Wind Farms Design and Optimization

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

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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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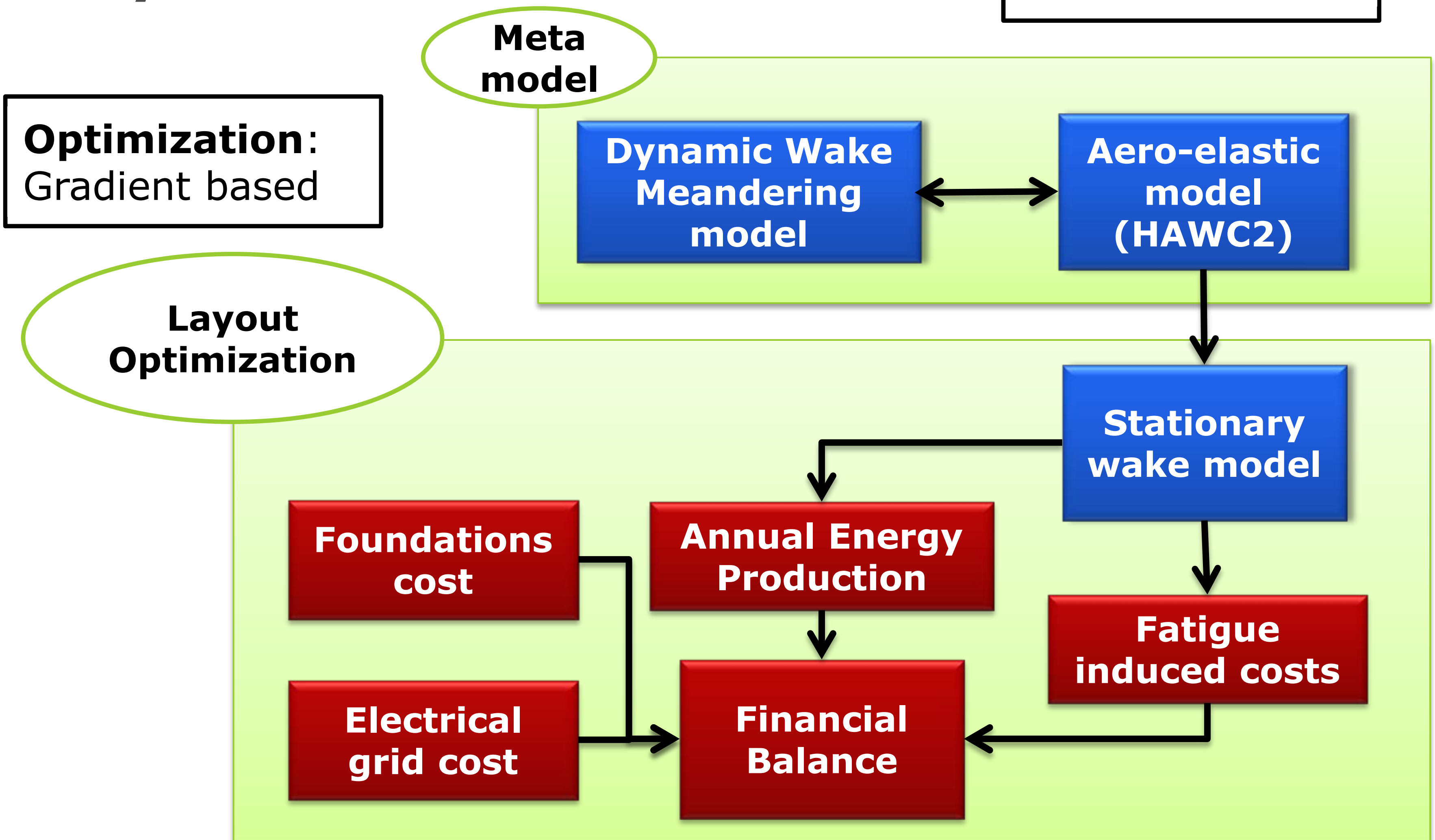
TOPFARM
Main Idea

- **TOPFARM** = **T**opology **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:
2^{nd} Level



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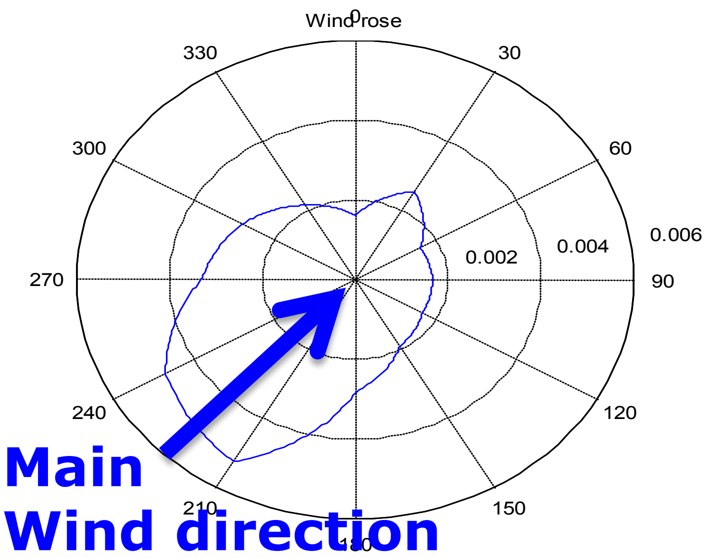
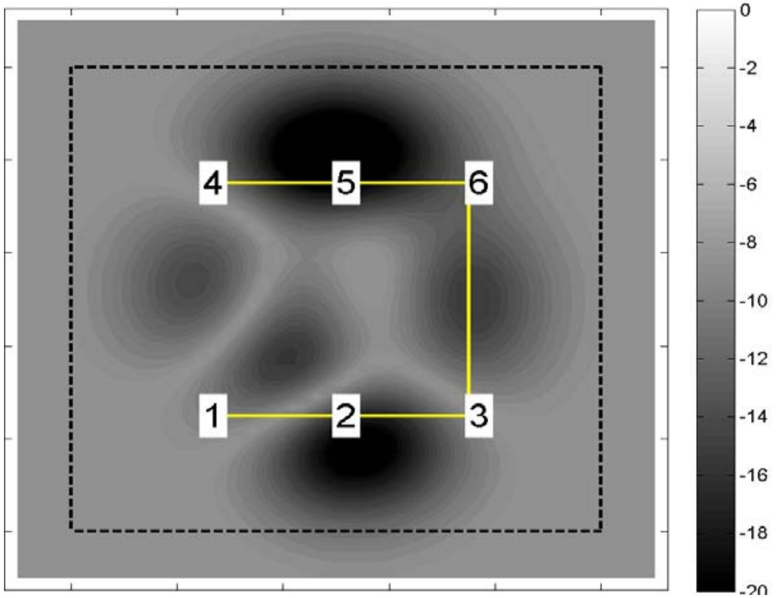
TOPFARM
Demonstration example 1

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



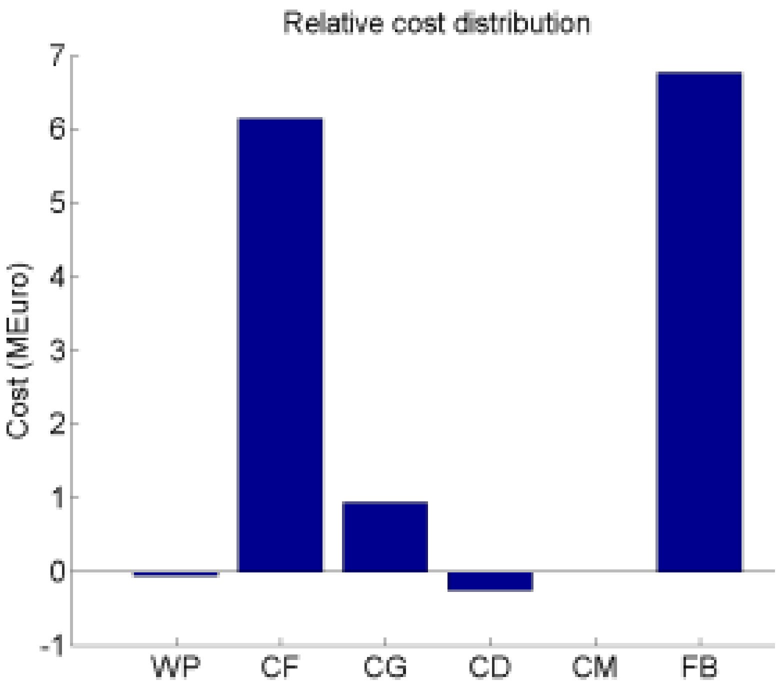
Wind direction probability density distribution

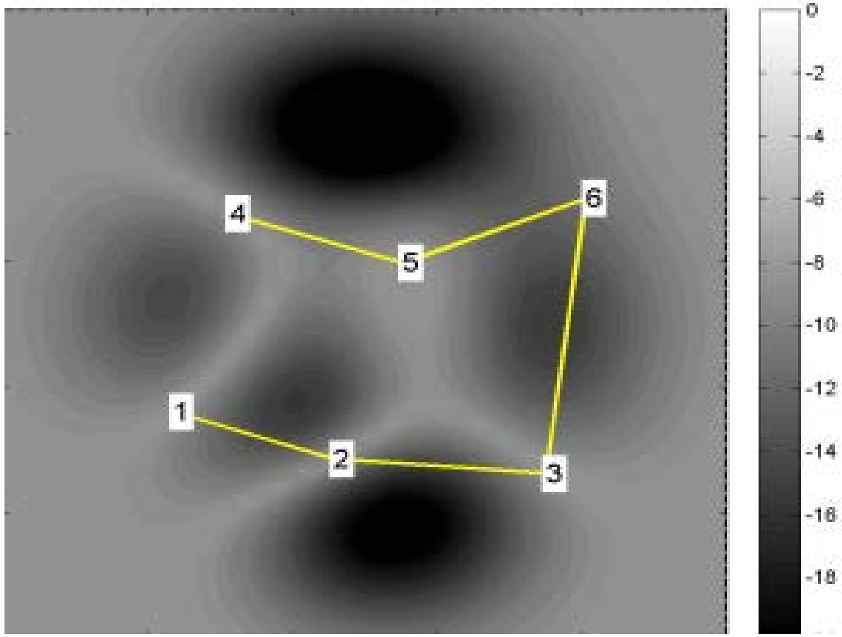


Gray color: Water depth [m]
Yellow line: Electrical grid

TOPFARM
Demonstration example 1

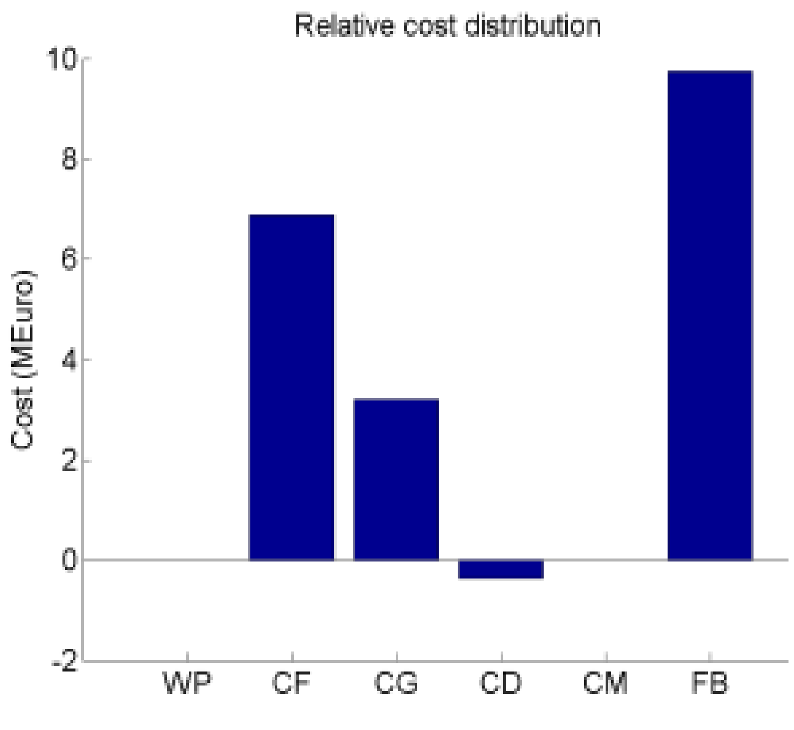
- Result of a gradient based optimization:

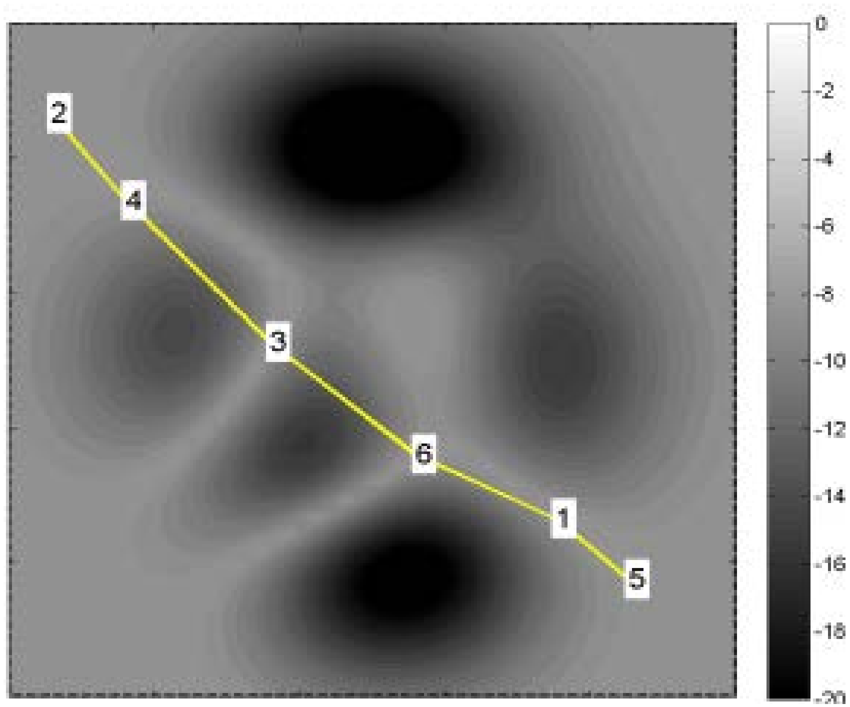




TOPFARM
Demonstration example 1

- Result of a genetic algorithm + gradient based optimization



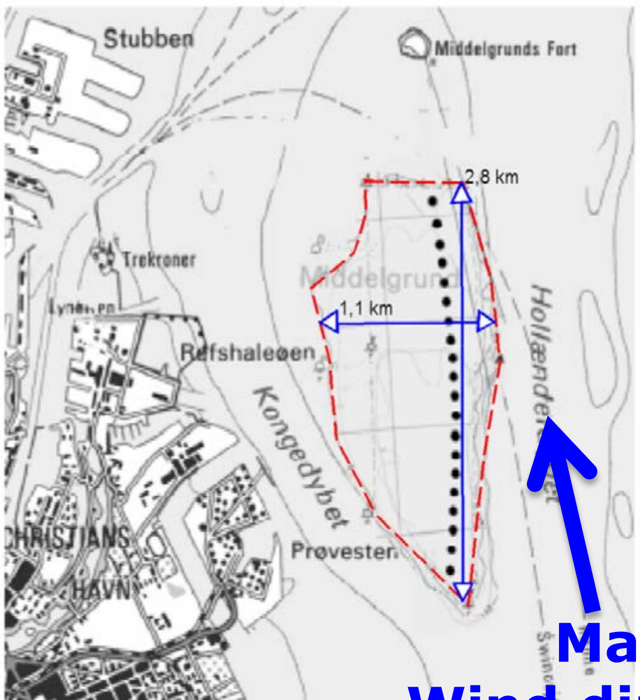


TOPFARM
Demonstration example 2

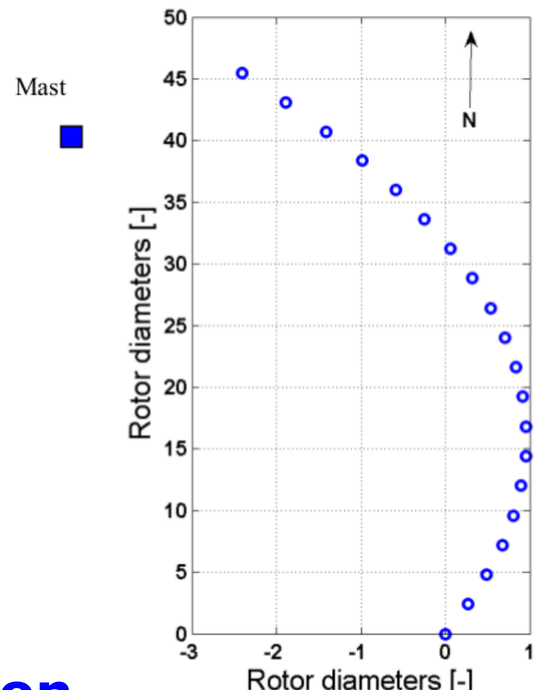
- Middelgrunden

TOPFARM
Demonstration example 2

- Middelgrunden



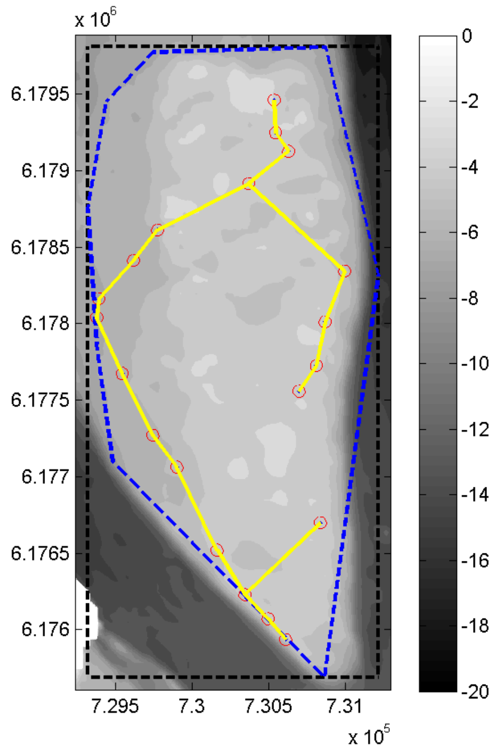
Allowed wind turbine region

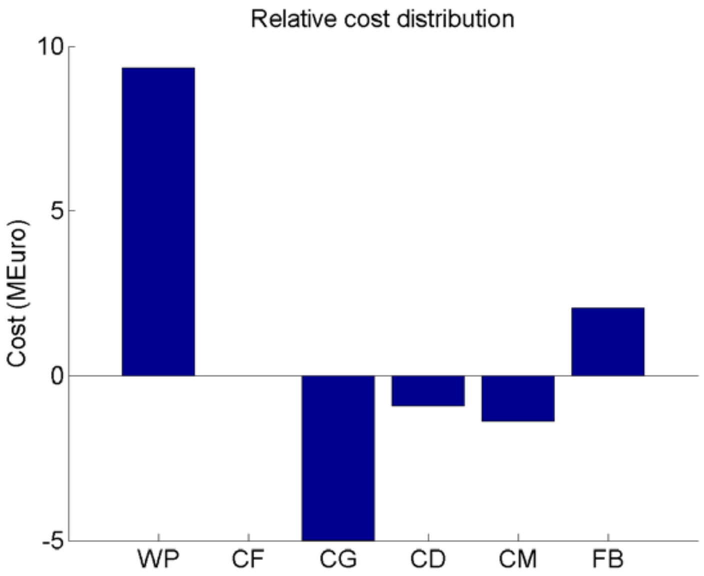


Middelgrunden layout

TOPFARM
Demonstration example 2

- Middelgrunden iterations: 1000 SGA + 20 SLP

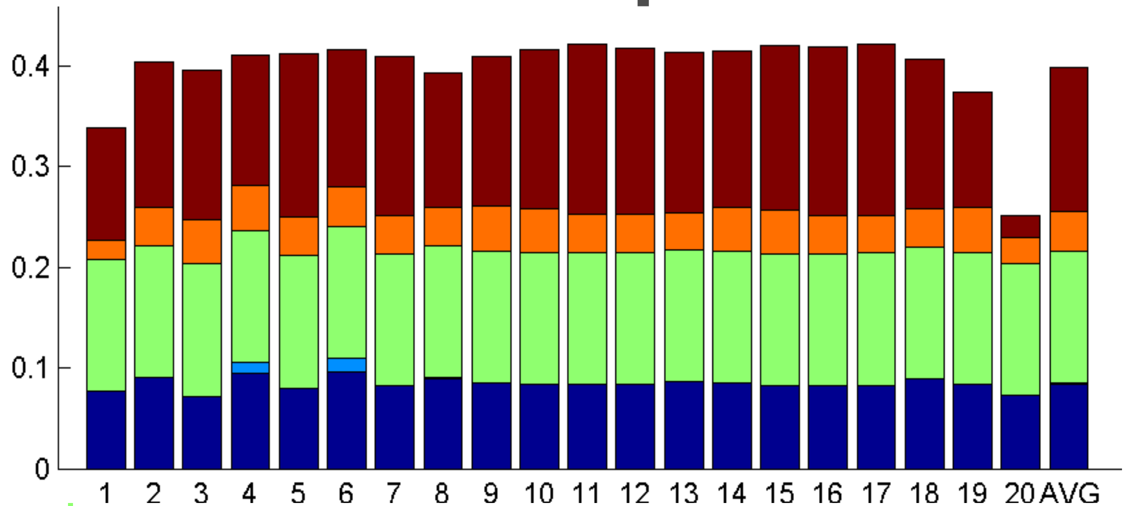


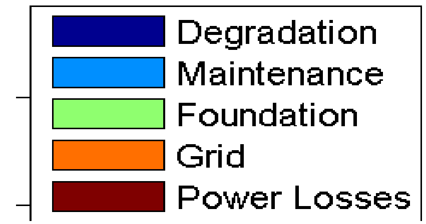


Optimum wind farm layout (left) and financial balance cost distribution relative to baseline design (right).

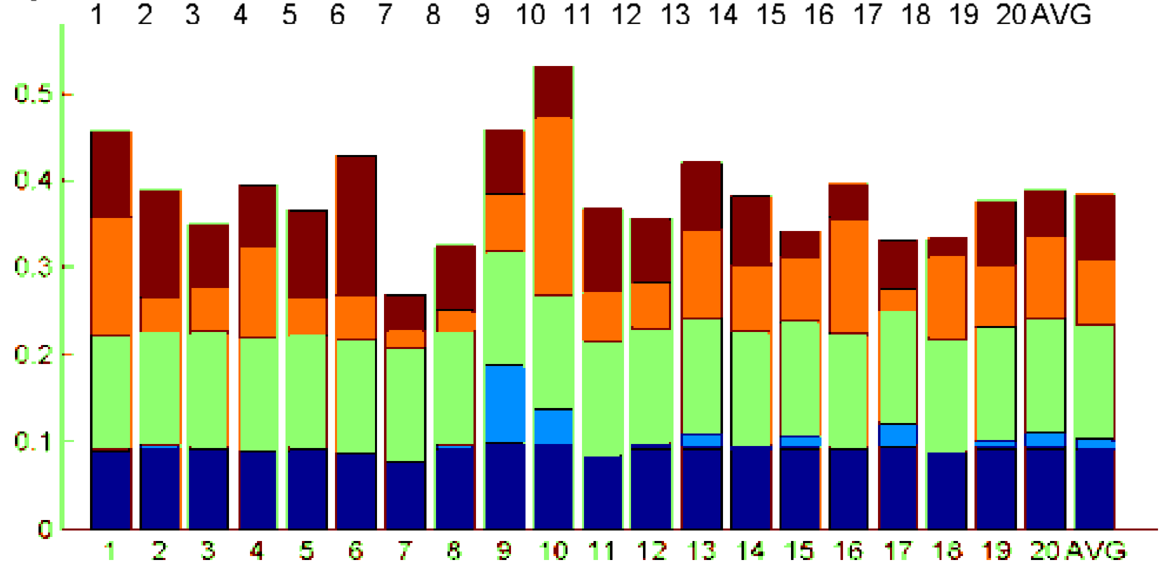
TOPFARM
Demonstration example 2

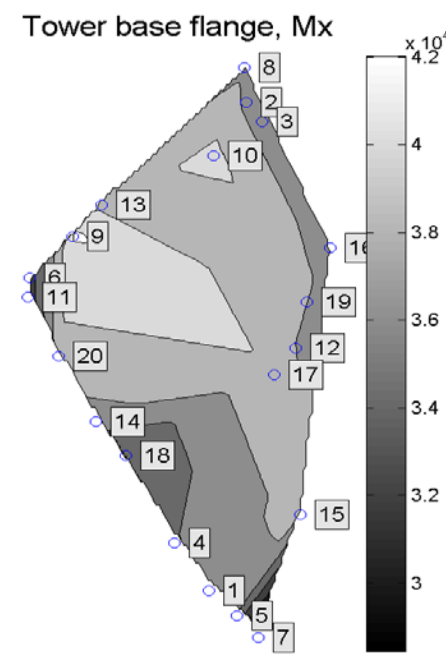
Before





After





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 <u>open</u> 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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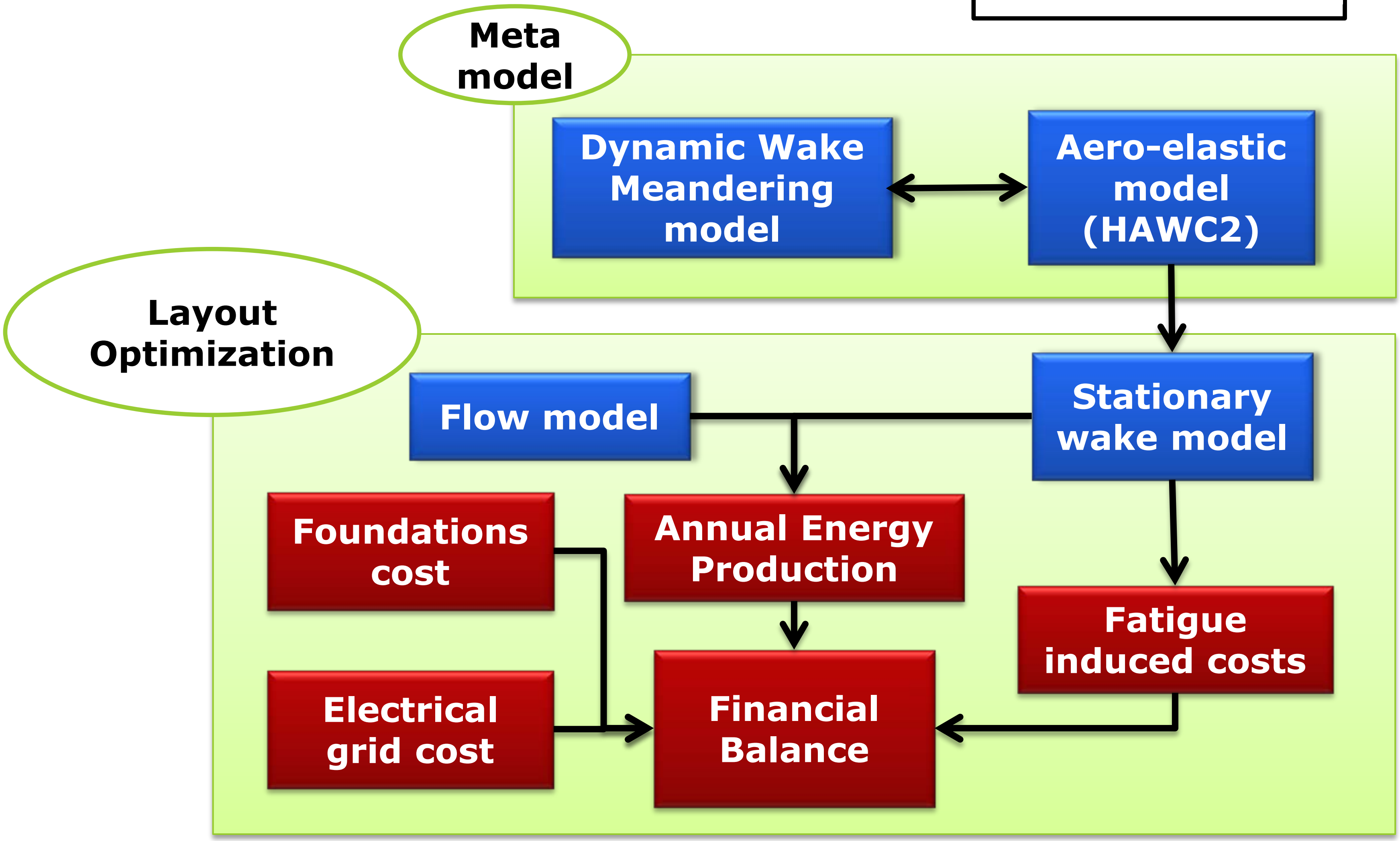
TOPFARM II
Main Ideas

- 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:
2^{nd} Level



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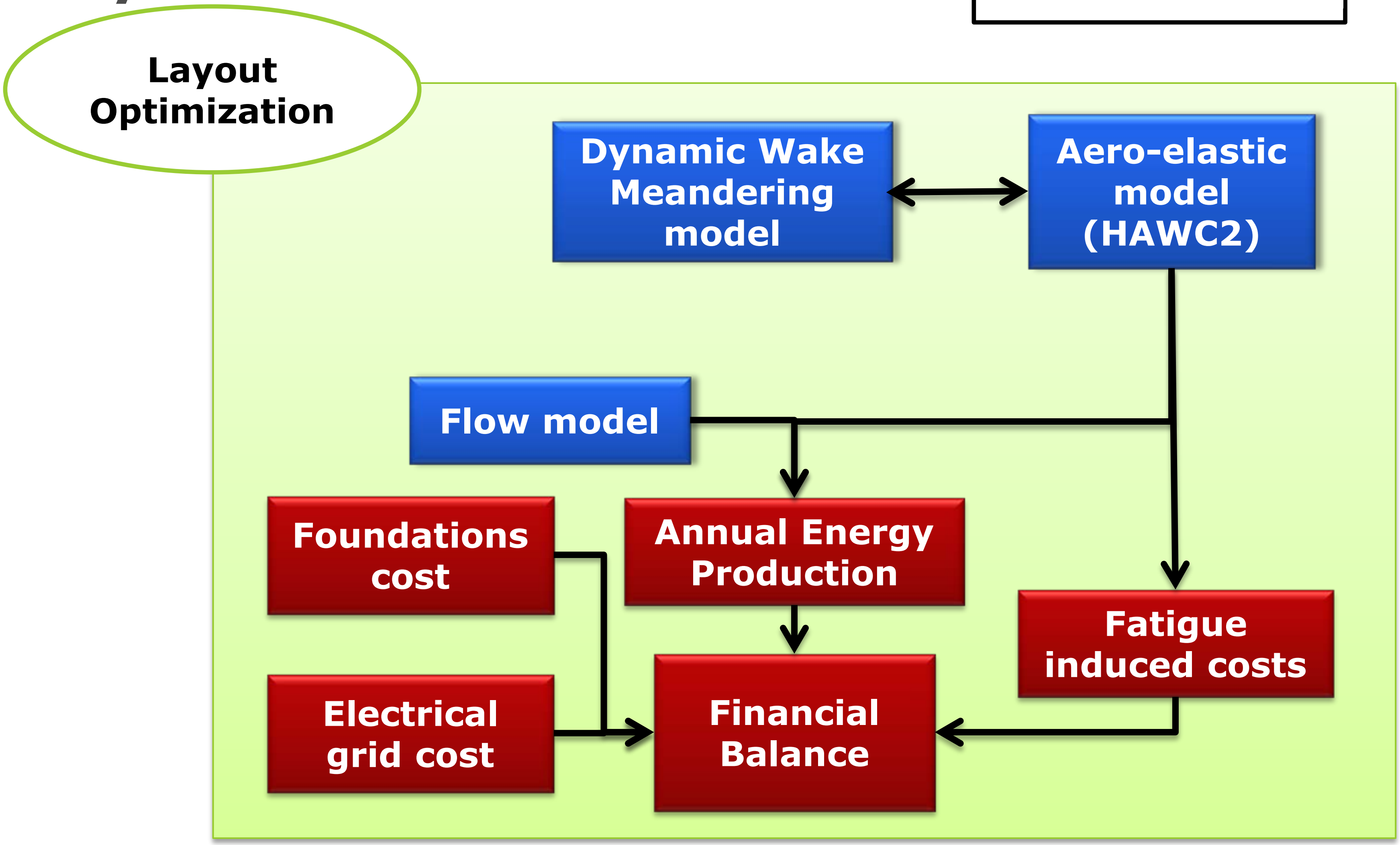
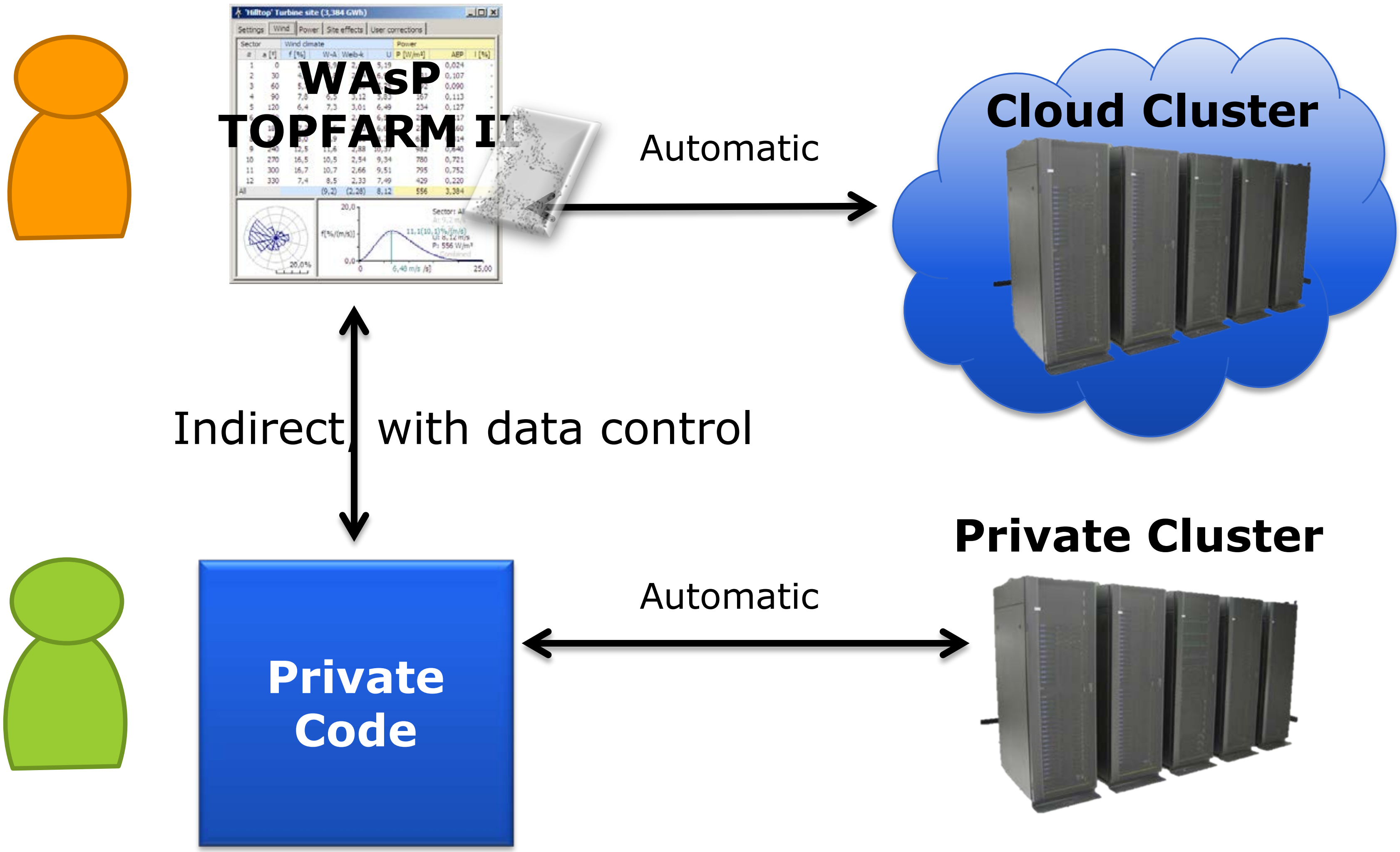
TOPFARM II
System Overview

Multi-fidelity:
3rd Level



TOPFARM II
User Scenario



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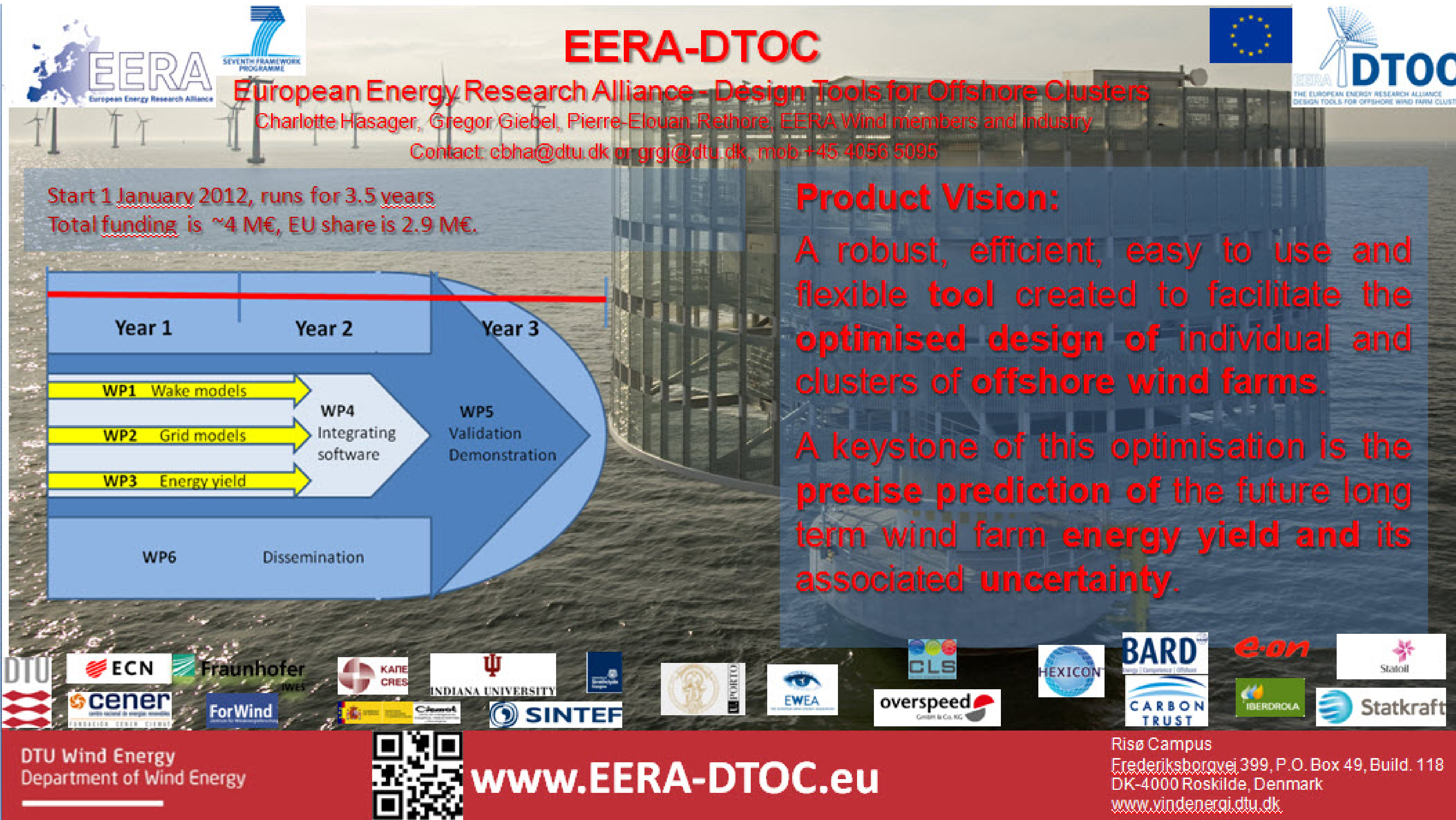
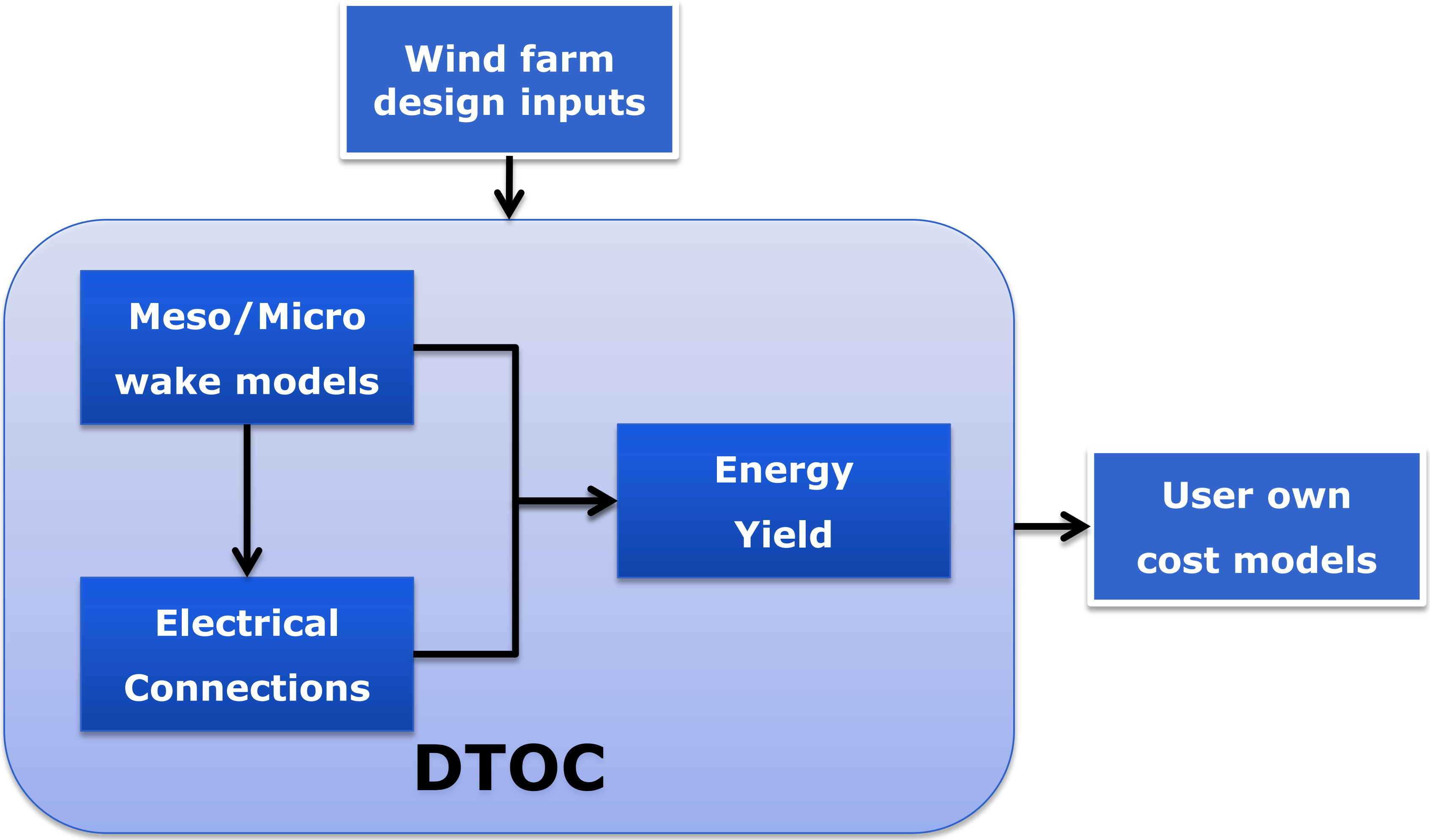
EERA-DTOC
Main Ideas

- **EERA: E**uropean **E**nergy **R**esearch **A**lliance
- **DTOC: D**esign **T**ool for **O**ffshore (wind farm) **C**lusters
- 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

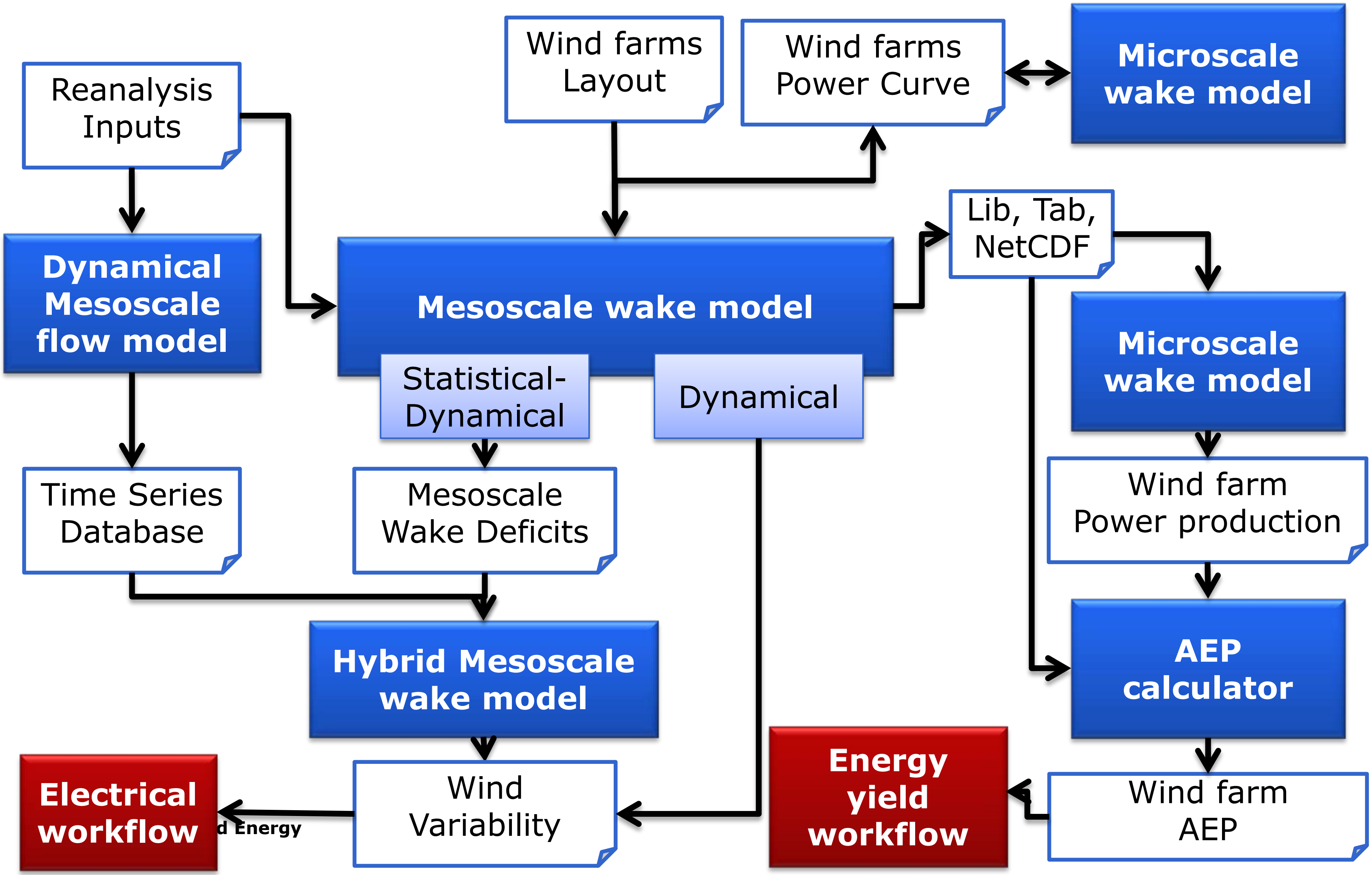
EERA-DTOC summary slide



EERA-DTOC
System Global Overview

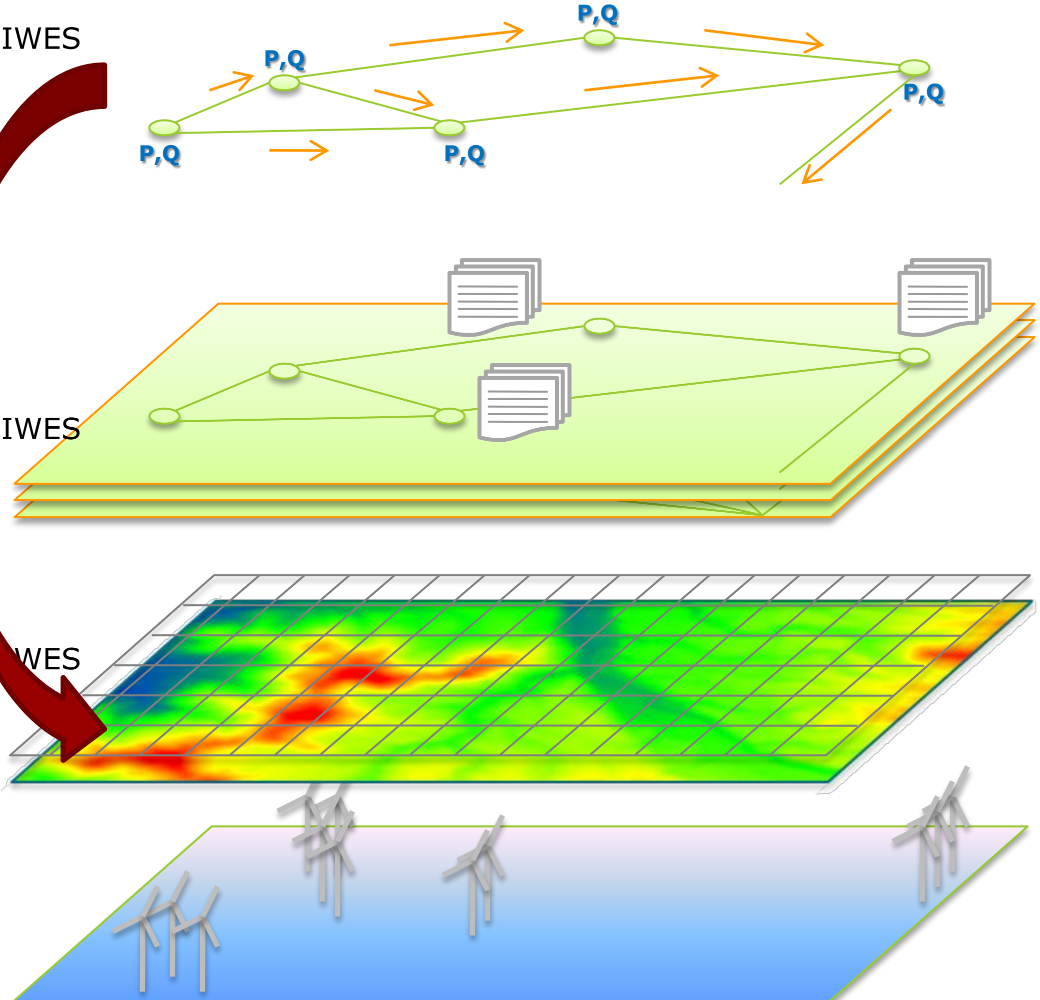


EERA-DTOC
Wake Models Workflow



EERA-DTOC
Electrical Grid Models Workflow

- Fraunhofer IWES



- Strath
- SINTEF

- SINTEF
- Fraunhofer IWES
- Strath
- Statoil
- Hexicon

- Risoe DTU
- Fraunhofer IWES
- CIEMAT

WCMS model
Analysis of the availability of power plant system services
2.4

Grid Codes compliance
PSS/e & PSCAD/EMTDC
Transient analysis
2.3

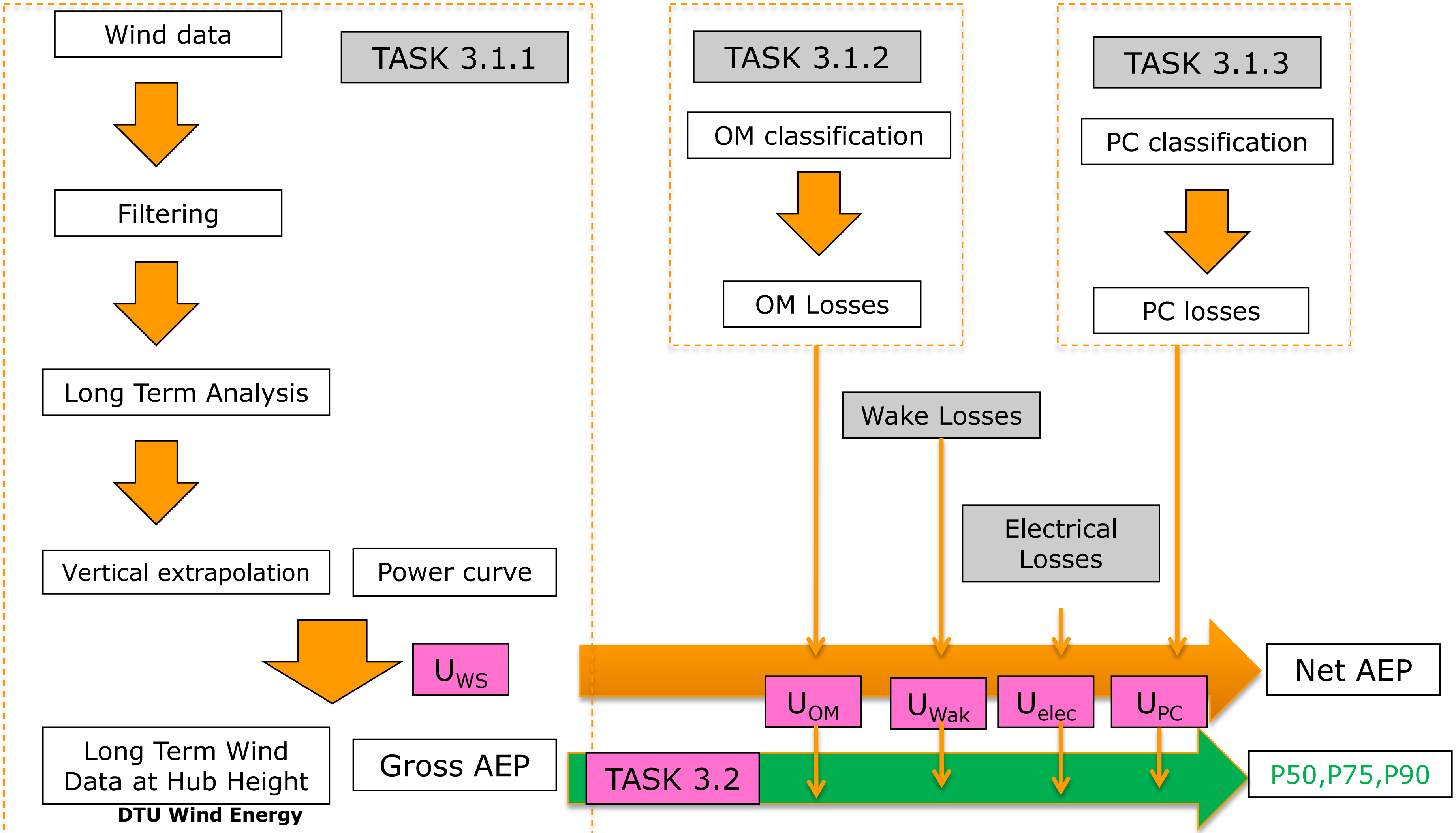
NET-OP model
Grid optimization
Steady-state
2.2

Analysis on variability & predictability
2.1

CorWind model

Off-shore development
Wake modelling
WP 1

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 Systesm (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/