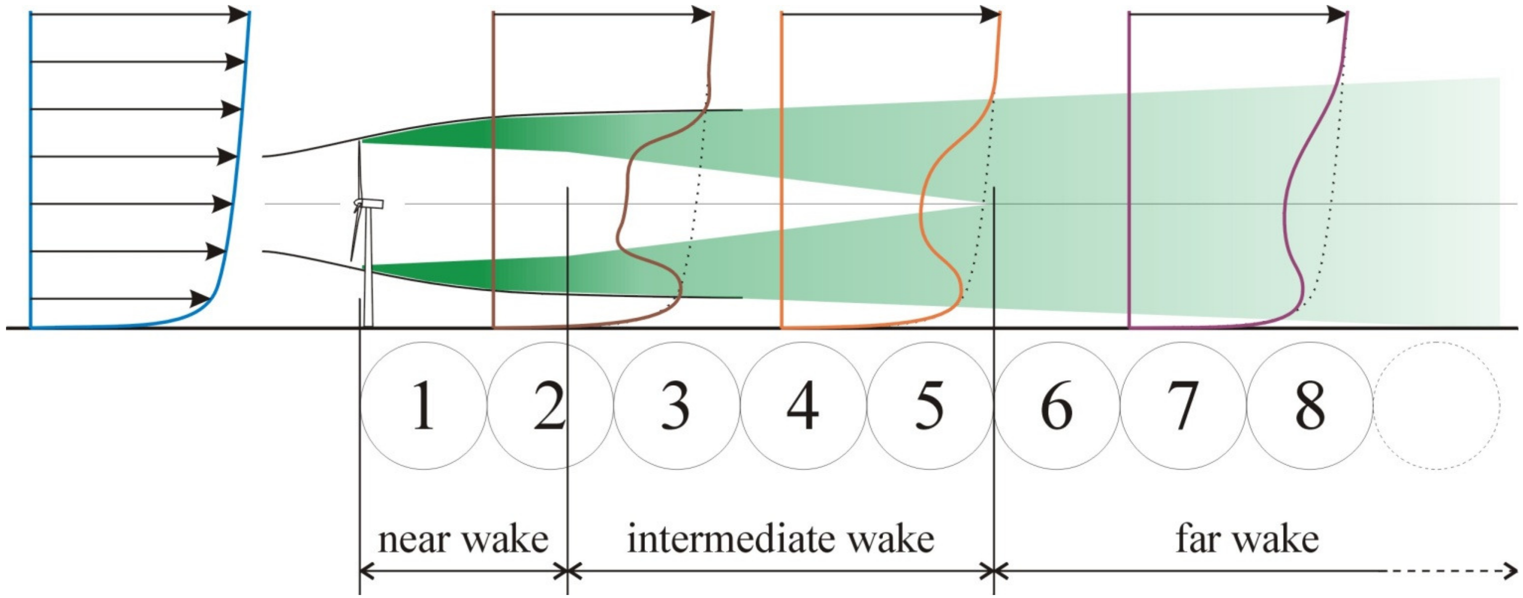


- Calculates:
  - Losses and added turbulence due to wakes
  - Annual energy production (AEP)
- The model is based on UPMWAKE [1])/WAKEFARM
  - Modified by ECN since 1993
  - Extensively validated with results from ECN's research farms and measurements from EU projects (e.g. ENDOW, Upwind, EERA-DTOC)

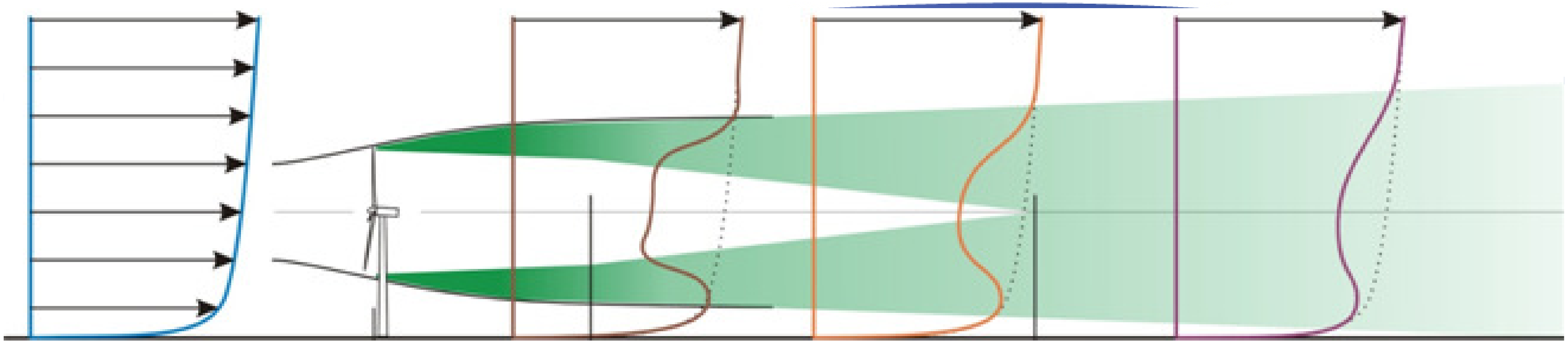
[1]) Crespo et al. 1988

FARMFLOW: Theory and the Model description

- Solves the Parabolized Navier-Stokes equation
- Turbines modelled as actuator disc, prescribed by C_{Dax}
- Wake modelled with a k-ε turbulence model



FARMFLOW: Advanced Model Properties



- Parabolisation: Fast, but how to solve the near wake where axial pressure gradients are significant?
- Solution:
  - Prescribe axial pressure gradients from free vortex wake method!
    - Fast database approach
    - Wake interaction fully modeled including the effect of a non-zero pressure gradient and retaining the (fast) parabolisation
- Adjusted k-ε turbulence model parameters in near wake to account for actuator disc assumption, based on:
  - Measurements from ECN's research farms and Horns Rev farm
  - Detailed wake measurements in TUDelft wind tunnel underway *)

*) Lorenzo Lignaroli, TUDelft, personal communication

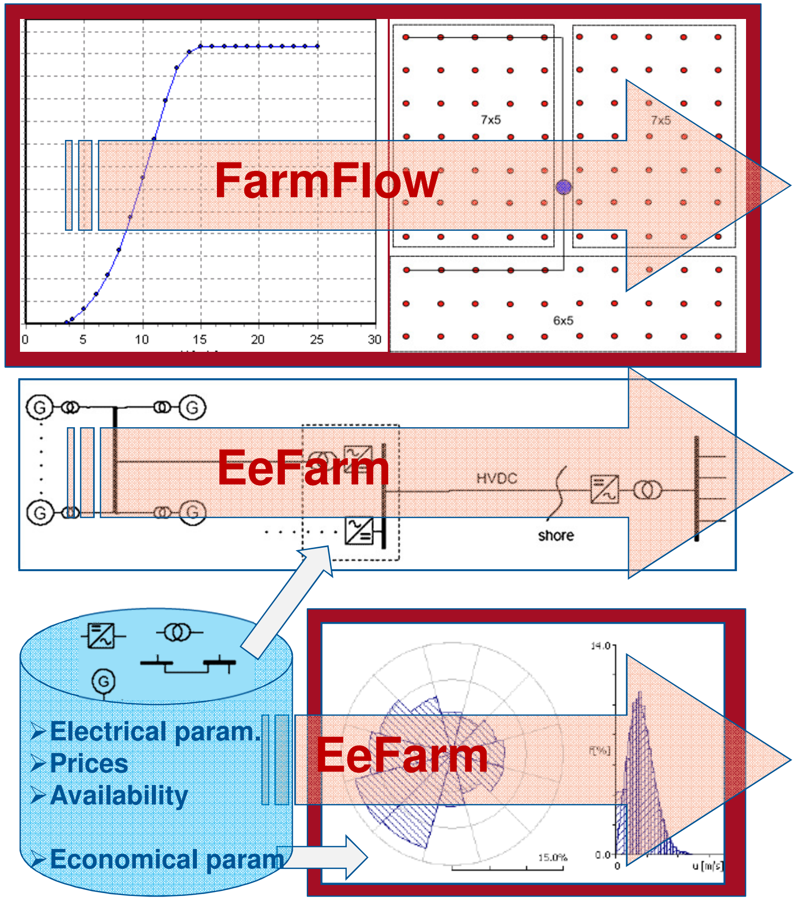
What is EEFARM?

ECN

EERA DTOC

- Program to study and optimise the electrical performance of wind farms.
- Program is used to determine the:
  - Energy production,
  - Electrical losses,
  - Component failure losses
  - Price of the produced electric power

EeFarm-II linked to FarmFlow!



Aerodynamic power:

$P_{WT1} \ldots P_{WTN} = f\,(Vw, Vdir)$

Investments

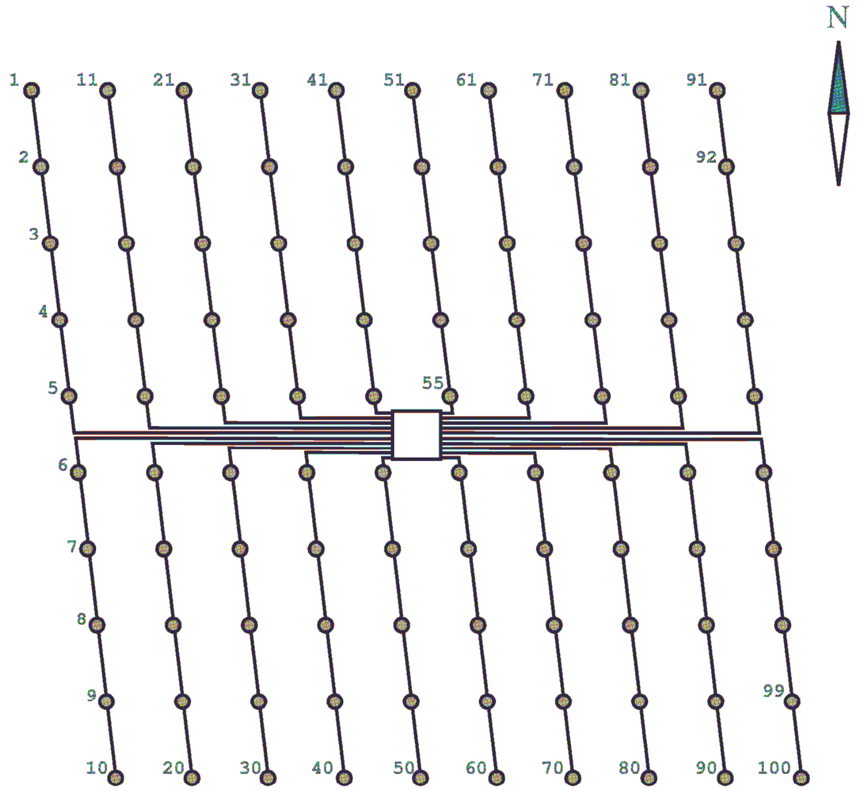
P_{loss}

P_{fail}

per component

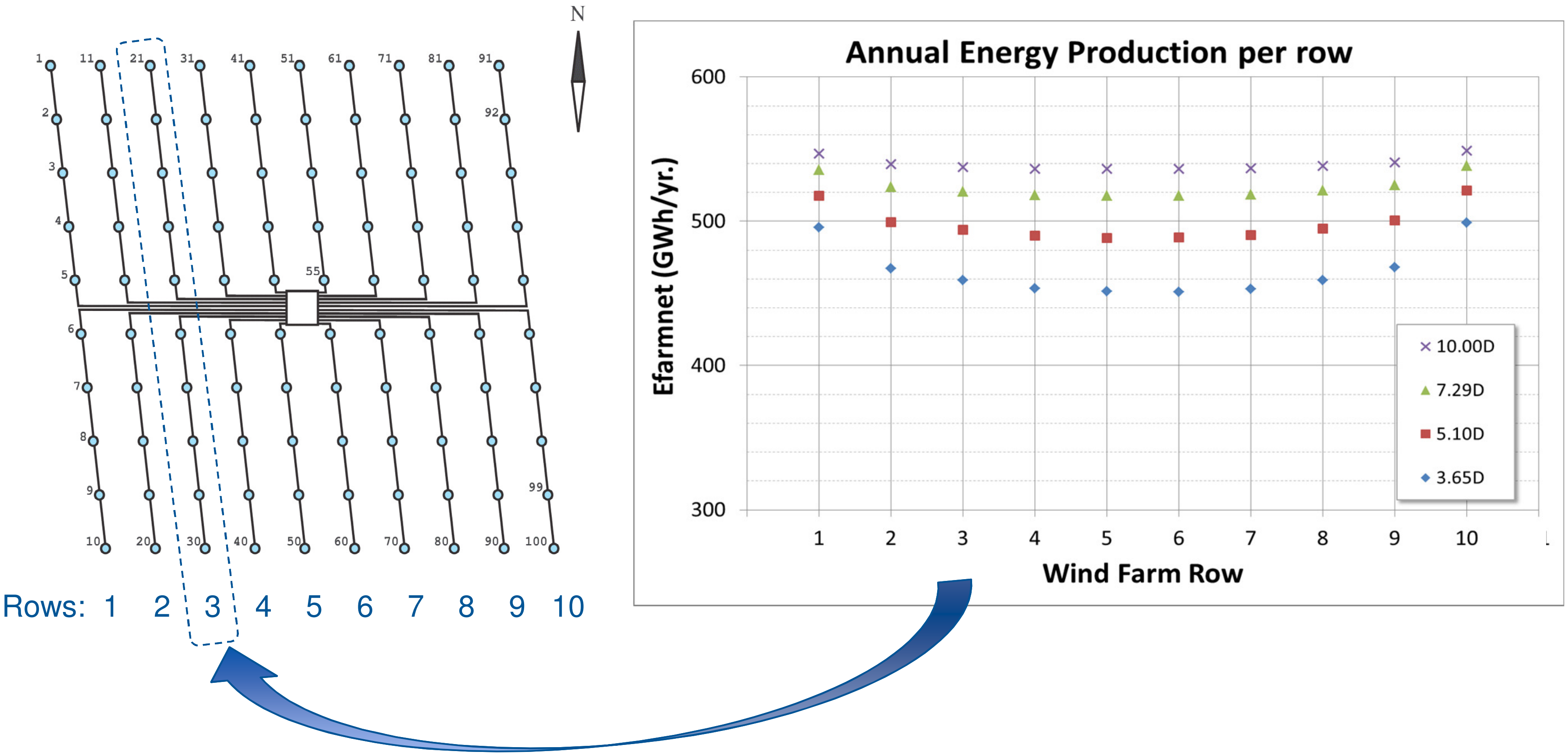
Levelized Production Costs

Reminder: Lay-out of 1GW farm

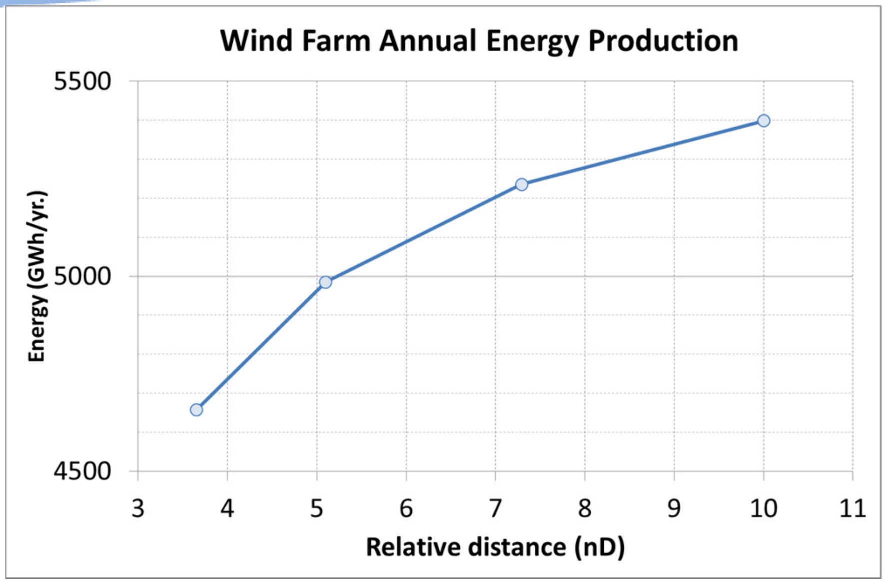


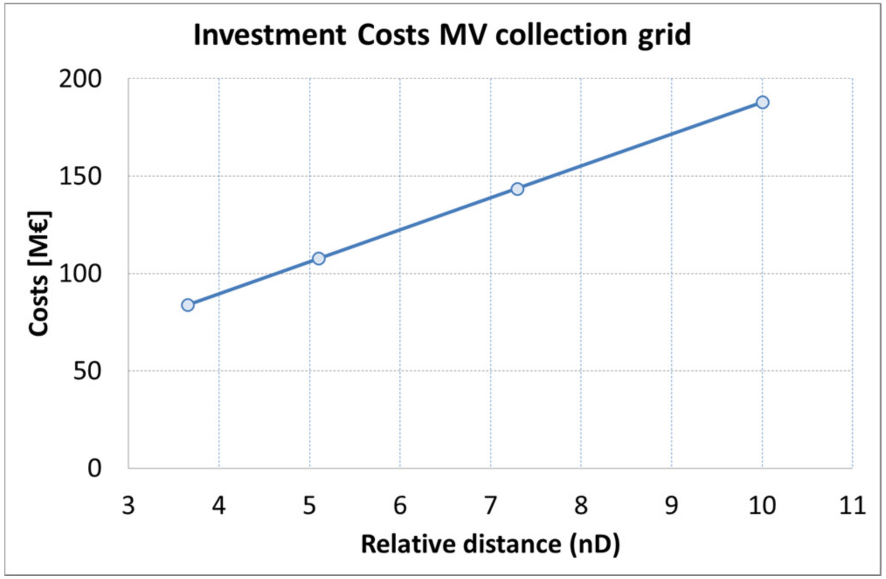
- 100 INNWIND.EU reference turbines of 10 MW
- Inter turbine distance is a variable between 3.6 and 10 D
- 20 parallel grid lines connecting 5 turbines to central substation

Annual Energy Production per row



Main results





Net energy farm production (including aerodynamic **and** electrical losses)

- **Increase** with distance
- Increase **levels off** with distance

Investment costs of electrical infrastructure

- **Linear increase** with distance

Conclusions and Outlook

- Within the EERA-DTOC project a wind farm design tool is developed which combines existing wake models with electrical grid models
- The integrated tool is demonstrated on basis of likely scenarios
- A sequence of scenarios is defined ranging from a base scenario to a far future scenario with a near future scenario in between

Conclusions and Outlook, ctd

- The near future scenario has been calculated with a combination of ECN's aerodynamic tool FarmFlow and the electrical tool EEFARM
- The **net** energy yield increases with distance but the increase becomes less with distance
- The investment costs of the electrical infrastructure increase linearly with distance

Conclusions and Outlook, ctd

- The near future scenario has been calculated with a combination of ECN's aerodynamic tool FarmFlow and the electrical tool EEFARM
- An increase from 3.6 to 10 rotor diameters is earned back in 1.5 years with an energy price of 0.1 Euro/kWh
- First results from an overall cost model (using the energy yield and investments costs of the present study) indicate a decrease in COE when distance is increased from 3.5 to 10 rotor diameters but decrease becomes less with distance
- Work on a cost model which includes the actual FarmFlow/EEFARM parameters (energy yield and investment costs) is underway at ECN based on the former OWECOP model [1]

[1] S.A. Herman Probabolistic Cost model for analysis of offshore wind energy, costs and potential, ECN-I-02-007, 2002, Energy Research Centre of the Netherlands, ECN

Thank you very much for your attention