

## **Wind Farm Optimization and Multi-Fidelity Wake Modelling** Presentation of TOPFARM I & II, FUSED-Wake

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# Wind Farm Optimization and Multi-Fidelity Wake Modelling

Presentation of **TOPFARM I & II**, **FUSED-Wake**

Pierre-Elouan Réthoré et al.

Senior Researcher

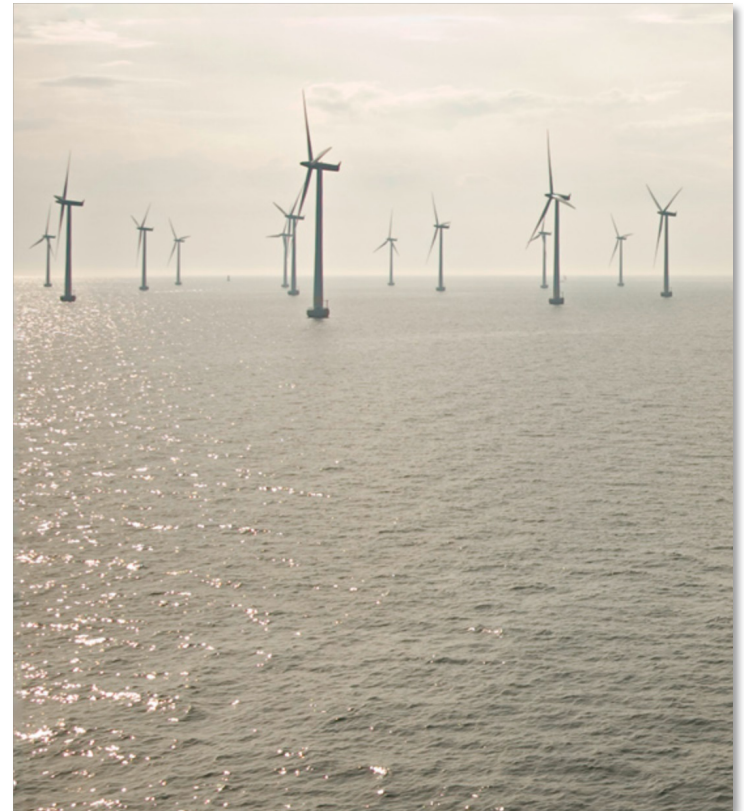
Aero-Elastic Design Section

DTU – Wind Energy, Risø

DTU Wind Energy

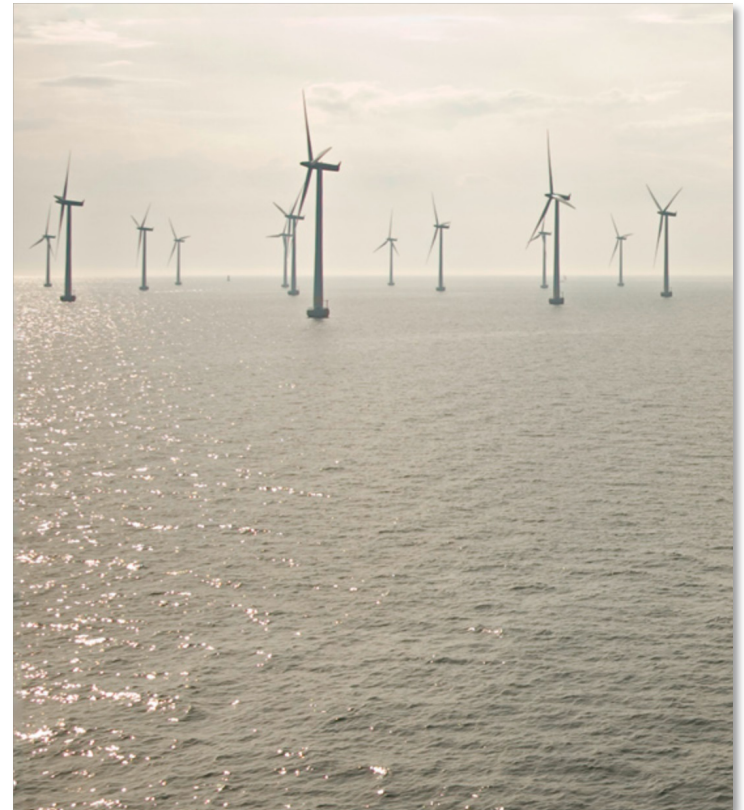
Department of Wind Energy

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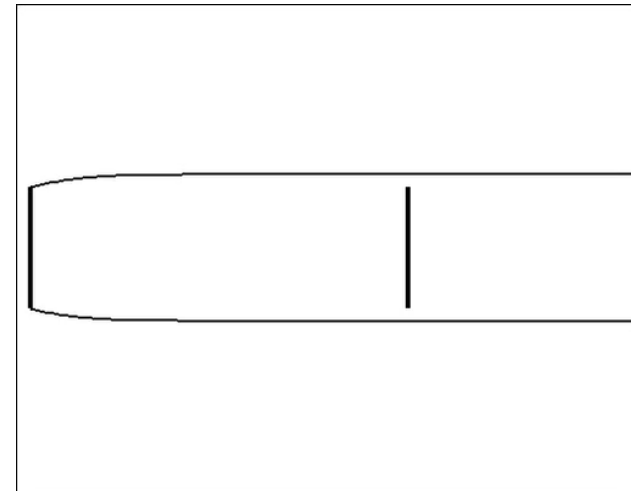
# Outline

- Background
- TOPFARM
  - Main Idea
  - System Overview
  - Some Results
  - Feedbacks from the industry
- FUSED-Wake
- TOPFARM II
  - Main Ideas
  - System Overview
- Conclusions



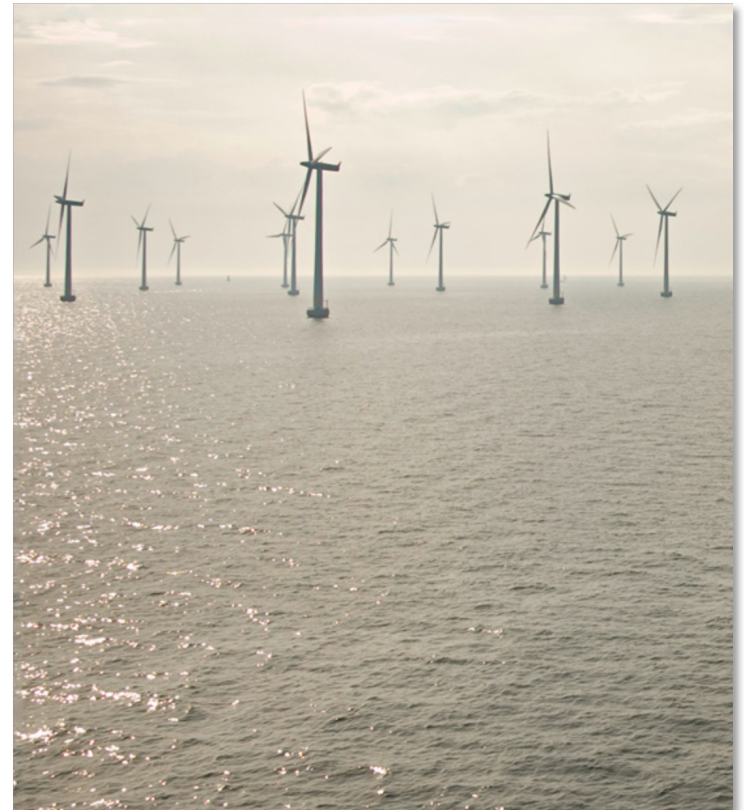
## Background

- Aero-Elastic Design Section is principally interested in wind turbine design
- Wind turbines design depends of inflow inputs (upstream wakes)
- Dynamic Wake Meandering (DWM) 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

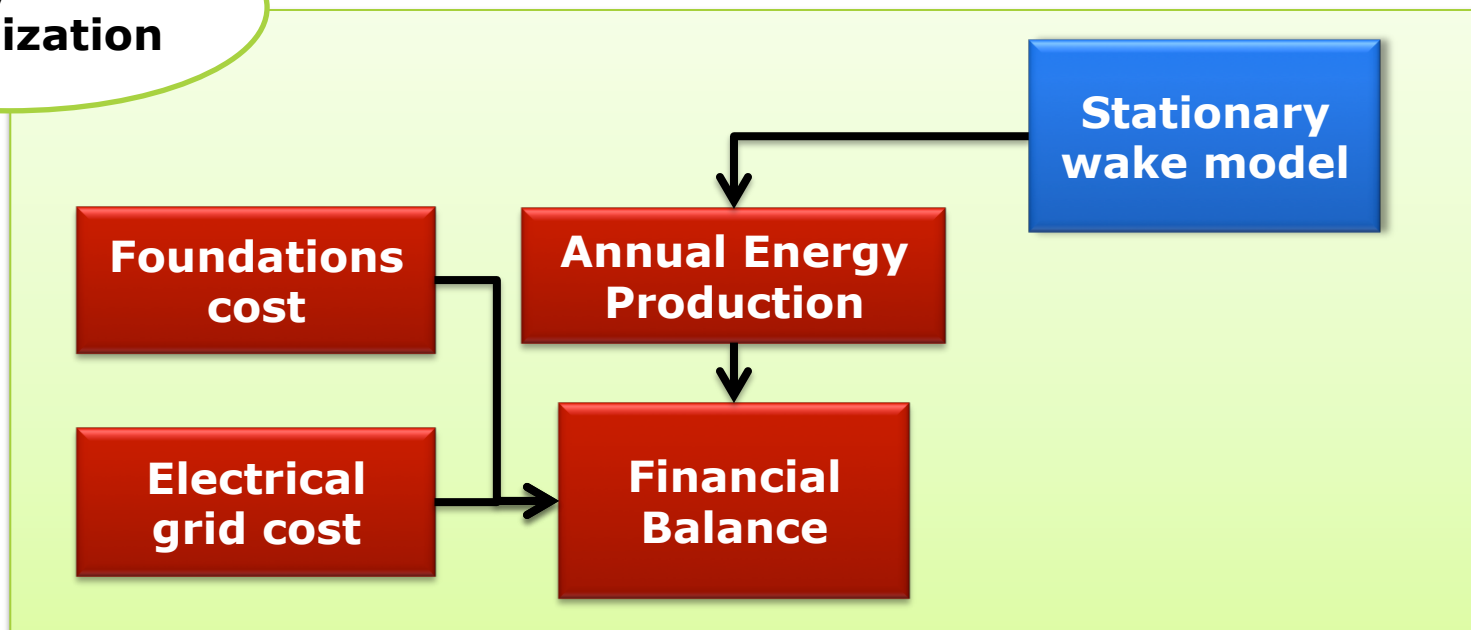
# TOPFARM

## System Overview

**Multi-fidelity:**  
1<sup>st</sup> Level

**Optimization:**  
Gradient based

**Layout  
Optimization**



# TOPFARM System Overview

**Multi-fidelity:**  
2<sup>nd</sup> 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

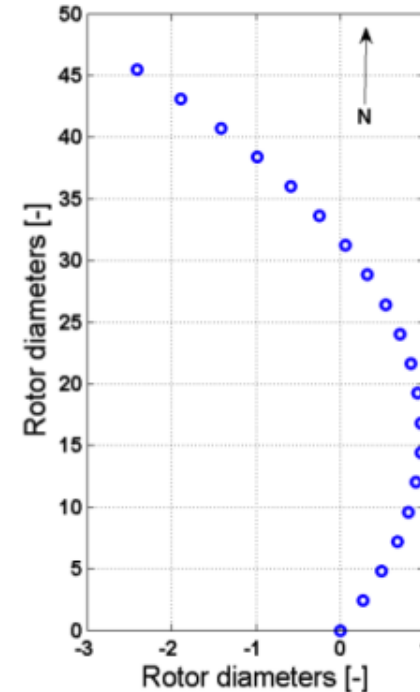
## Demonstration example

- Middelgrunden



Allowed wind turbine region

Mast

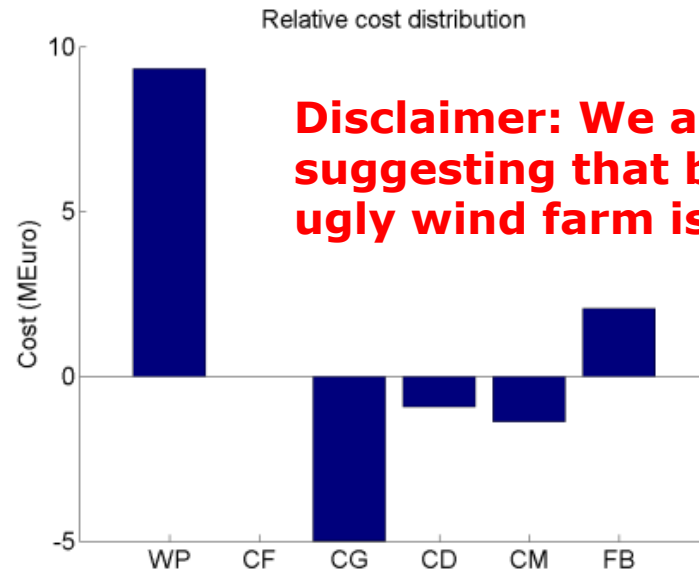
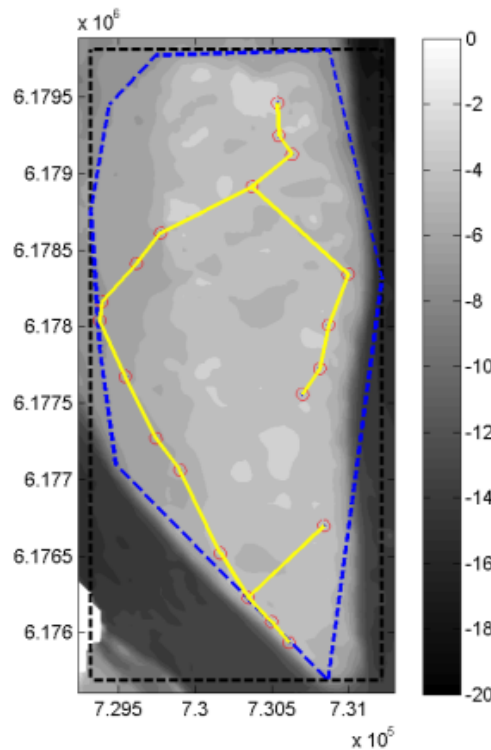


Middelgrunden layout

# TOPFARM

## Demonstration example

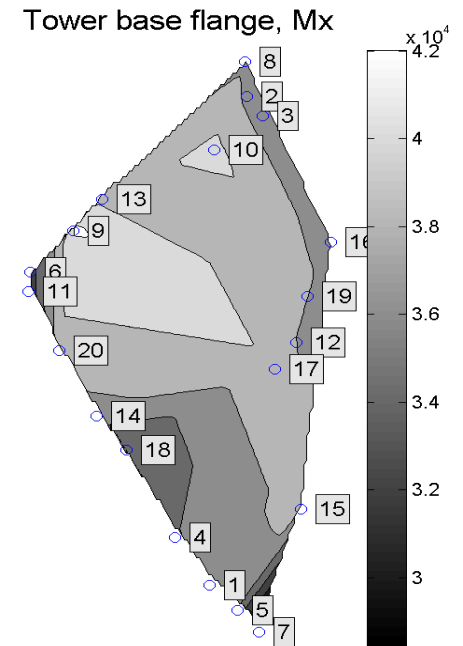
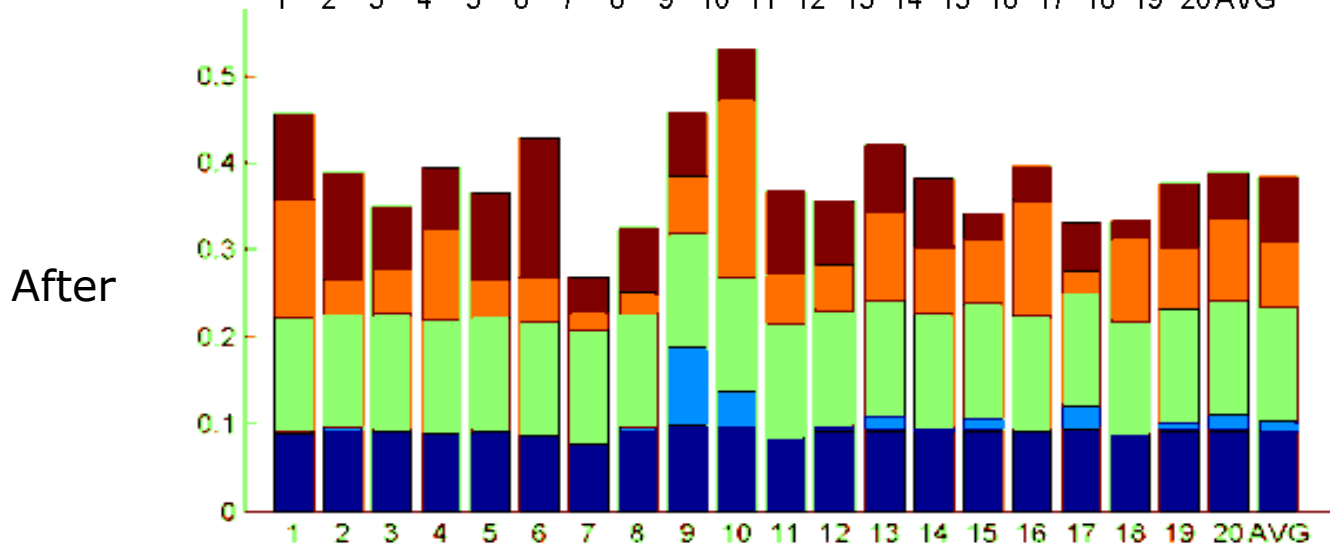
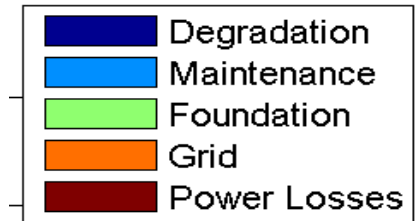
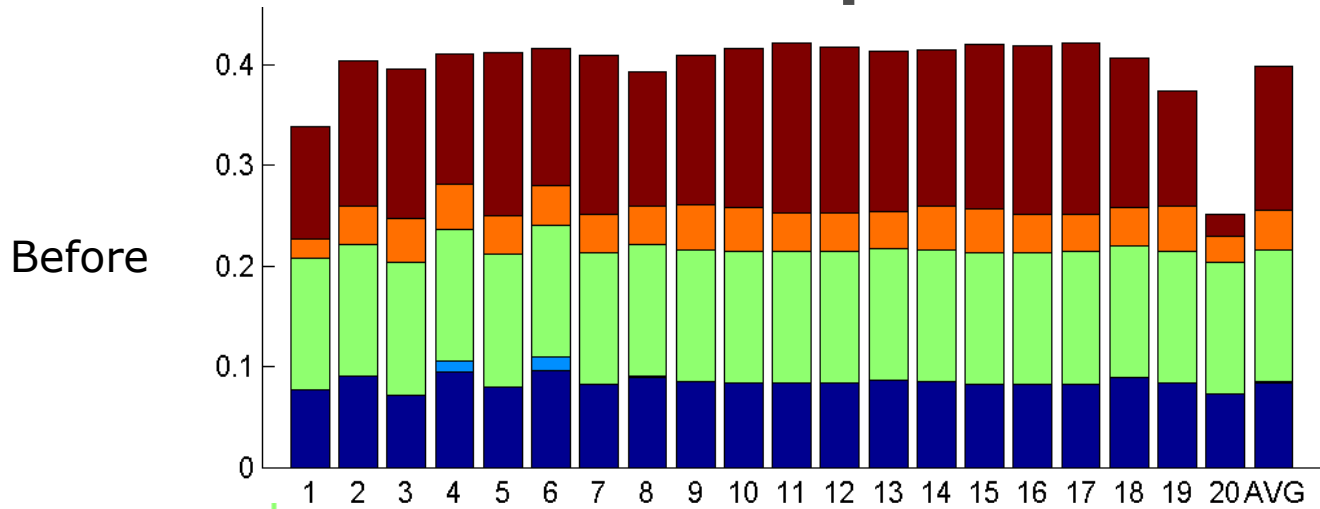
- Middelgrunden iterations: 1000 SGA + 20 SLP



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

# TOPFARM

## Demonstration example



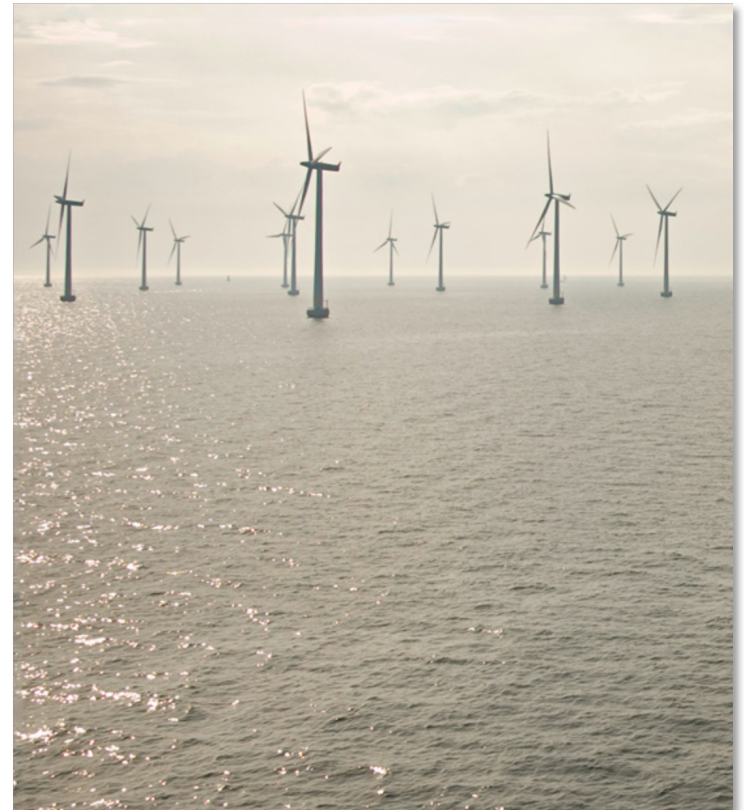
# TOPFARM

## 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.
- Integrate the 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.

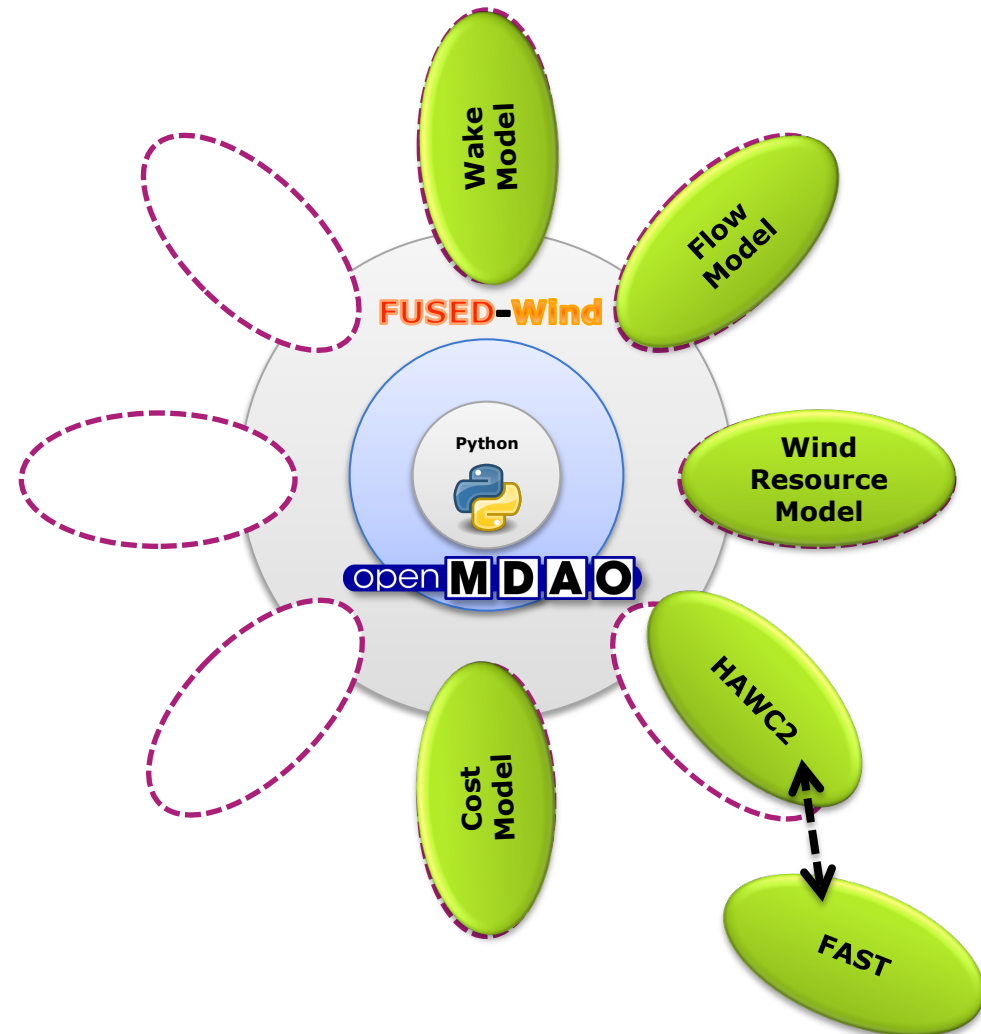
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# FUSED-Wind

- Collaborative effort between **DTU** and **NREL** to create a **Framework for Unified System Engineering and Design of Wind** energy plants.
- Based on OpenMDAO, a python based **Open** source framework for **Multi-Disciplinary Analysis and Optimization**.

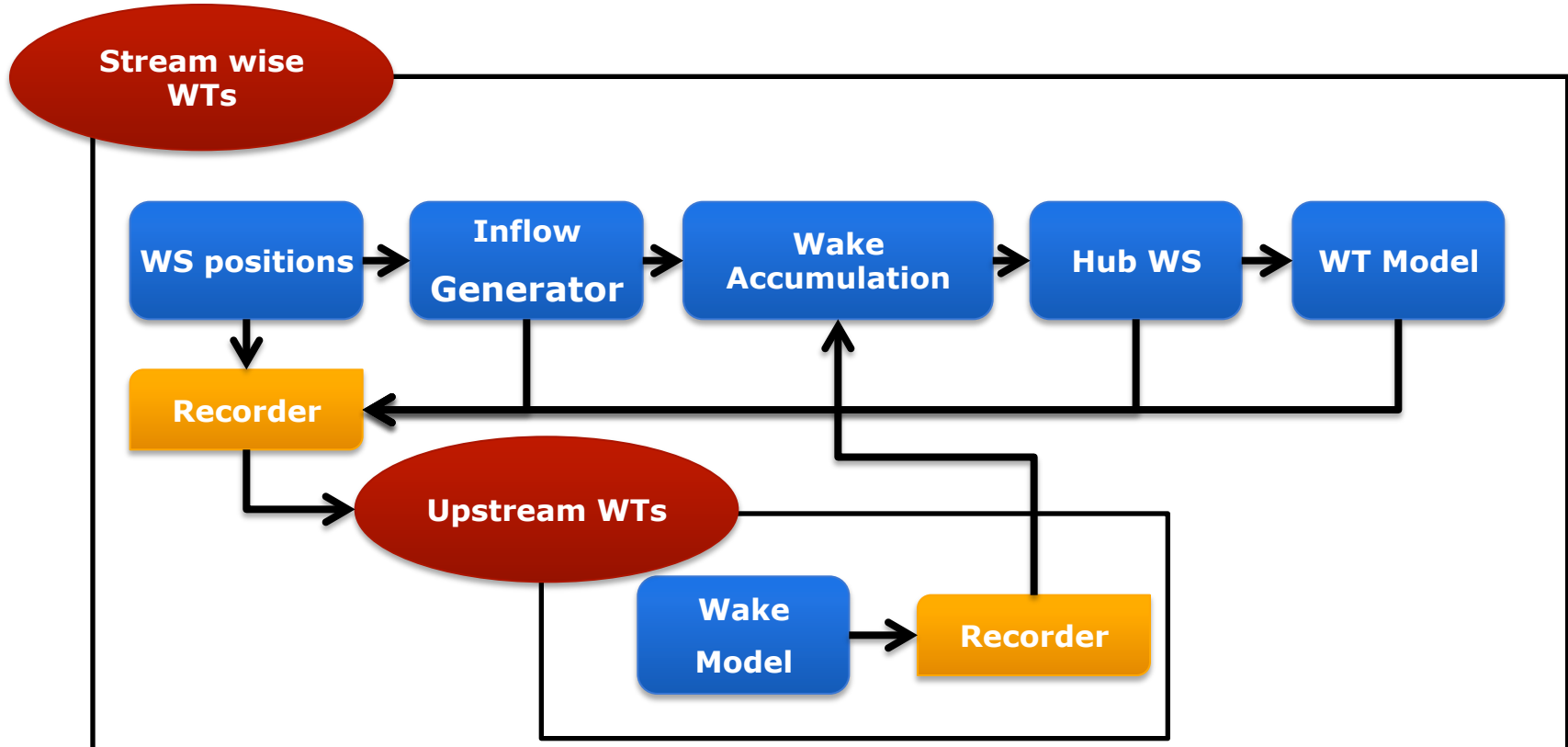


## FUSED-Wake

- Collaborative open source tool developed by DTU
- General purpose (AEP, Loads, Optimization, steady/unsteady)
- Modular (workflow divided in sub components)
- Each component is “swappable”
- Each component have multiple fidelity levels
- Derivatives friendly (faster Uncertainty Quantification & Optimization)
- **Open Source** framework + Closed source subcomponents
- Alpha version is ready for testing

# Research tool: Modularized concept

- The wind farm wake models are split into a generalized workflow





# Potential applications of the framework

- Model automatic selection
- Model Averaging (combining the information of several models)
- Machine learning (systematic model recalibration)
- Uncertainty quantification
- Multi-fidelity optimization
- Robust optimization
- Standard way to run wind farm models
- Bridging the gap between researchers and industry

## FUSED-Wake: Status

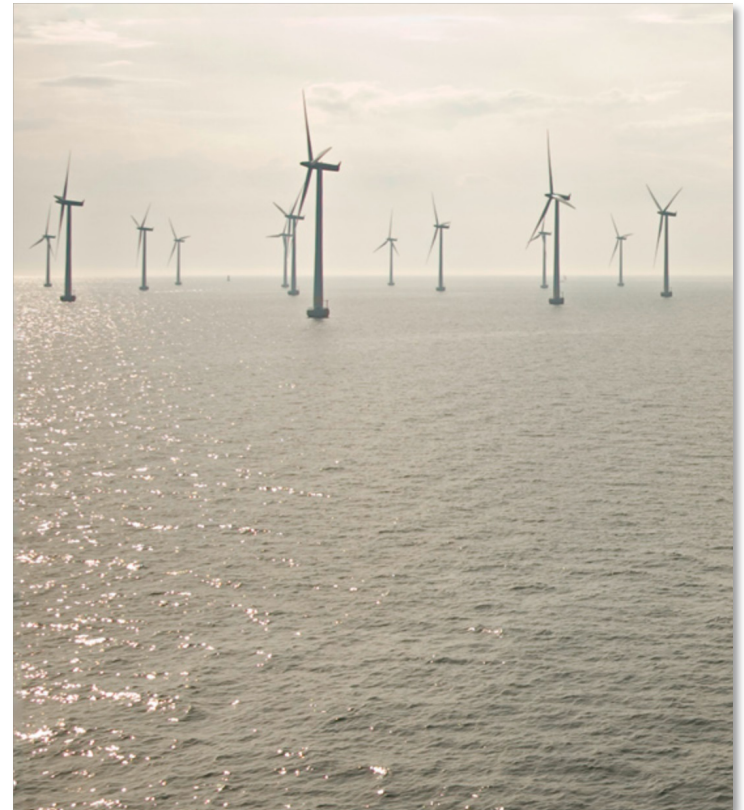
- Framework in alpha version is ready for testing
  - N.O. Jensen
  - G.C. Larsen
  - FUGA
  - EllipSys
  - DWM

## Next steps

- Gathering interest group
- Alpha release to interest group
- Public release of beta version
- Forming a project portfolio to coordinate the efforts

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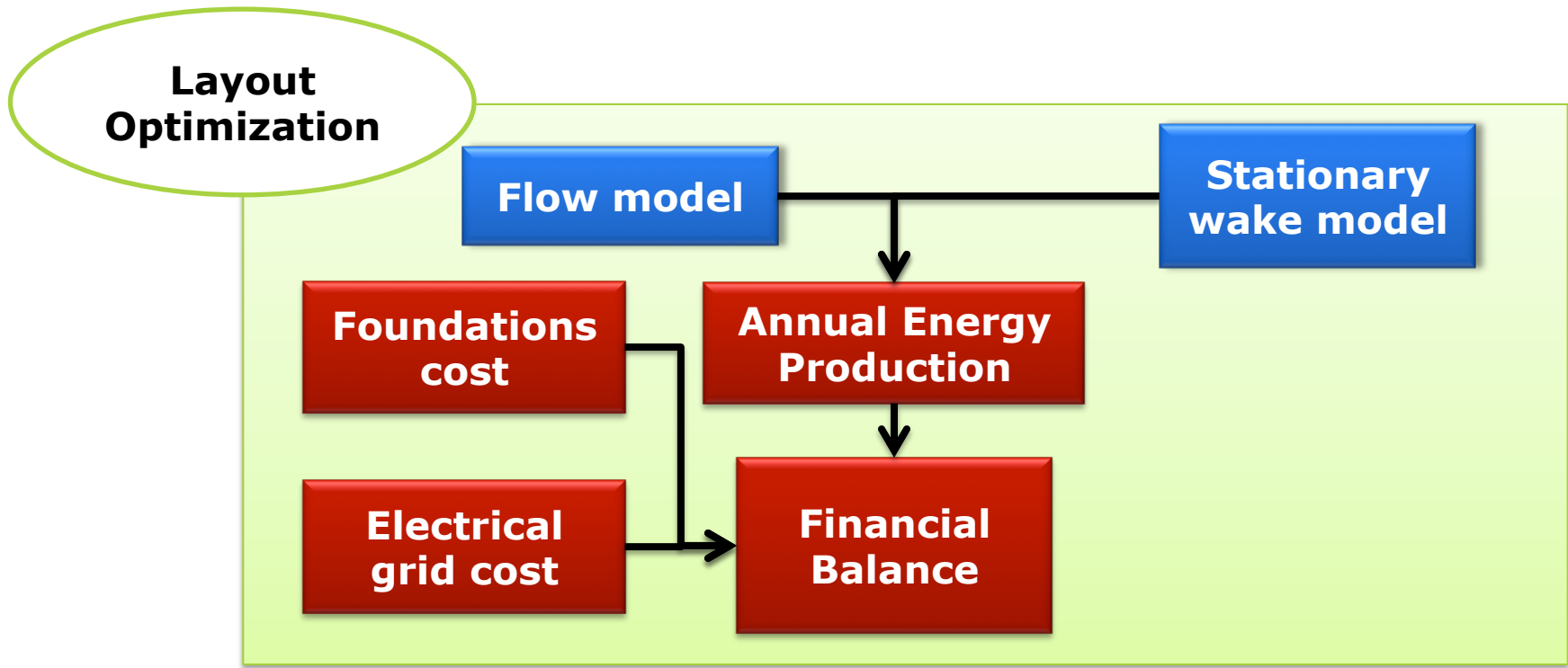
# TOPFARM II

## Main Ideas

- Framework based on **FUSED-Wind**
- Use **WAsP** & **WRF** engine to calculate accurate local wind resources
- Multi-fidelity wake model based on **FUSED-Wake**
- 3<sup>rd</sup> level of fidelity: running the whole wind farm with dynamic wake models (**DWM & AL/LES**)
- More advanced multi-fidelity optimization strategy
- Higher degree of parallelization
- Expert driven iterative design process
- GUI connected to **WAsP**

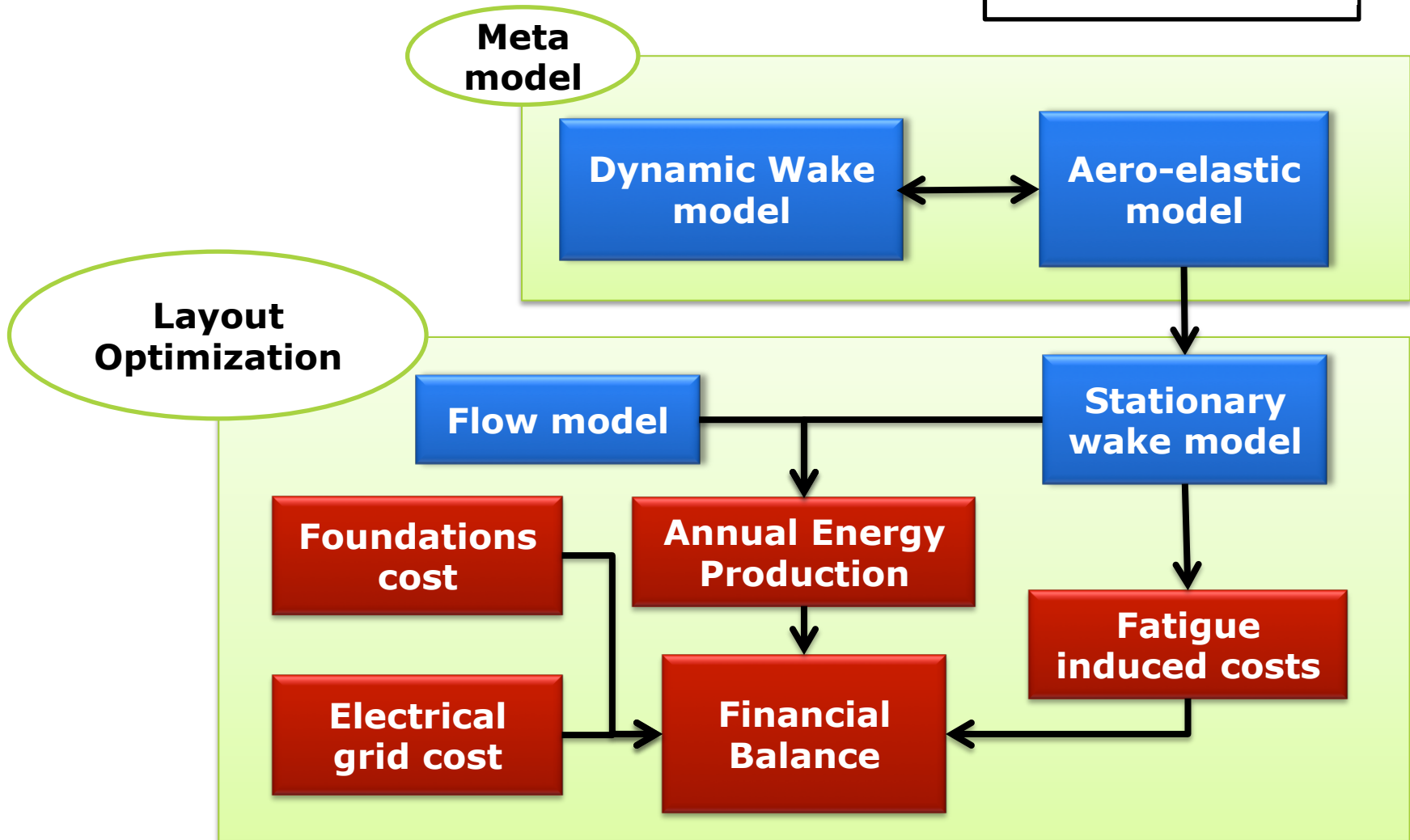
# TOPFARM II System Overview

**Multi-fidelity:**  
1<sup>st</sup> Level



# TOPFARM II System Overview

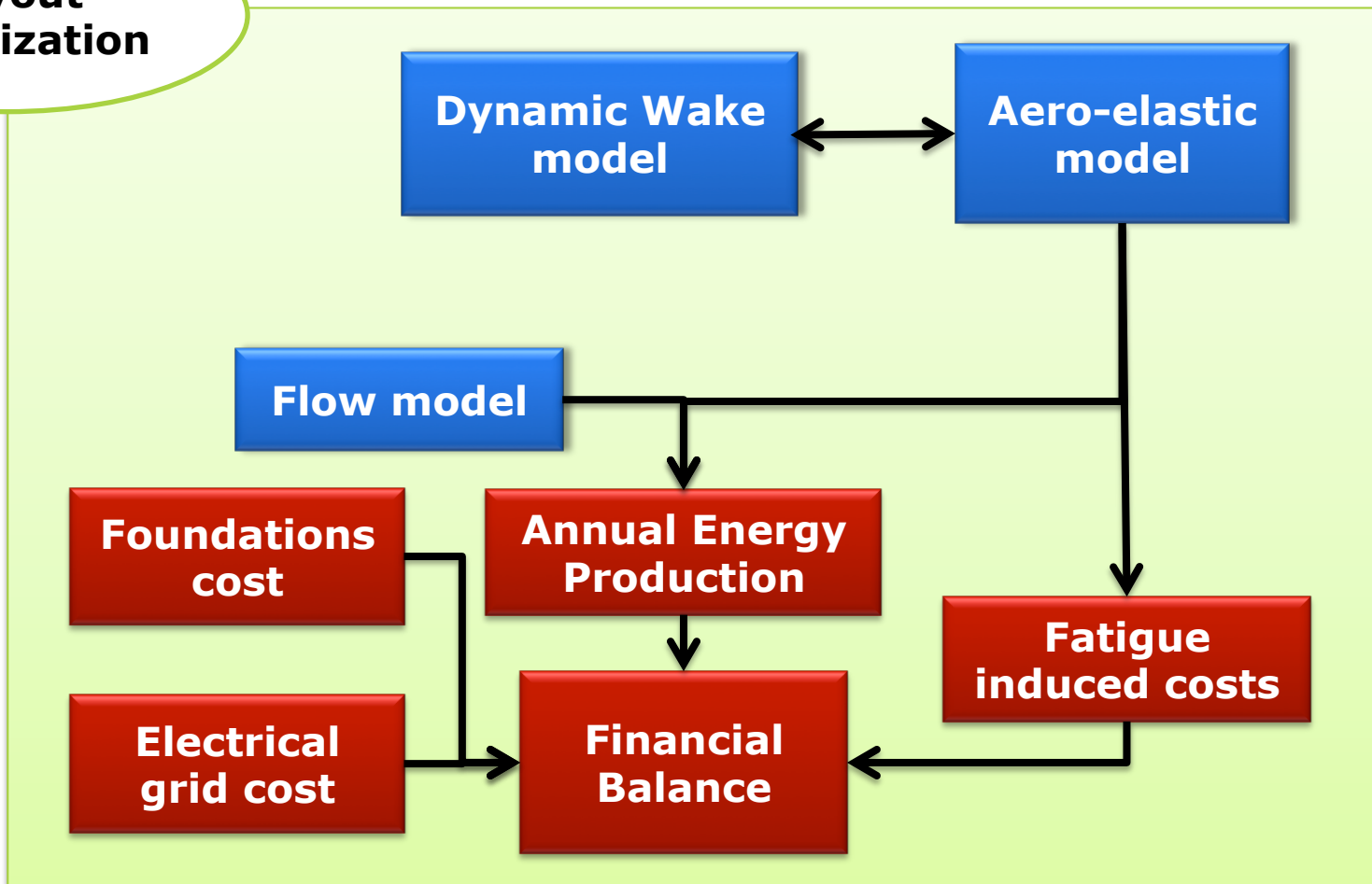
**Multi-fidelity:**  
2<sup>nd</sup> Level



# TOPFARM II System Overview

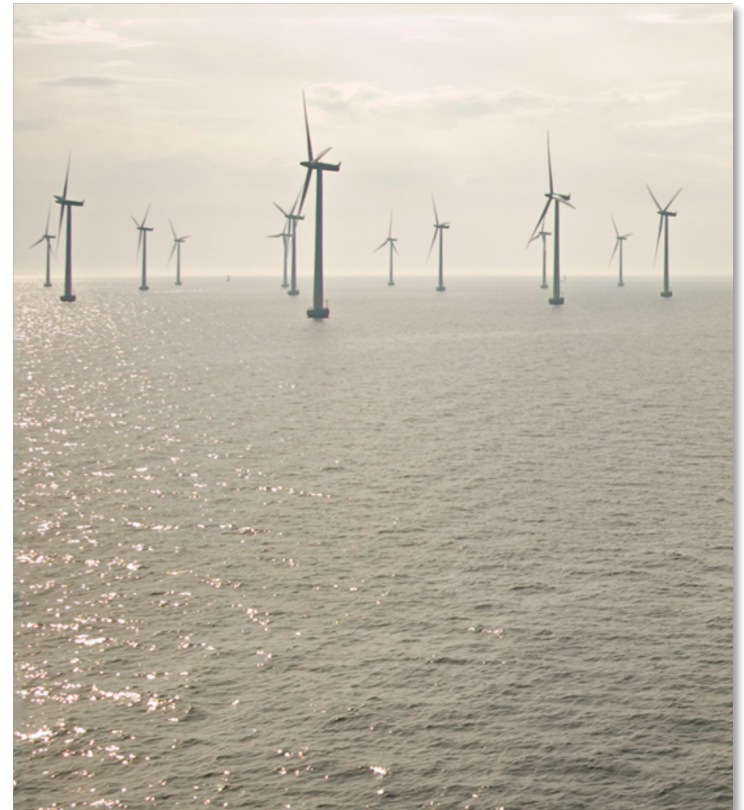
**Multi-fidelity:**  
3<sup>rd</sup> Level

**Layout  
Optimization**



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# Conclusions

- When we design a system, you have to take the user into account
- “press-of-a-button” is not expert friendly
- Multi-disciplinary = Multi-user = Communication “challenges”
- Open framework is important
- Wake induced fatigue is relevant for wind farm design & optimization

