

Wind Farms Design and Optimization

Presentation of TOPFARM and EERA-DTOC

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Wind Farms Design and Optimization

Presentation of **TOPFARM** and **EERA-DTOC**

Dr. Pierre-Elouan Réthoré

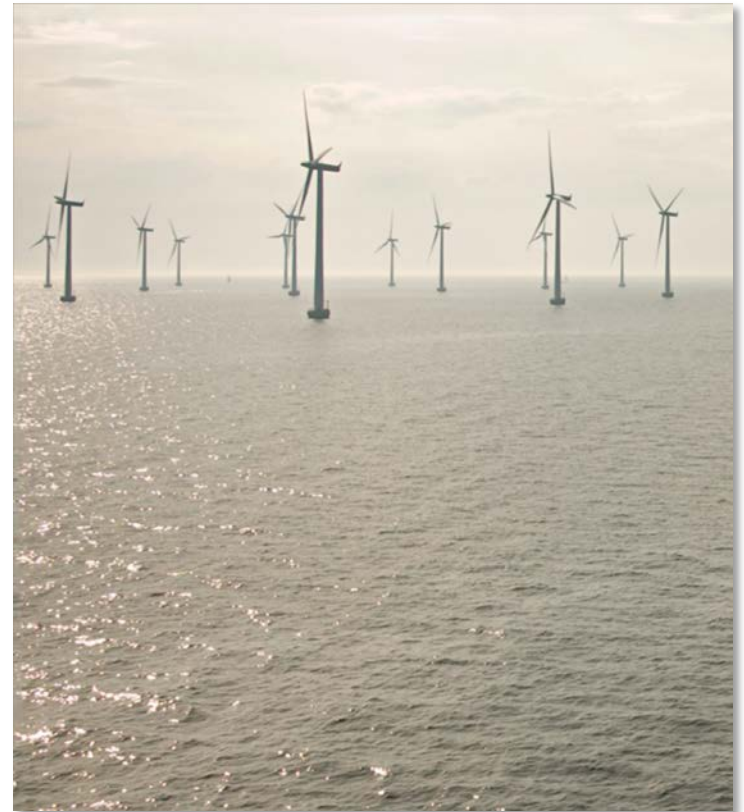
Senior Researcher

Aero-Elastic Design Section

DTU – Wind Energy, Risø

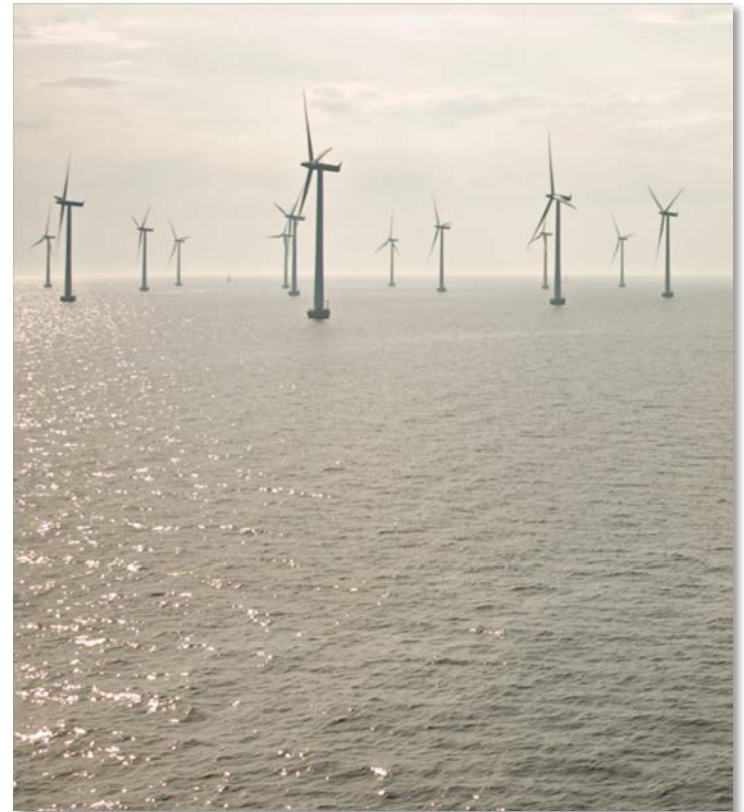
DTU Wind Energy

Department of Wind Energy



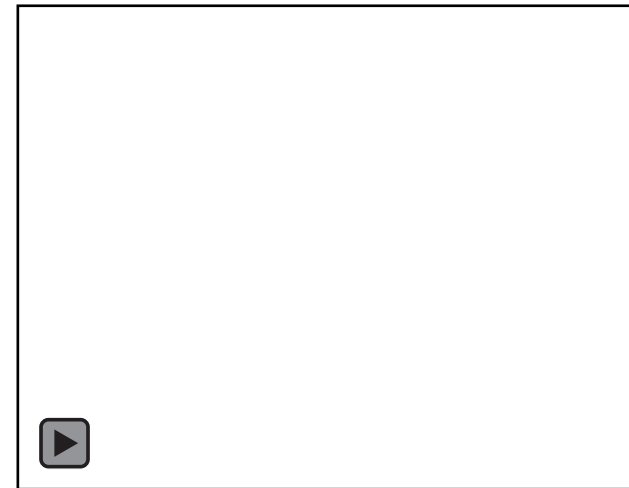
Outline

- Background
- TOPFARM
 - Main Ideas
 - System Overview
 - Some Results
 - Feedbacks from the industry
- Unified Framework
- TOPFARM II
 - Main Ideas
 - System Overview
- EERA-DTOC
 - Main Idea
 - System Overview
- Conclusions



Background

- Aero-Elastic Design Section is principally interested in wind turbine design
- Wind turbines design depends of inflow inputs (upstream wakes)
- Dynamic Wake Meandering can calculate wake induced loads
- Other wake models can calculate power production (e.g. FUGA)
- How can we introduce these tools together into wind farm design?



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TOPFARM

Main Idea

- **TOPFARM** = Topology **OP**timization of wind **FARM**
- **EU-FP6** Funded project 2006-2010
- **Multi-fidelity** framework for wind farm layout optimization
- Optimization from the **wind farm developer** perspective
- Objective function is the wind farm lifetime **financial balance**
- The cost models take into account:
 - Wake effects on power production
 - Wake effects on wind turbines components fatigue
 - Offshore foundation costs
 - Electrical grid cabling
 - Financial parameters

TOPFARM System Overview

Multi-fidelity:
2nd Level

Optimization:
Gradient based

Meta model

Dynamic Wake Meandering model

Aero-elastic model (HAWC2)

Layout Optimization

Stationary wake model

Foundations cost

Annual Energy Production

Fatigue induced costs

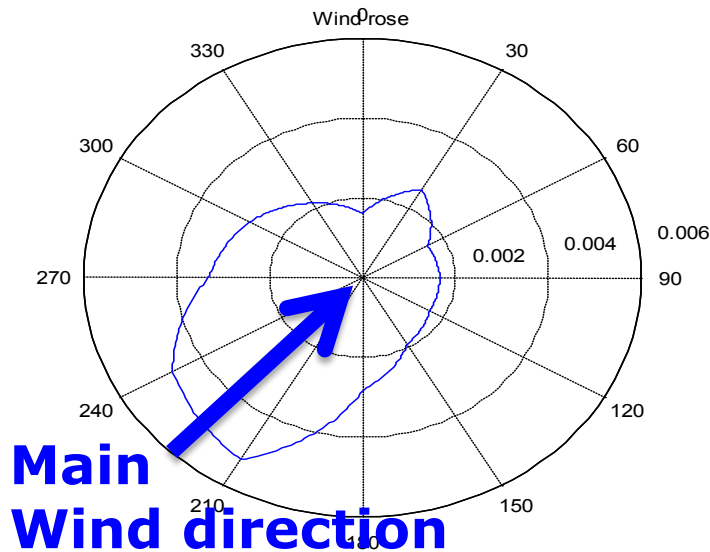
Electrical grid cost

Financial Balance

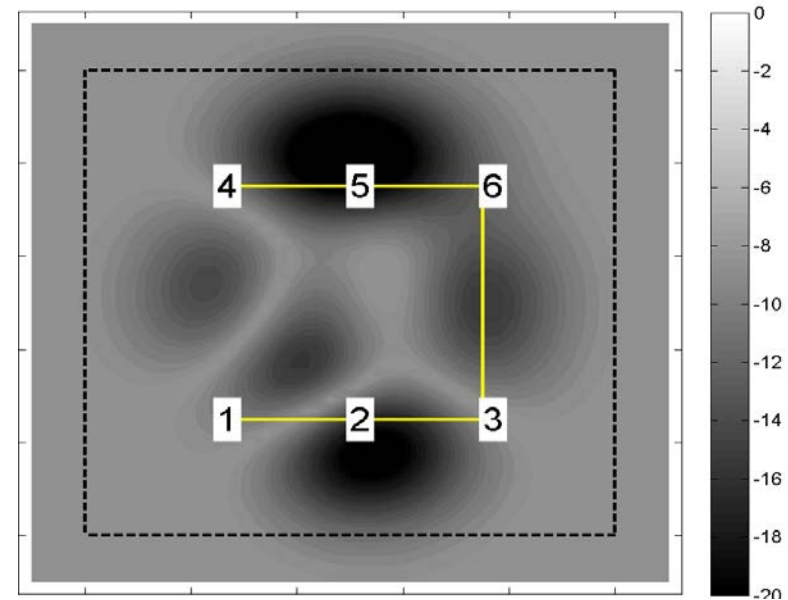
TOPFARM

Demonstration example 1

- Generic offshore wind farm:
 - 6 × 5MW offshore wind turbines
 - Water depths between 4m and 20m



Wind direction probability density distribution

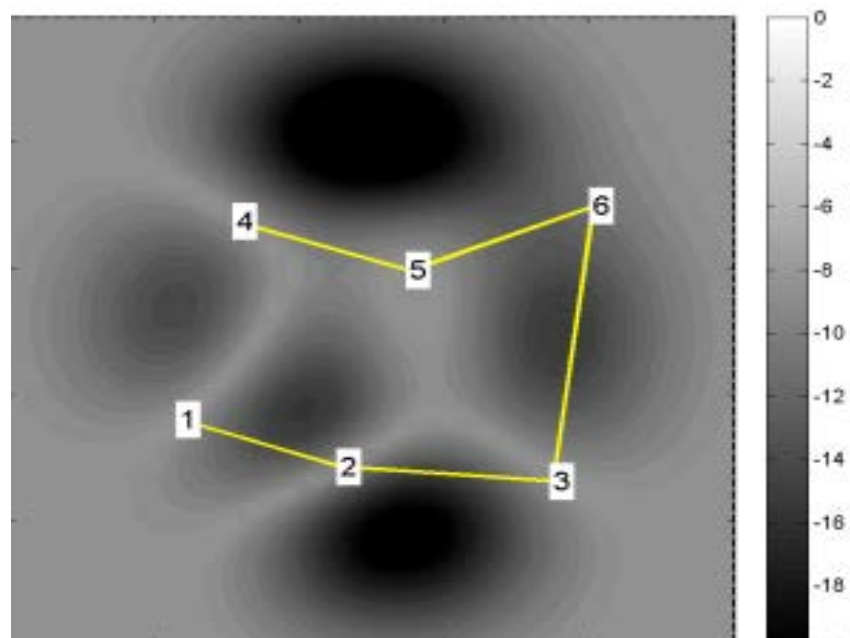
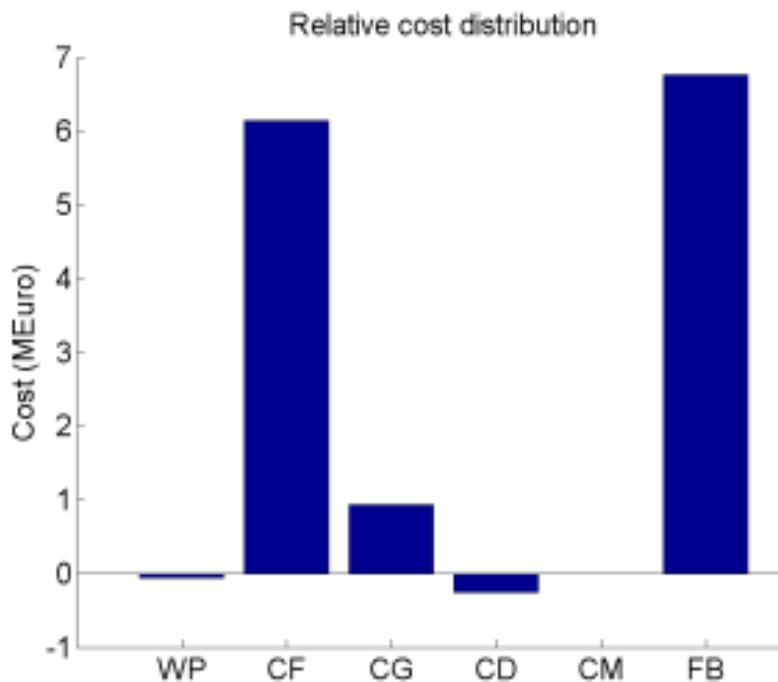


Gray color: Water depth [m]
Yellow line: Electrical grid

TOPFARM

Demonstration example 1

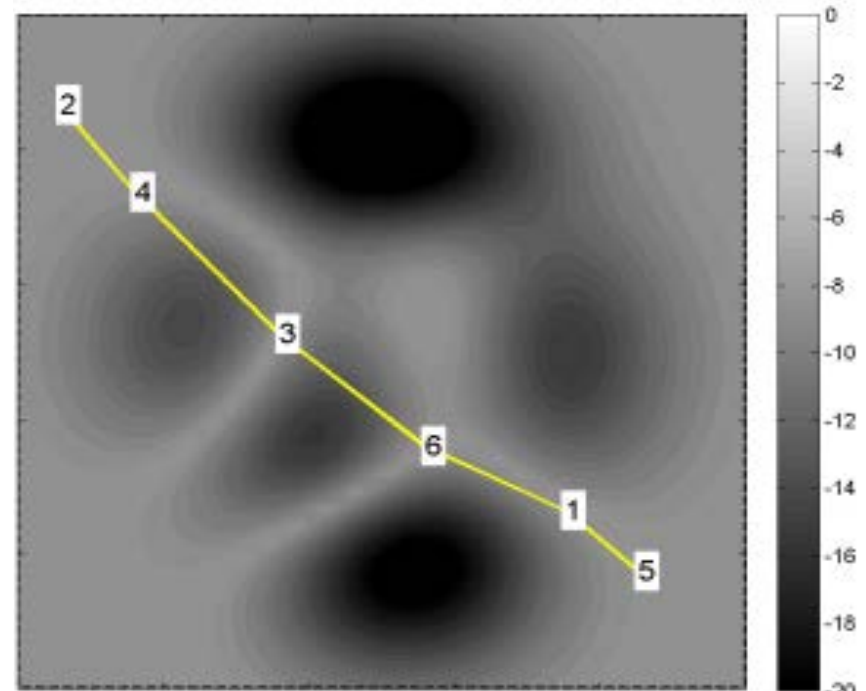
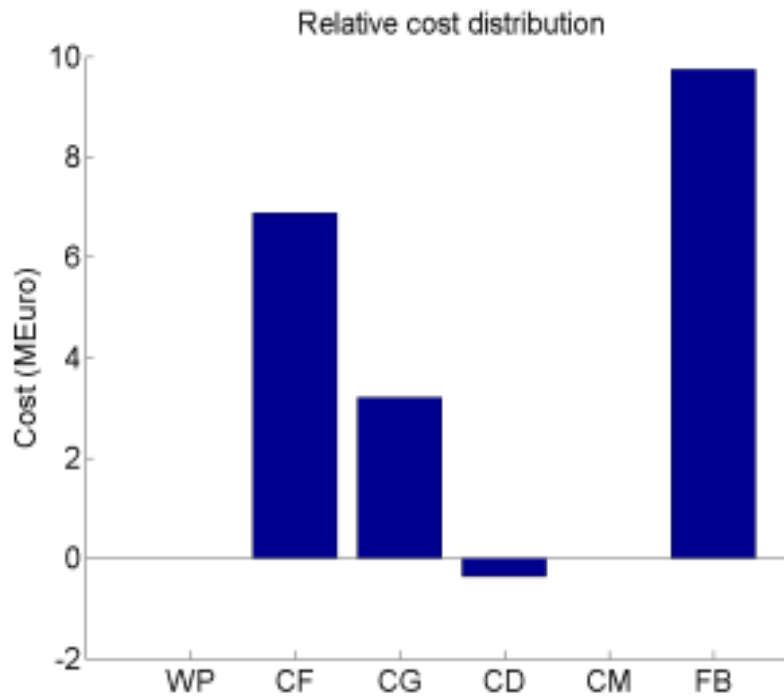
- Result of a gradient based optimization:



TOPFARM

Demonstration example 1

- Result of a genetic algorithm + gradient based optimization



TOPFARM

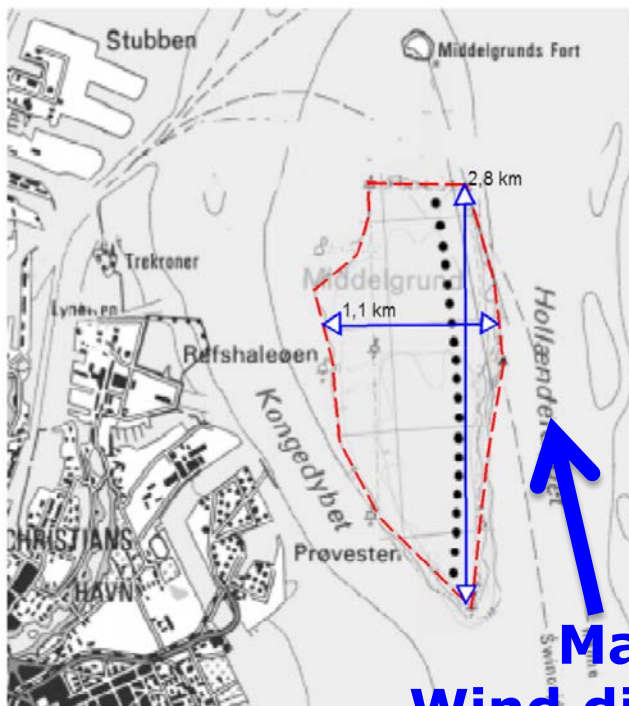
Demonstration example 2

- Middelgrunden

TOPFARM

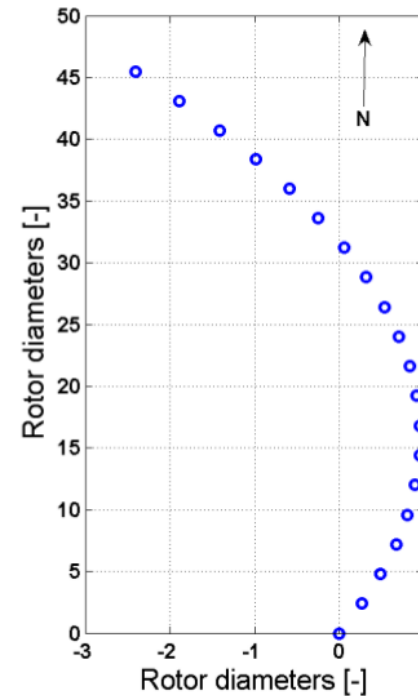
Demonstration example 2

- Middelgrunden



Allowed wind turbine region

Mast

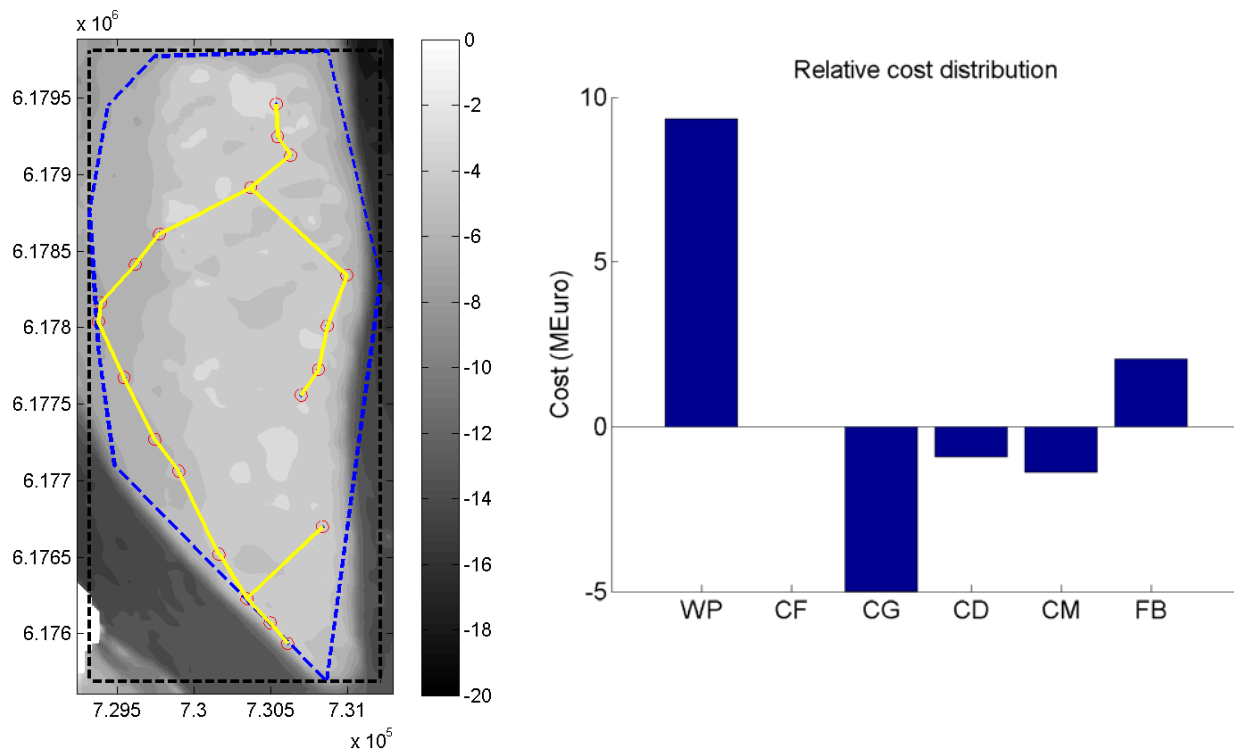


Middelgrunden layout

TOPFARM

Demonstration example 2

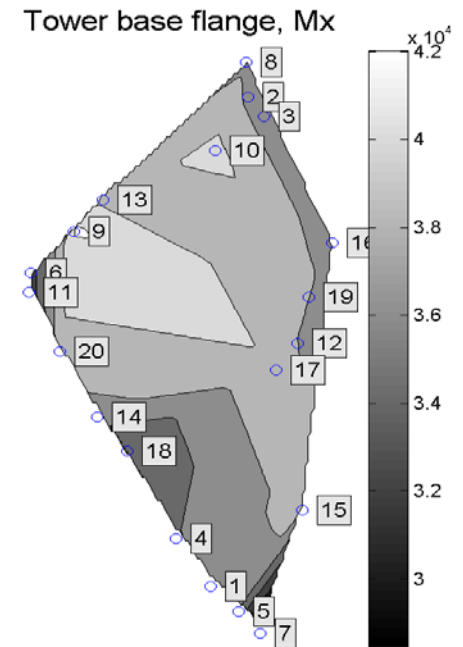
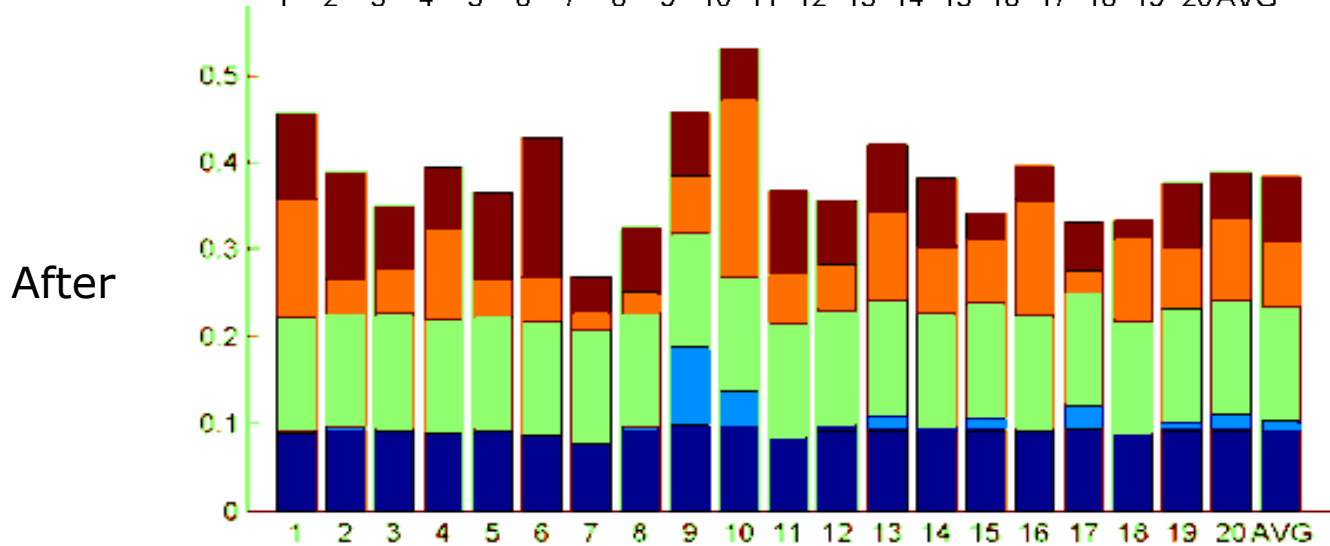
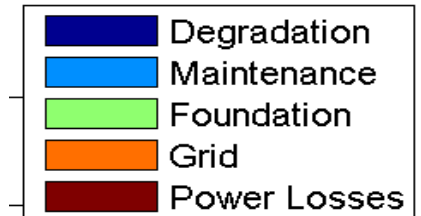
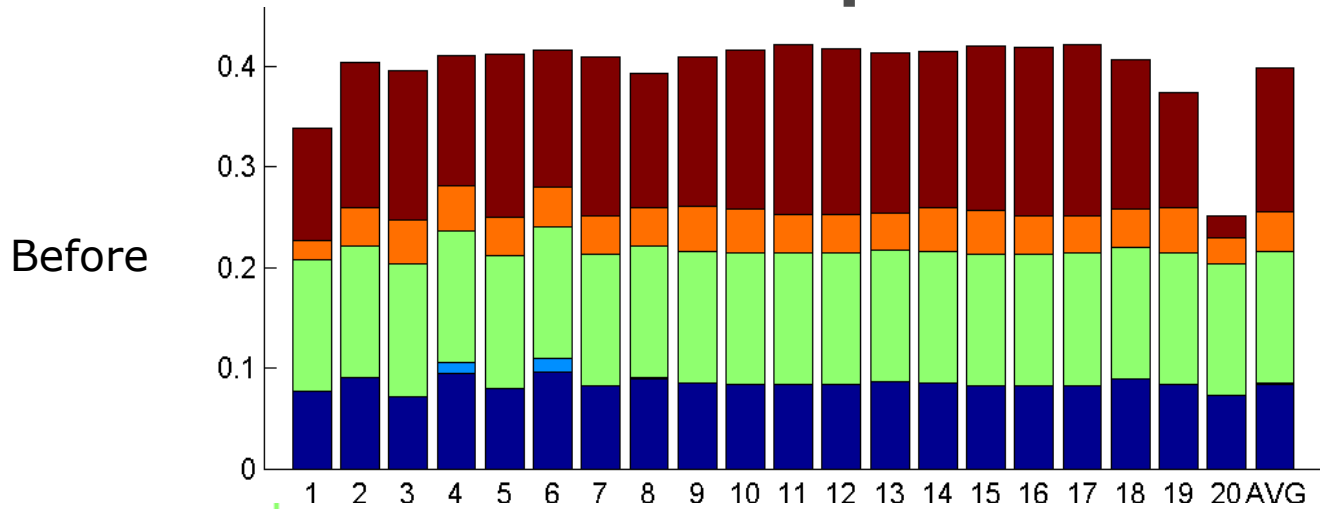
- Middelgrunden iterations: 1000 SGA + 20 SLP



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

TOPFARM

Demonstration example 2



TOPFARM

Feedbacks from the wind industry

- Nice to be able to estimate the wake induced fatigue
- Workflow not ready for a *push-of-a-button* holistic solution
- Multi-disciplinary design tools are difficult to be use in large “bureaucratic” organizations.
- Expert(s) opinion(s) within optimization loop, *somehow*
- Wish for an open framework, to use their own cost & physical models they already have experience with.

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Unified Framework

- In Python
- Based on OpenMDAO (supported by NASA)
- Based on a common wind energy library between DTU & NREL to connect models
- Open source Framework & open/closed modules
- Possibility to easily define and connect your own cost and physical models

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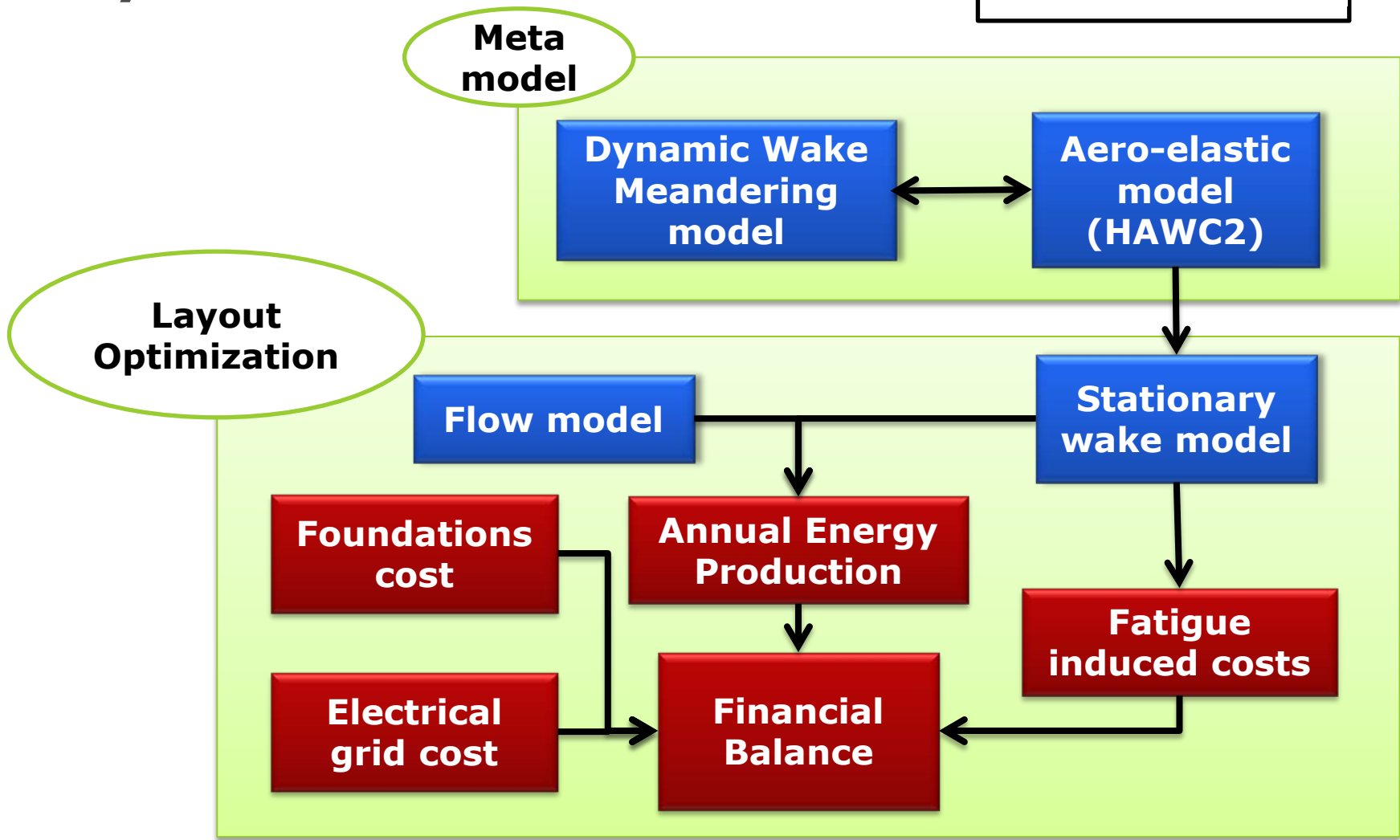
TOPFARM II

Main Ideas

- Use FUGA as the main stationary wake model
- Use WAsP & WRF engine to calculate accurate local wind resources
- 3rd level of fidelity: running the whole wind farm with DWM
- More advanced multi-fidelity optimization strategy
- Higher degree of parallelization
- Expert driven iterative design process
- GUI connected to WAsP

TOPFARM II System Overview

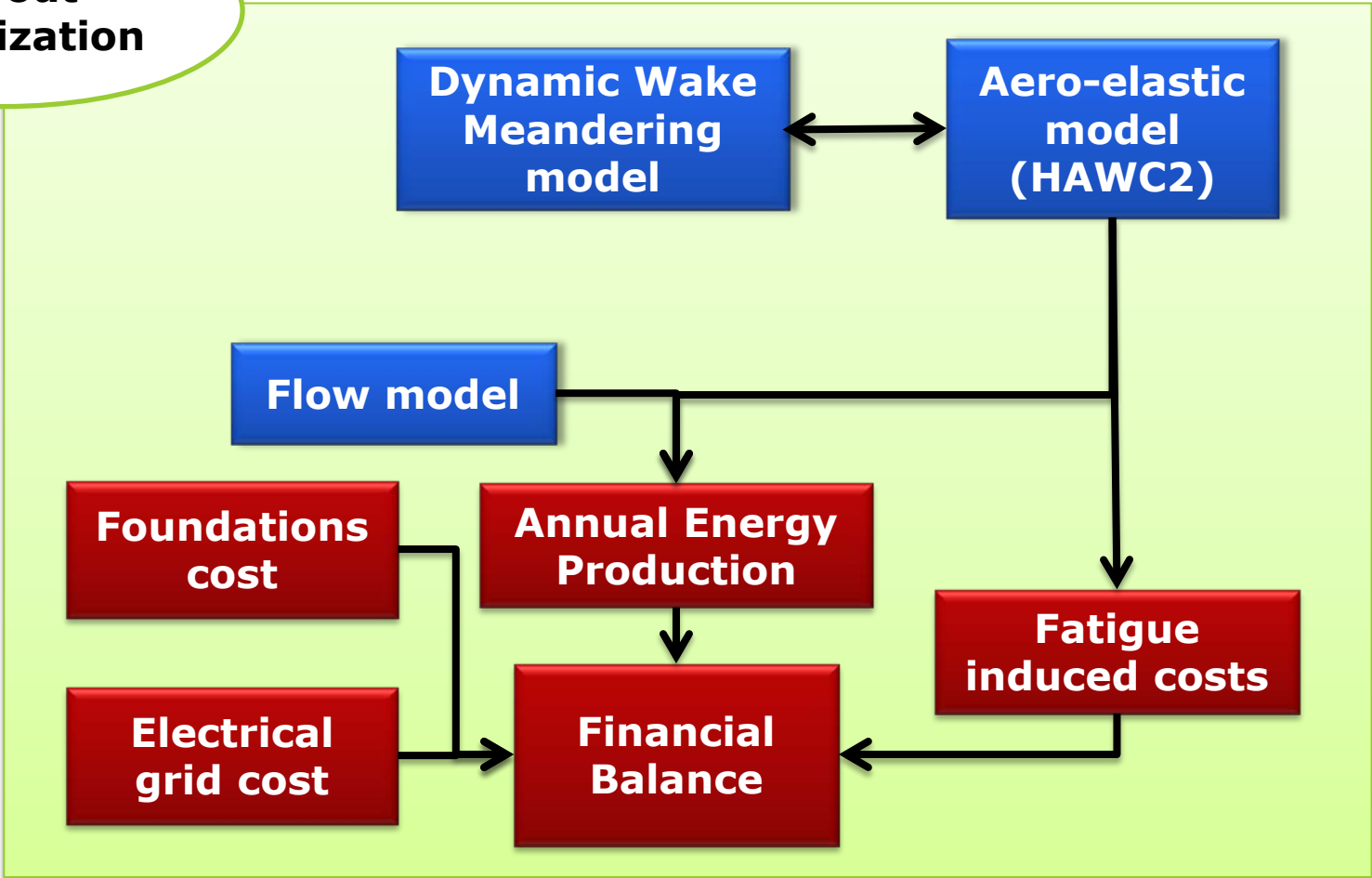
**Multi-fidelity:
2nd Level**



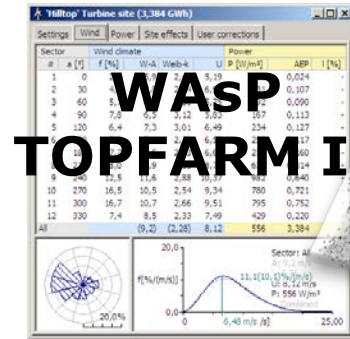
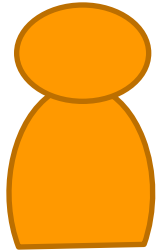
TOPFARM II System Overview

**Multi-fidelity:
3rd Level**

**Layout
Optimization**



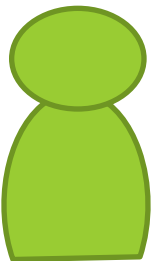
TOPFARM II User Scenario



Automatic



Indirect with data control



Automatic

Private Cluster



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EERA-DTOC

Main Ideas

- **EERA: European Energy Research Alliance**
- **DTOC: Design Tool for Offshore (wind farm) Clusters**
- EU-FP7 funded project, 2012-2015
- Focus on designing wind farm **clusters** considering:
 - Inter wind farms **wake losses**
 - Inter wind farms **electrical cabling**
- Work is underway to deliver an integrated tool for the design of individual wind farms and clusters of wind farms
- The tool is composed of existing models as available throughout Europe
- The tool will be available in December 2014

EERA-DTOC summary slide



EERA-DTOC

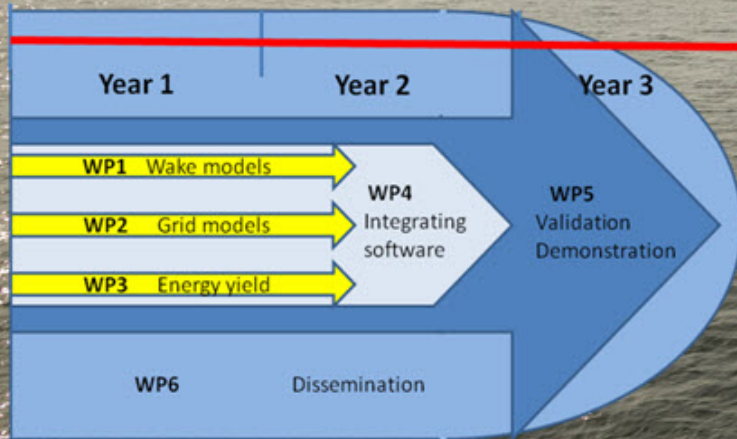


European Energy Research Alliance - Design Tools for Offshore Clusters

Charlotte Hasager, Gregor Giebel, Pierre-Elouan Rethore, EERA Wind members and industry

Contact: cbha@dtu.dk or grgi@dtu.dk, mob +45 4056 5095

Start 1 January 2012, runs for 3.5 years
 Total funding is ~4 M€, EU share is 2.9 M€.



Product Vision:

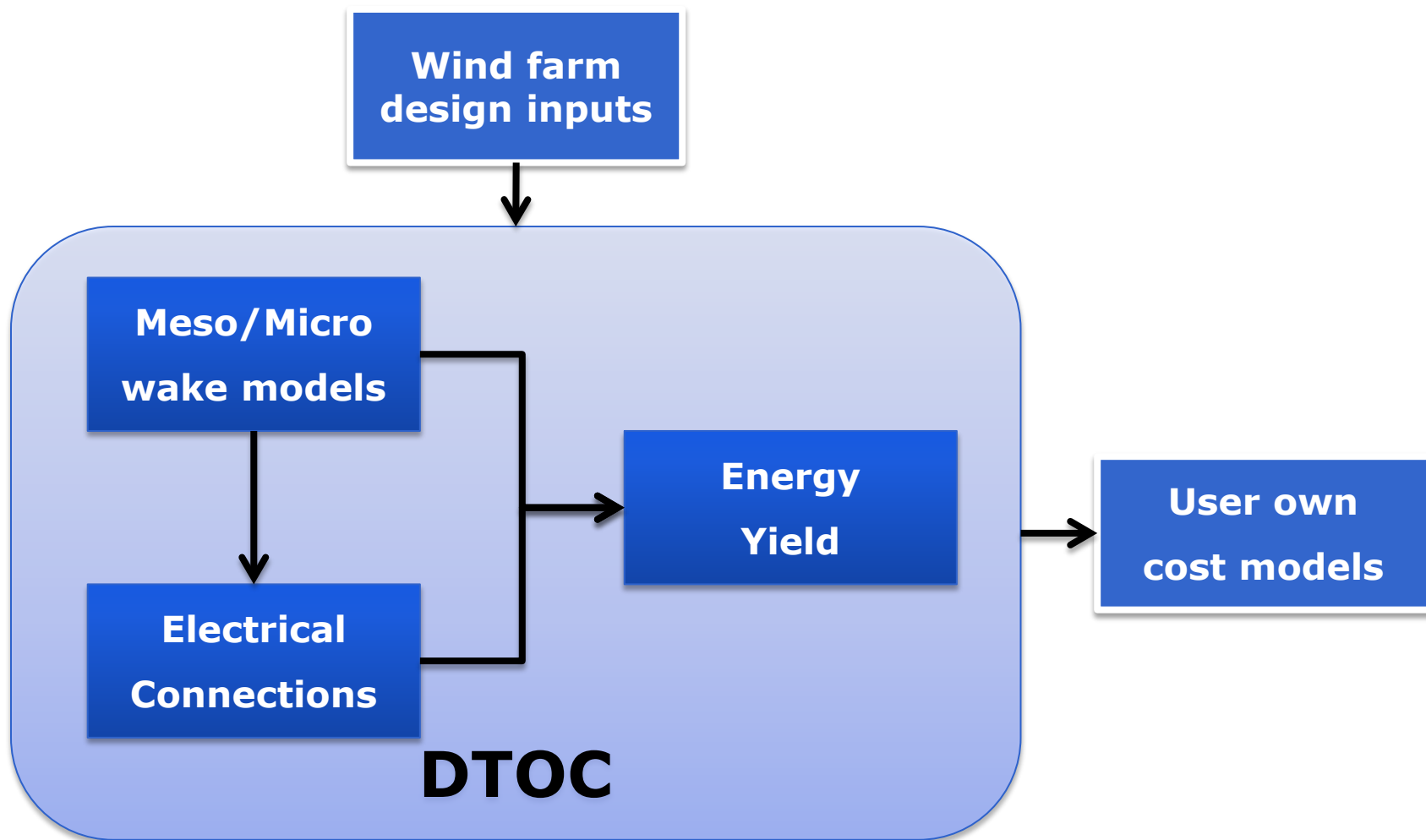
A robust, efficient, easy to use and flexible **tool** created to facilitate the **optimised design of individual and clusters of offshore wind farms.**

A keystone of this optimisation is the **precise prediction of the future long term wind farm energy yield and its associated uncertainty.**



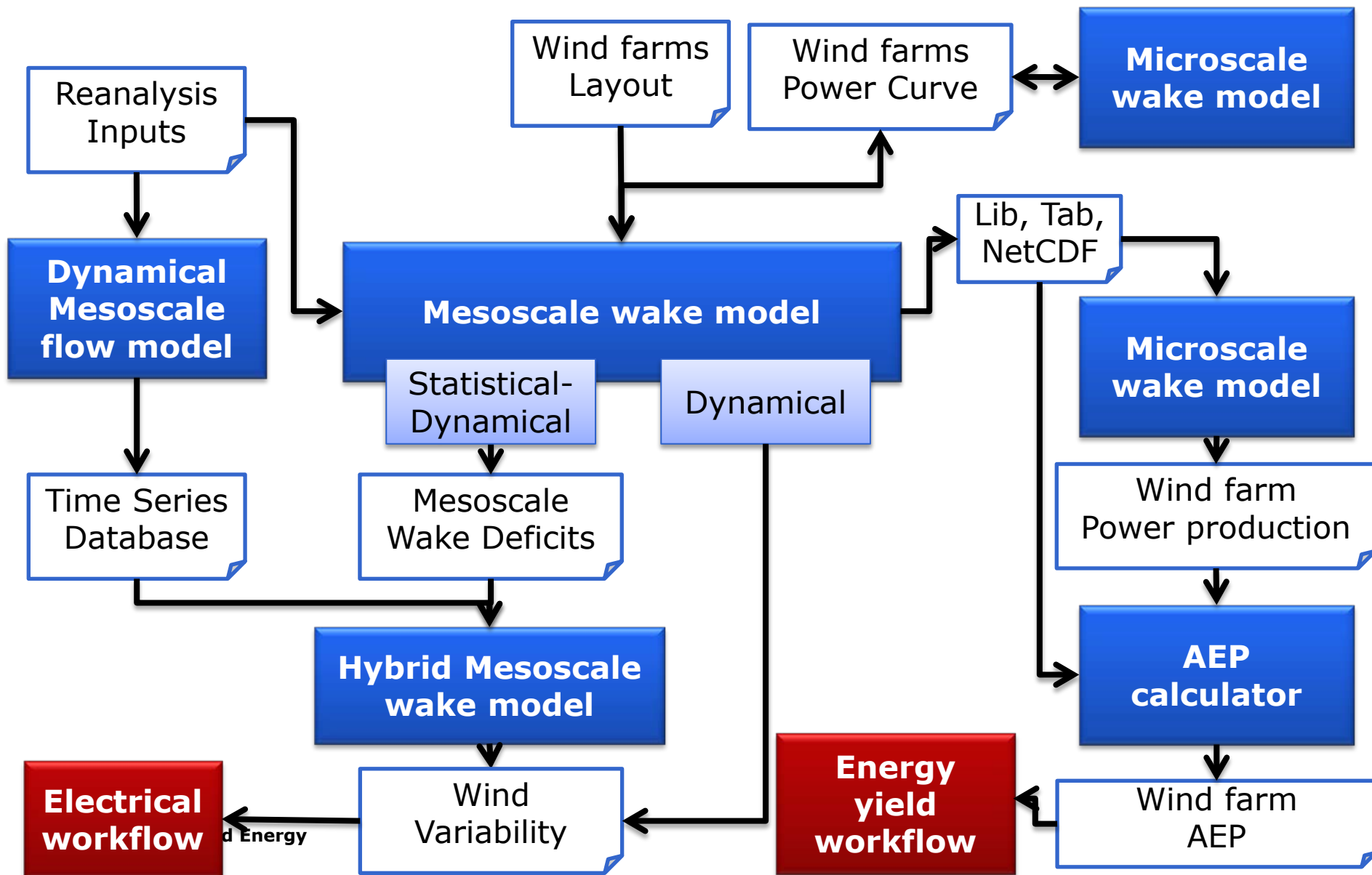
EERA-DTOC

System Global Overview



EERA-DTOC

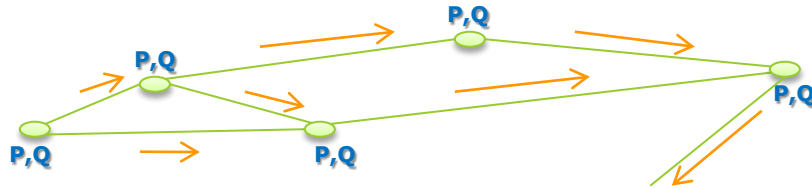
Wake Models Workflow



EERA-DTOC

Electrical Grid Models Workflow

- Fraunhofer IWES

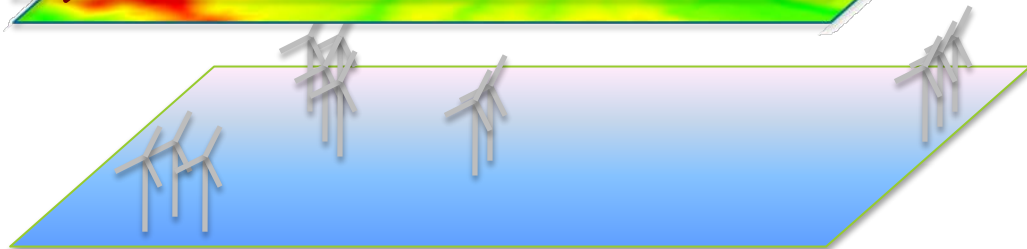
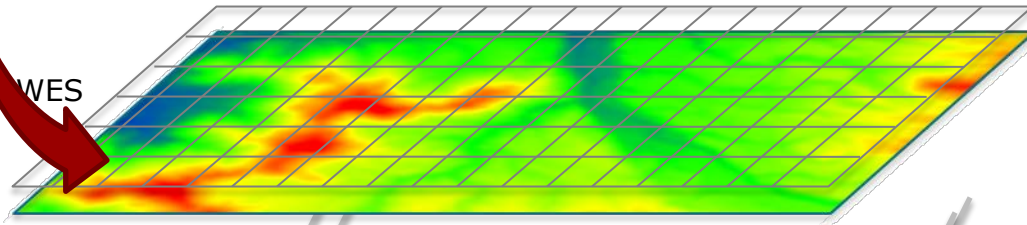


- Strath
- SINTEF



- SINTEF
- Fraunhofer IWES
- Strath
- Statoil
- Hexicon

- Risoe DTU
- Fraunhofer IWES
- CIEMAT



DTU Wind Energy

WCMS model
Analysis of the availability of power plant system services



Grid Codes compliance
PSS/e & PSCAD/EMTDC
Transient analysis



NET-OP model
Grid optimization
Steady-state



Analysis on variability & predictability



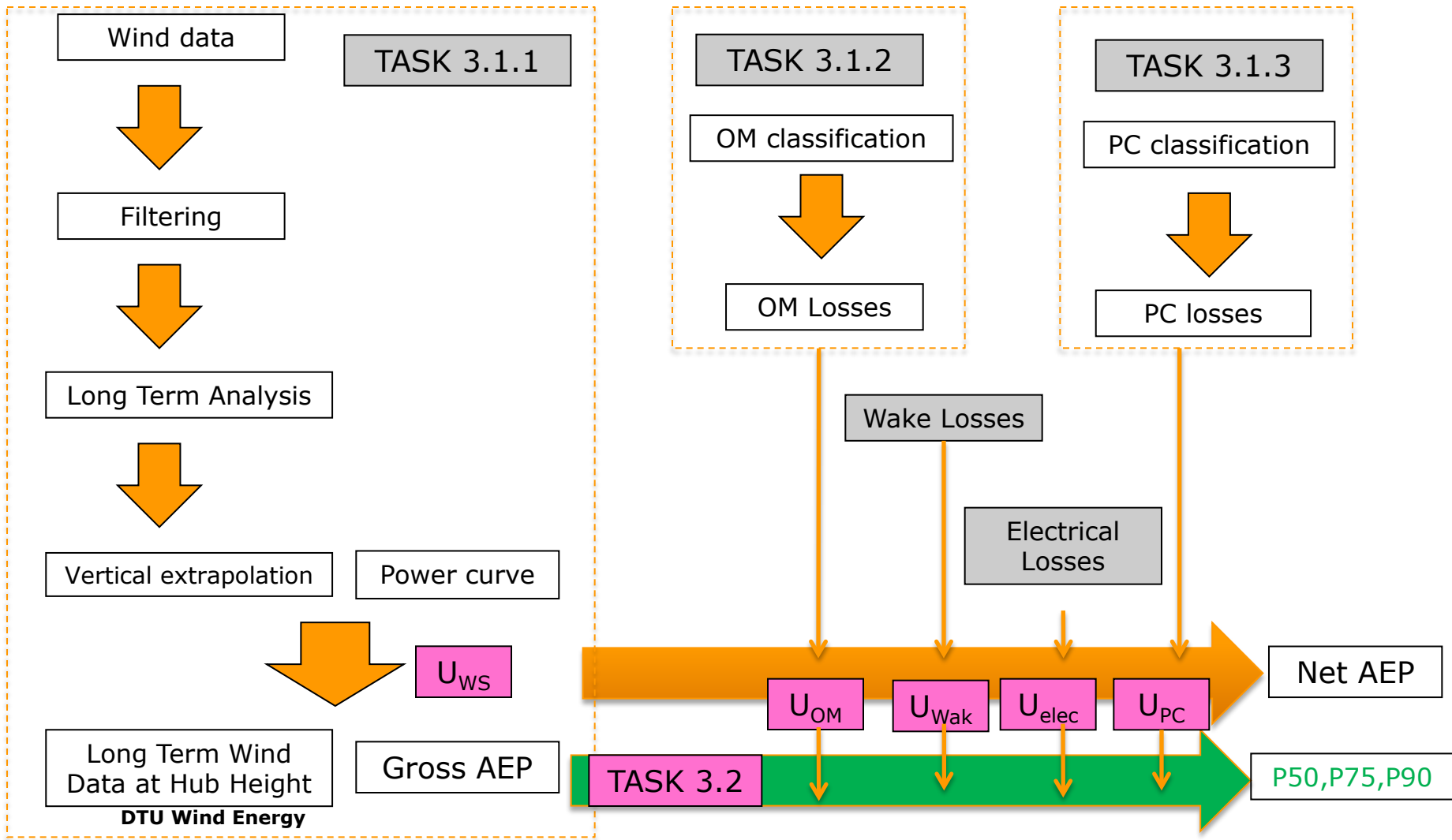
CorWind model

Off-shore development
Wake modelling



EERA-DTOC

Energy Yield Models Workflow



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Conclusions

- “press-of-a-button” is not expert friendly
- Open framework is important
- Multi-disciplinary = Multi-user = Communication “challenges”
- Wake induced fatigue is relevant for wind farm design & optimization
- In the future we will have to take the potential wind farms into account in the risk analysis



**Invitation to workshop on
Offshore Wind Farm Clusters: Focus on Northern European Seas
London, UK, 6 June 2013 from 9.00 to 17.00**

In line with the targets of the European Strategic Energy Technology Plan (SET Plan) of the European Commission, the offshore wind energy industry in Europe is to benefit by research and development by two large international projects co-funded by the European Union.

The projects are ***Cluster Design*** and ***EERA DTOC***.

The workshop is aimed at developers of offshore wind farm clusters, strategic planner and transmission system operators.

The workshop will include a series of presentations from the participants of Cluster Design and EERA DTOC. Keynote speakers: Peter Hauge Madsen (DTU Wind Energy), Rory Donnelly (3E), Mariano Faiella (IWES Fraunhofer), Elena Cantero (CENER), Gerard Schepers (ECN), Gregor Giebel (DTU Wind Energy), Pierre-Elouan Réthoré (DTU Wind Energy),

EERA DTOC is European Energy Research Alliance – Design Tools for Offshore Wind Farm Clusters

Venue: Renewable Energy System (RES) in London

For further information, please visit our web-sites

FP7-ENERGY-2011-1/n° 282797 EERA DTOC <http://www.eera-dtoc.eu>

FP7-ENERGY-2011-1/n° 283145 Cluster Design <http://www.cluster-design.eu/>

DTU Wind Energy