



EERA DeepWind'2014

11'th Deep Sea Offshore Wind R&D Conference

Trondheim, 22 - 24 January 2014

# EERA Design Tool for Offshore wind farm Cluster (DTCOC)

PETER HAUGE MADSEN. Director

*Charlotte Hasager. Senior scientist*

*DTU Wind Energy*



Support by



# Project partners



- DTU Wind Energy (former Risø)
- Fraunhofer IWES
- CENER
- ECN
- EWEA
- SINTEF
- ForWind
- CRES
- CIEMAT
- University of Porto
- University of Strathclyde
- Indiana University
- CLS
- Statkraft
- Iberdrola Renovables
- Statoil
- Overspeed
- BARD
- Hexicon
- Carbon Trust
- E.On
- RES

# EERA partners



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**“Design Tool for Offshore wind farm Clusters” is the first EERA project.  
EERA is based on national science activities.**

# EERA – European Energy Research Alliance



**Background:** The EERA JP Wind Energy was officially launched at the SET-Plan conference in Madrid in June 2010. The strategy and main activities of the JP is described in the "Strategic Action Plan" (yearly updated).

The programme vision is:

- to provide strategic leadership for the scientific–technical medium to long term research
- to support the European Wind Initiative and the Technology Roadmap's activities on wind energy, and on basis of this
- to initiate, coordinate and perform the necessary scientific research.

## Joint Programme and Sub-programmes

**Wind Conditions.** Coordinated by Prof. Erik Lundtang Petersen, DTU Wind Energy (DK)

**Aerodynamics.** Coordinated by Dr. Peter Eecen, ECN (NL)

**Offshore Wind Energy.** Coordinated by Dr. John O. Tande, SINTEF (NO)

**Grid Integration.** Coordinated by Dr. Kurt Rohrig, FhG IWES (DE)

**Research Facilities.** Coordinated by Dr. Pablo Ayesa Pascual, CENER (ES)

**Structural design and materials.** Coordinated by Dr. Denja Lekou, CRES (GR)

**Topic ENERGY.2011.2.3-2:**

**Development of design tools for Offshore Wind farm clusters**

*Open in call: FP7-ENERGY-2011-1*

*Funding scheme:* Collaborative project

- EERA DTOC is 3.5 years: January 2012 to June 2015
- Budget is 4 m€ hereof 2,9 m€ from EC
- Parallel project is ClusterDesign coordinated by 3E



- To contribute to the SET-Plan on the development of offshore wind power.
- To demonstrate the capability of designing virtual wind power plants composed of wind farms and wind farm clusters while minimizing the negative spatial interactions, improving the overall power quality output and providing confidence in energy yield predictions.

The objective of this topic is to develop new **design tools** to optimise the exploitation of individual wind farms as well as wind farm clusters, in view of transforming them into virtual power plants.

Such design tools should integrate:

- Spatial modelling: medium (within wind farms) to long distance (between wind farms) **wake effects**
- **Interconnection optimisation**: to satisfy grid connection requirements and provide power plant system service.
- **Precise energy yield** prediction: to ease investment decisions based on accurate simulations

The project should focus on offshore wind power systems and **make optimal use of previously developed models.**

# ENERGY.2011.2.3-2: Call objective

## EERA DTOC Work Packages (WP)



The objective of this topic is to develop new **design tools** to optimise the exploitation of individual wind farms as well as wind farm clusters, in view of transforming them into virtual power plants.

Such design tools should integrate:

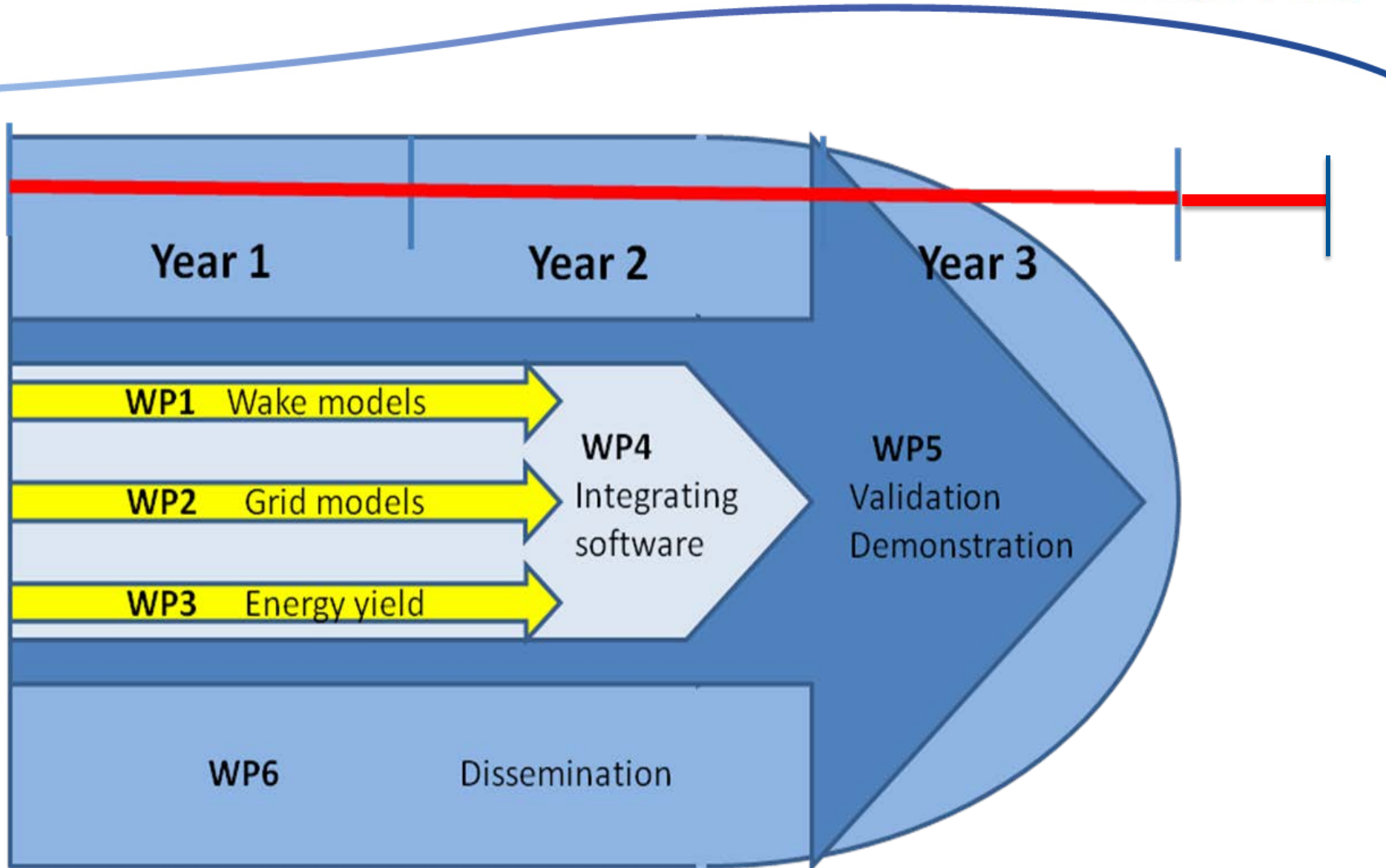
- Spatial modelling: medium (within wind farms) to long distance (between wind farms) **wake effects** **WP1 wake**
- **Interconnection optimisation**: to satisfy grid connection requirements and provide power plant system services **WP2 grid**
- **Precise energy yield** prediction: to ease investment decisions based on accurate simulations **WP3 yield**

The project should focus on offshore wind power systems and **make optimal use of previously developed models.**

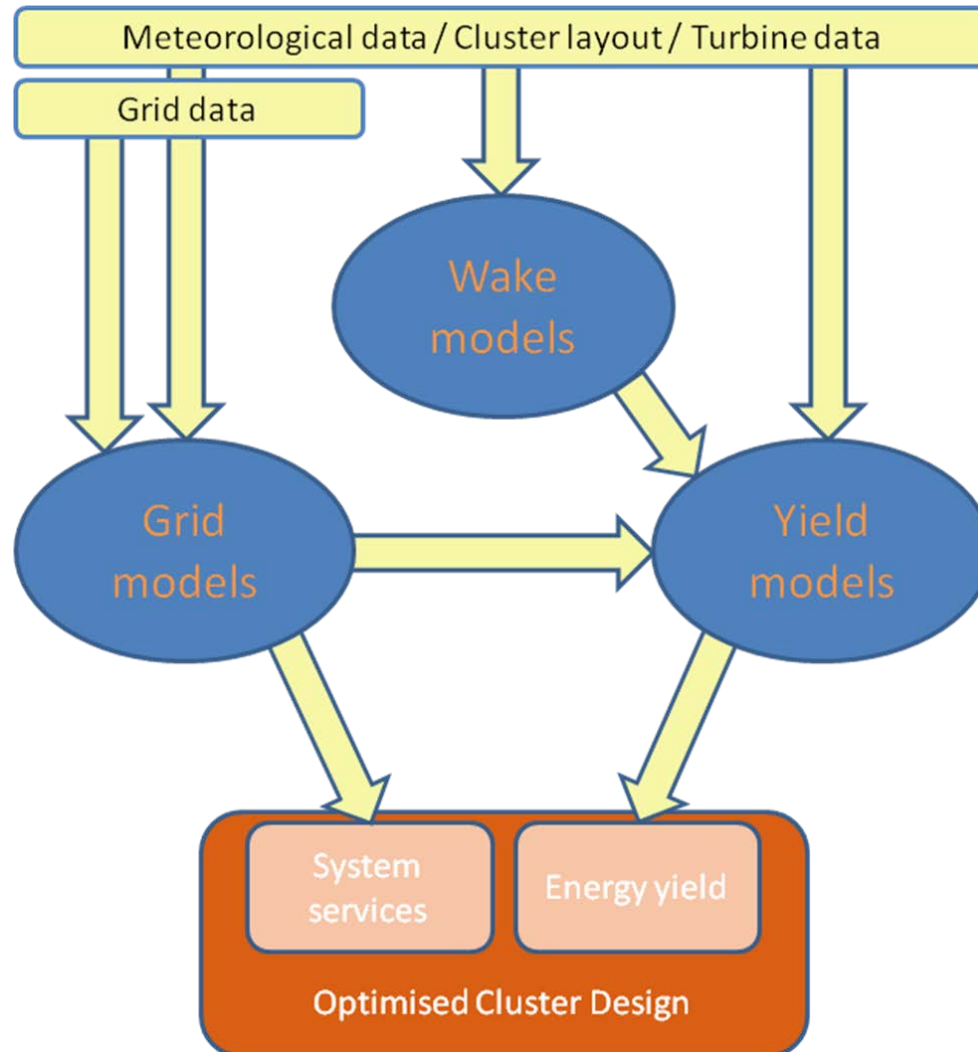
**WP4 tool and WP5 demo**



# WP structure



# EERA DTOC concept



- 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 final tool

# EERA DTOC portfolio of models



Name	Partner	Status	Programs	Input/output	Script/GUI	Database interface	IPR	Com
<b>CFDWake</b>	<b>CENER</b>		Fluent, C++, OpenFOAM	ASCII	script	Yes		
<b>CorWind</b>	<b>Risoe DTU</b>	Ope	DOS exe Delphi	CSV files	no	no	+	+
<b>CRES-farm</b>	<b>CRES</b>	Ope	Linux/ Fortran77	ASCII	no	no	+	
<b>CRES--flowNS</b>	<b>CRES</b>	Ope	Linux/ Fortran77	ASCII	no	no		
<b>DWM</b>	<b>Risoe DTU</b>	Ope	Fortran, pc, pc-cluster	ASCII	script		+	
<b>ECNS</b>	<b>ECN</b>	Beta	Linux/ Fortran90	ASCII	No	No	+	
<b>EeFarm</b>	<b>ECN</b>	Alpha	Matlab	Matlab scripts	Script/GUI	yes	+	+
<b>Farm-farm interaction</b>	<b>ECN</b>	Ope	Fortran	ASCII	No	no	+	
<b>FarmFlow</b>	<b>ECN</b>	Ope	Delphi	ASCII/ binary	GUI	Yes	+	+
<b>FlowARSM</b>	<b>CRES</b>	Alpha	Linux/ Fortran77	ASCII	no	no		
<b>FUGA</b>	<b>Risoe DTU</b>	Ope	Fortran, C, Delphi, pc	ASCII	Script/ GUI	No	+	
<b>NET-OP</b>	<b>SINTEF</b>	Proto type	Matlab	ASCII	script	No	+	
<b>Skiron/WAM</b>	<b>CENER</b>	Ope	Unix/ Fortran	GRIB	script	yes		
<b>TOPFARM</b>	<b>Risoe DTU</b>	Beta	Matlab/C/ Fortran	ASCII	script		+	
<b>UAEP</b>	<b>Risoe DTU</b>		Matlab, pc	ASCII/ binary	no	yes		
<b>VENTOS</b>	<b>UPorto</b>	Beta	Unix/ Fortran	ASCII	no	yes	+	+
<b>WAsP</b>	<b>Risoe DTU</b>	Ope	Windows pc	ASCII	Script/ GUI	No	+	+
<b>WCMS</b>	<b>Fraunhofer</b>	Ope	Matlab/JAVA	OracleDB		yes	+	
<b>WRF</b>	<b>Risoe DTU</b>	Ope	Unix, Linux, Fortran90	netCDF	Shell script	yes		
<b>WRF/ROMS</b>	<b>CIEMAT</b>	Ope	Linux/ Fortran	netCDF	script	yes	+	

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Run on  
Windows, on a  
single PC

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Runs on Cluster  
under  
UNIX/Linux



# User Requirements

Design and model selection guided by end-users

Two **main user groups** were identified:

- Strategic planners
- Developers of offshore wind farms

Associated users could be:

- Consultants
- Research institutions
- Manufacturers
- System Operators

- As a developer I can determine the wake effects of neighbouring wind farm clusters on a single wind farm.
- As a developer I can determine the optimum spacing, position, turbine model and hub height of turbines within an offshore wind farm.
- As a strategic planner I can determine the optimum strategic infrastructure to accommodate offshore wind farm clusters.
- *14 relevant user stories in total*

- As a developer I can **determine the optimum** spacing, position, turbine model and hub height of turbines within an offshore wind farm.

Software supports the *comparison* of many design scenarios.

*Comparative* reporting enables selection of optimised configurations.

Score for comparison: Levelised Cost of Energy

## Optimisation Process

### 1. Generate Design Options

- Scenario 1
- Scenario 2
- Scenario 3
- Scenario 4
- Scenario 5
- Scenario 6
- Scenario 7

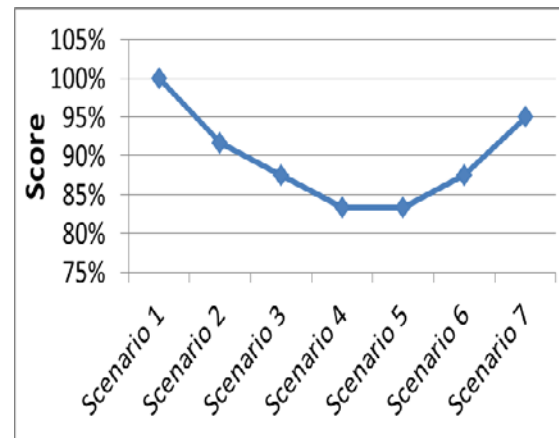
### 2. Evaluate Design Options

Wake Model

Electrical Model

Energy model

### 3. Compare Design Options



### 4. Iterate steps 1 to 3



**Score: Levelized cost of energy**

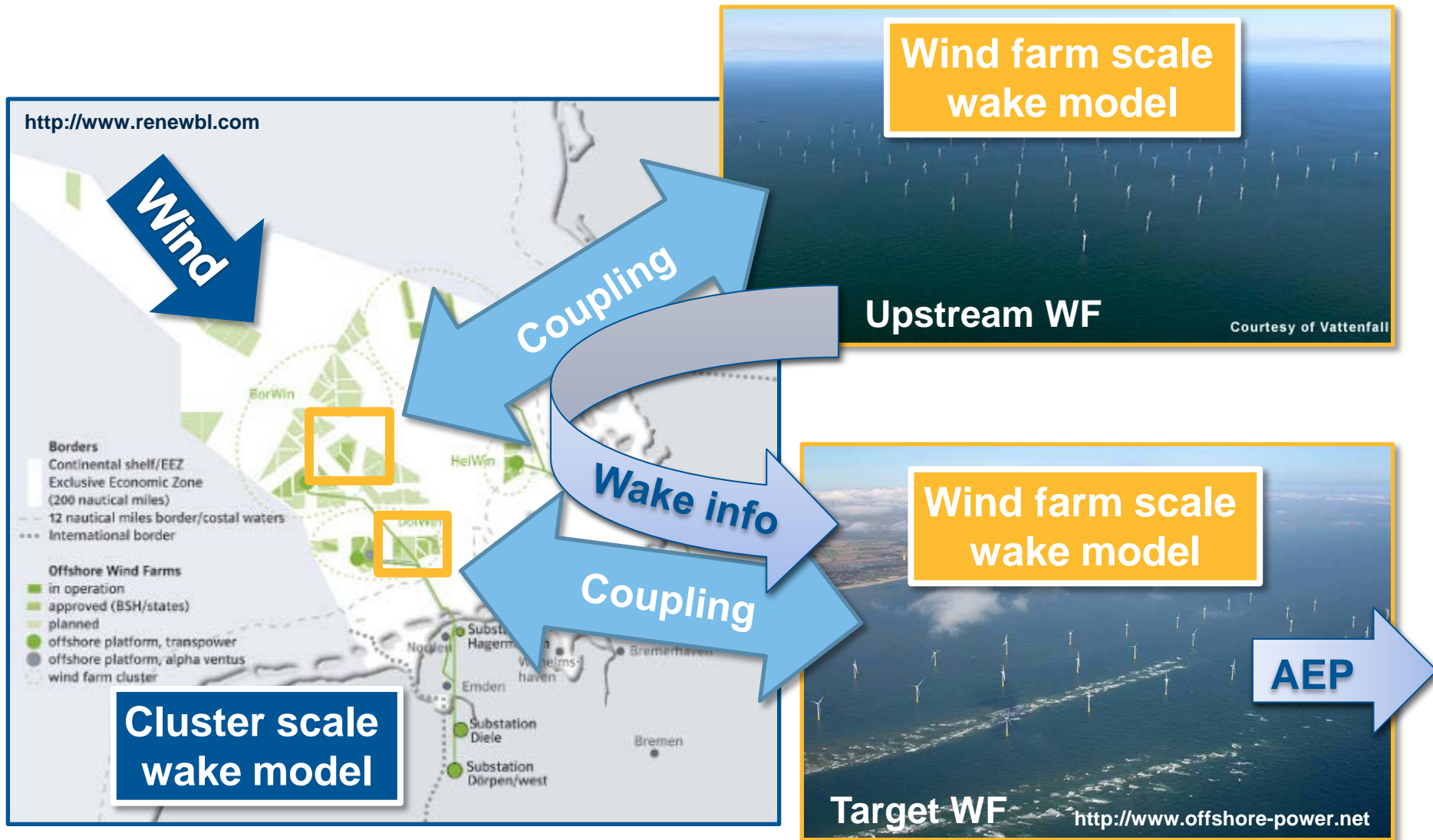
**What decision parameter can we use to compare design options?**

- 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.



# Introduction

## The “big wake” picture



# Wind farm scale wake models



DWM



WASP/NO  
J

U.PORTO

RANS



CRES  
flowNS



Ainslie



FarmFlow

FUGA

GCL

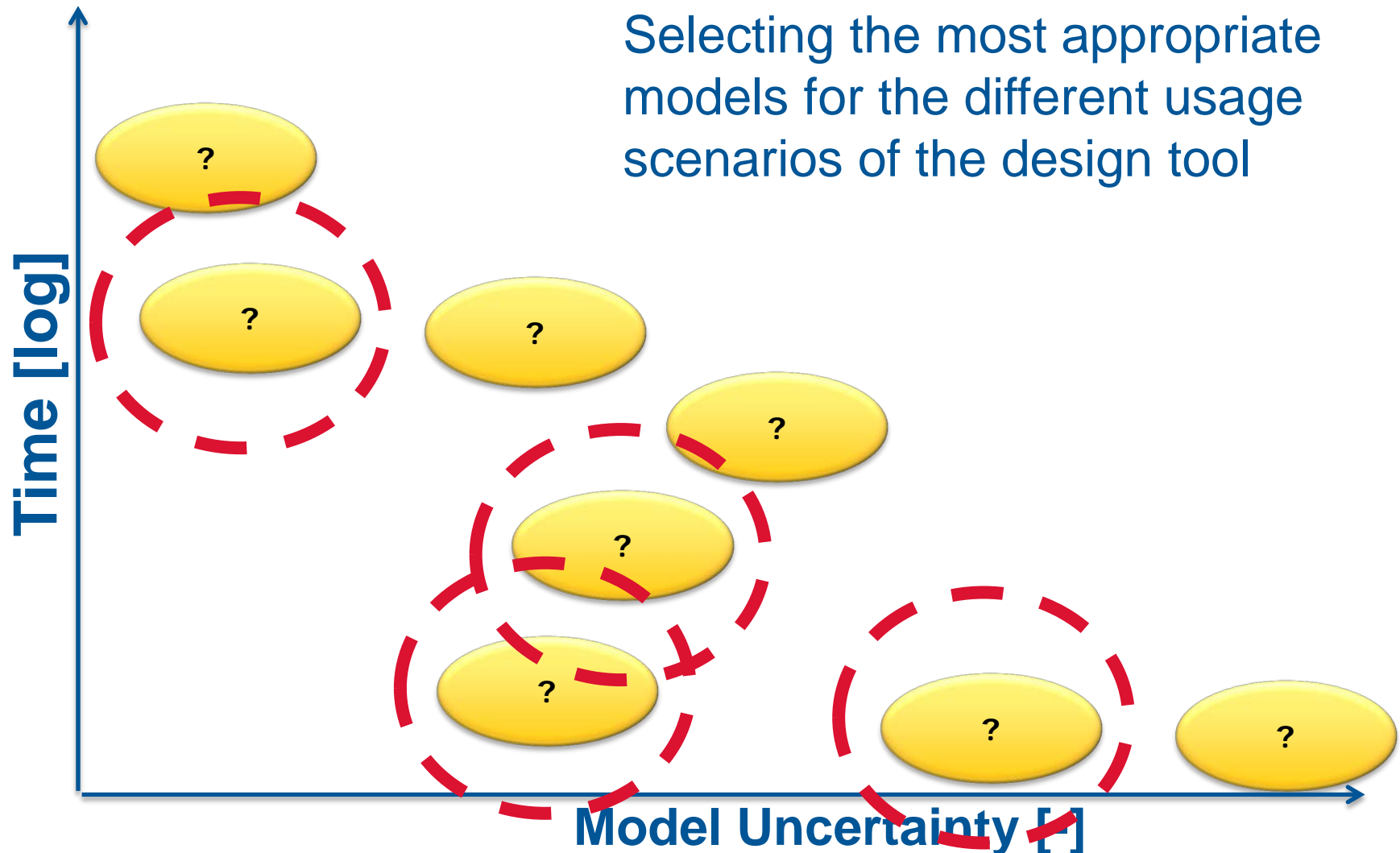
NOJ

Engineering

Simplified  
CFD

Full CFD

# Benchmarking purpose

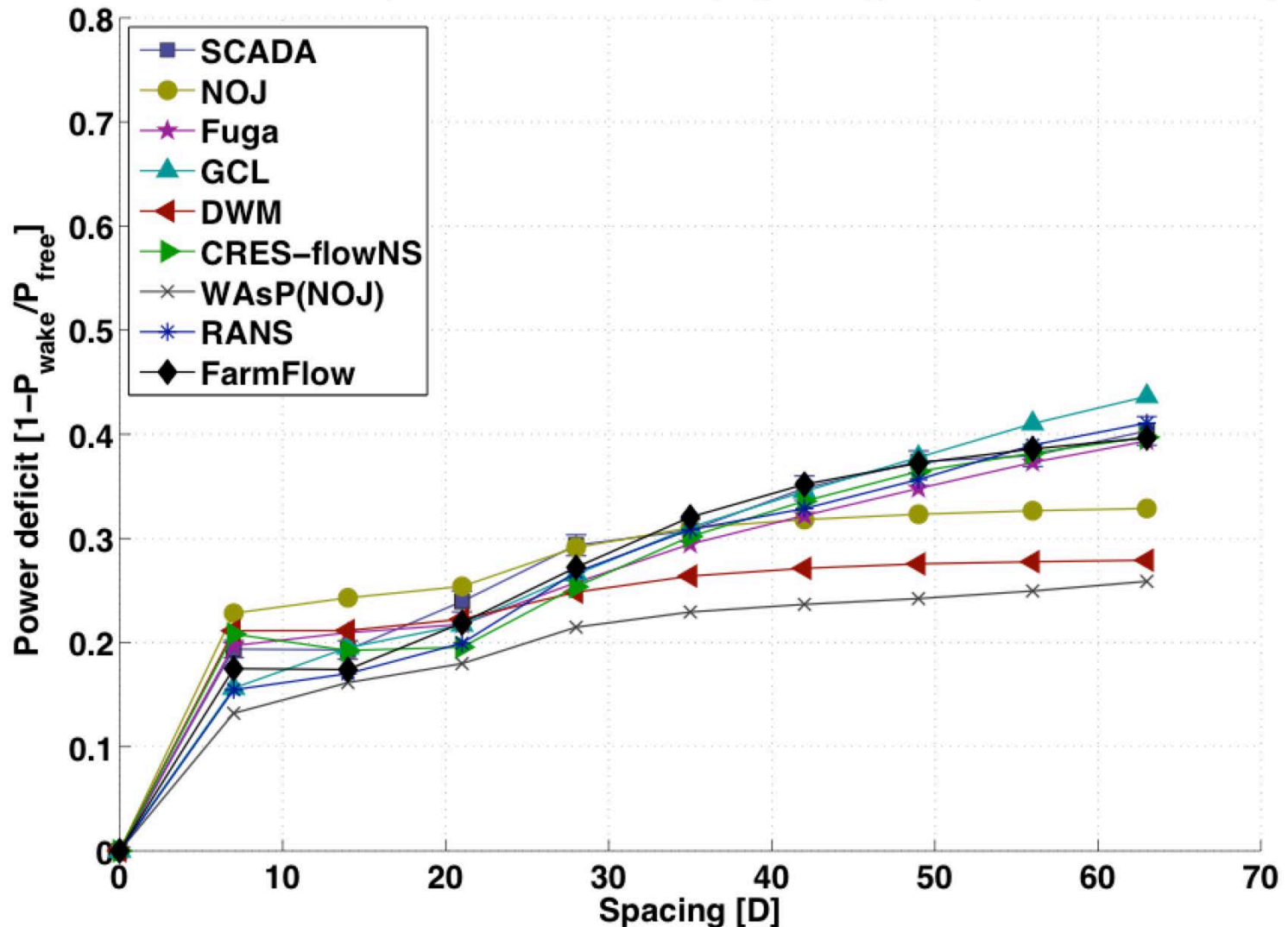
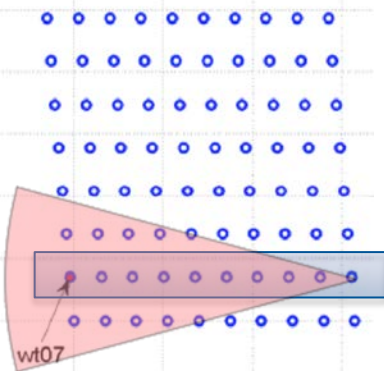


# Horns Rev 1 benchmark (DONG energy & Vattenfall)

## Lillgrund benchmark (Vattenfall)

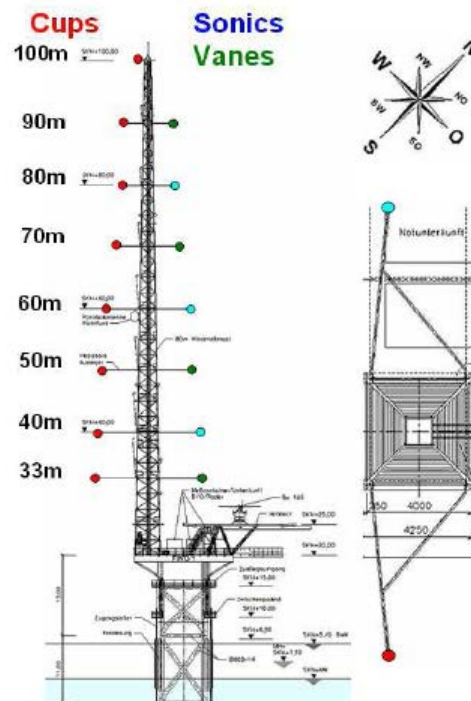
Horns Rev,  $w_{dir}=270 \pm 15^\circ$ , spacing=7D,  $w_s=8 \pm 0.5$  m/s

Example:  
Power deficit  
along one row



# Gross energy : FINO-1 test case (BMU)

- Wind speed and direction data (10 minutes)  
From 13/01/2005 to 30/06/2012 (total of 7.5 years data)  
(Generic power curve ( $1.225 \text{ kg/m}^3$ ))



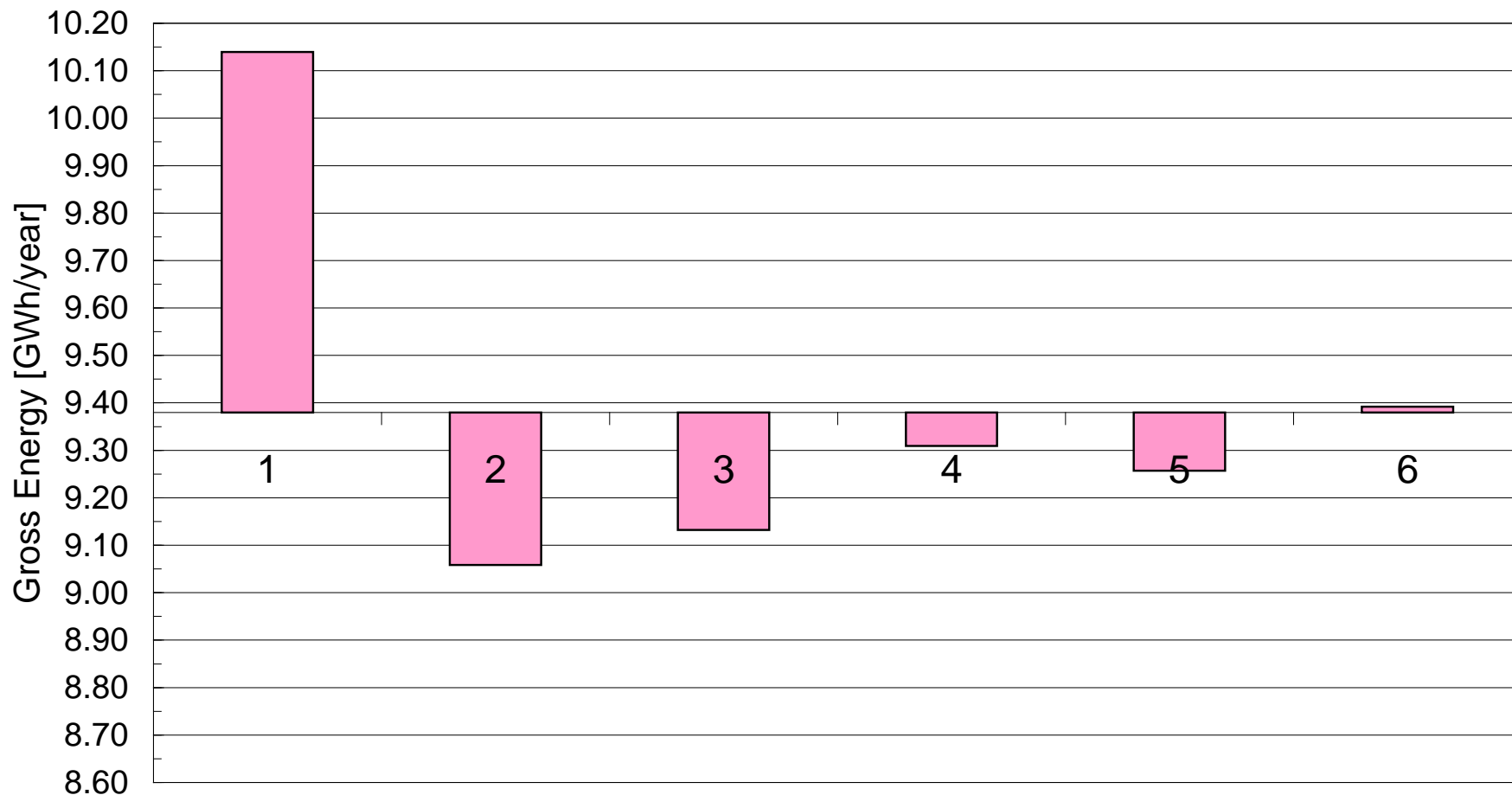
# Gross energy – output parameter checks

- Mean wind speed (before filtering)
- Mean wind speed (after filtering)
- Long term mean wind speed, free decision
- Vertical extrapolation between 100m and 120m
- Gross energy P50
- Gross energy P90



# Gross energy P90

Gross Energy P90. Mean value  $\pm 8.5\%$



# O&M losses

- Offshore Wind Farm

- Inputs

- Turbine layout and turbine model

- Site wave climate

- Location of O&M base (from 10 to 150 km)

- O&M strategy

- SWARM software

Wave Climate Scenario	Description	Mean Wind Speed at 100m [m/s]	% of Time Above Hs Limit	
			1.5 meters	2.0 meters
1	Benign Climate	9.0	16.5%	6.3%
2	Moderate Climate	9.4	21.0%	7.4%
3	Severe Climate	9.5	28.3%	12.6%

Scenario	Number of Workboats	Number of Helicopters	Wave Hs Limit for Boats [m]
1	5	0	1.5
2	5	0	2.0
3	5	2	2.0

# Aims of grid layout optimization

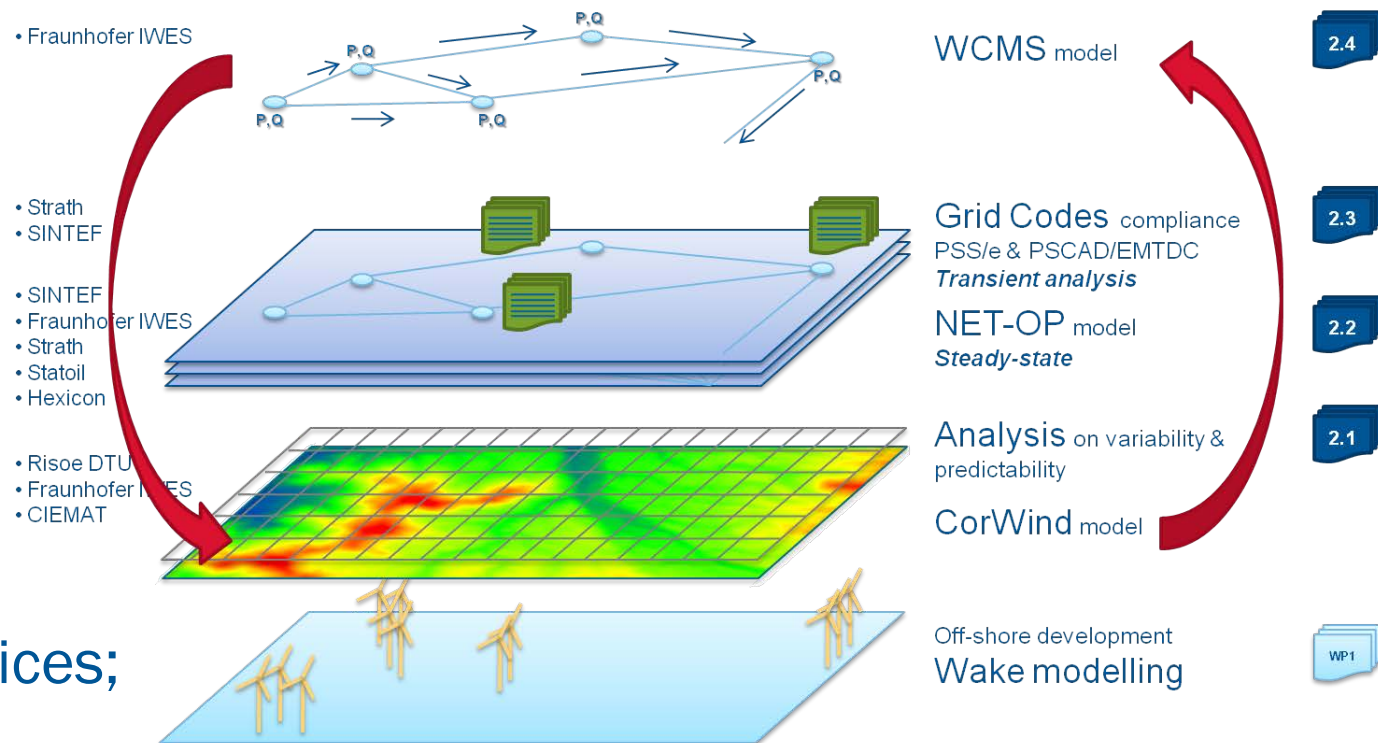
- Design tool and procedure assisting the optimization of the electrical design;

- Clustering;

- Grid code compliance;

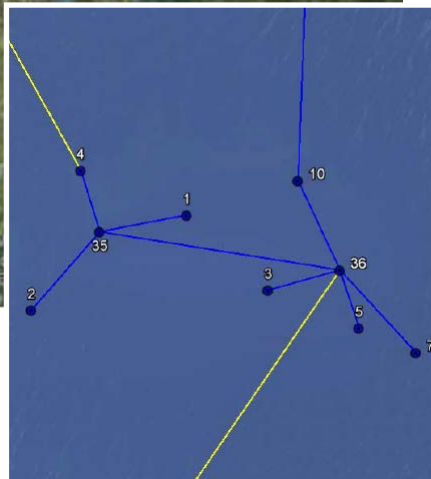
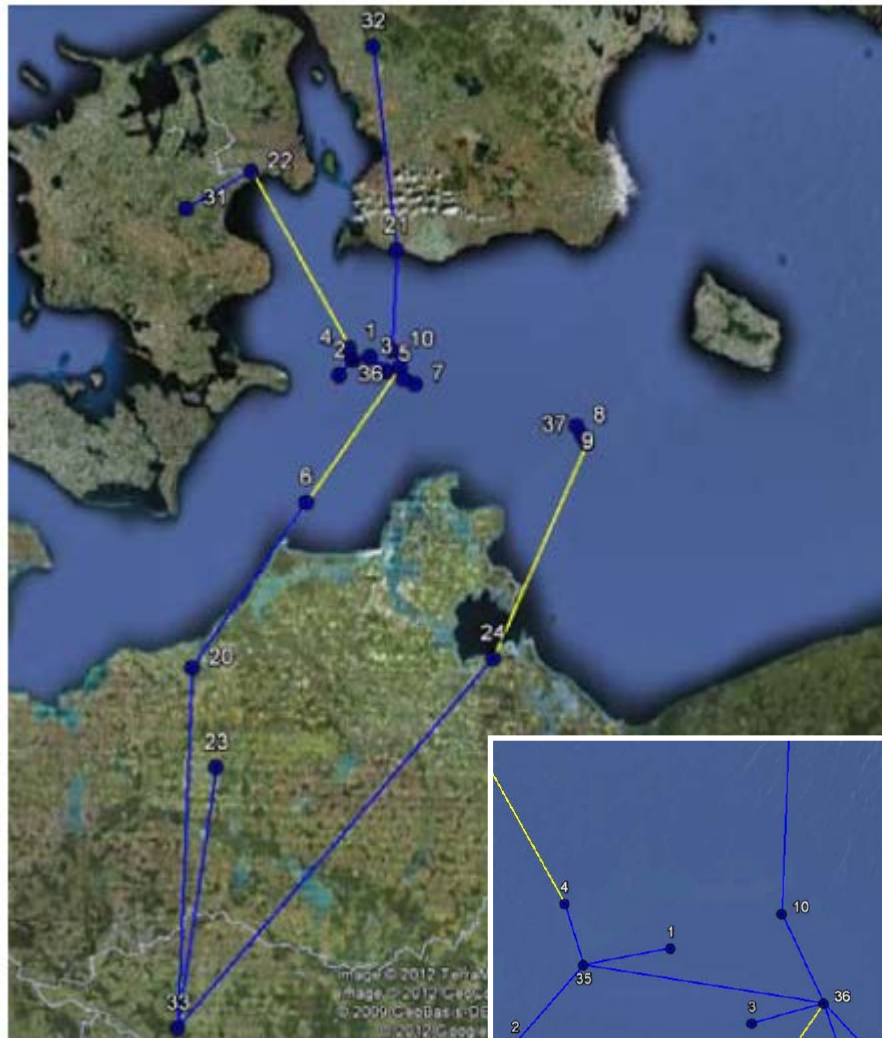
- Power plant ancillary services;

- Evaluate impact of the variability and the predictability.



1. Determine the models chain, interactions, I/O;
2. Establish the data flow/ data gaps according to the user cases;
3. Procedure to fill overcome gaps was investigated:
  1. Automatic electrical data generation
  2. User intervention providing accurate data.
  3. Implementation of a new module
4. Dry runs (based on scenarios)
5. Assessment/ convenience evaluation

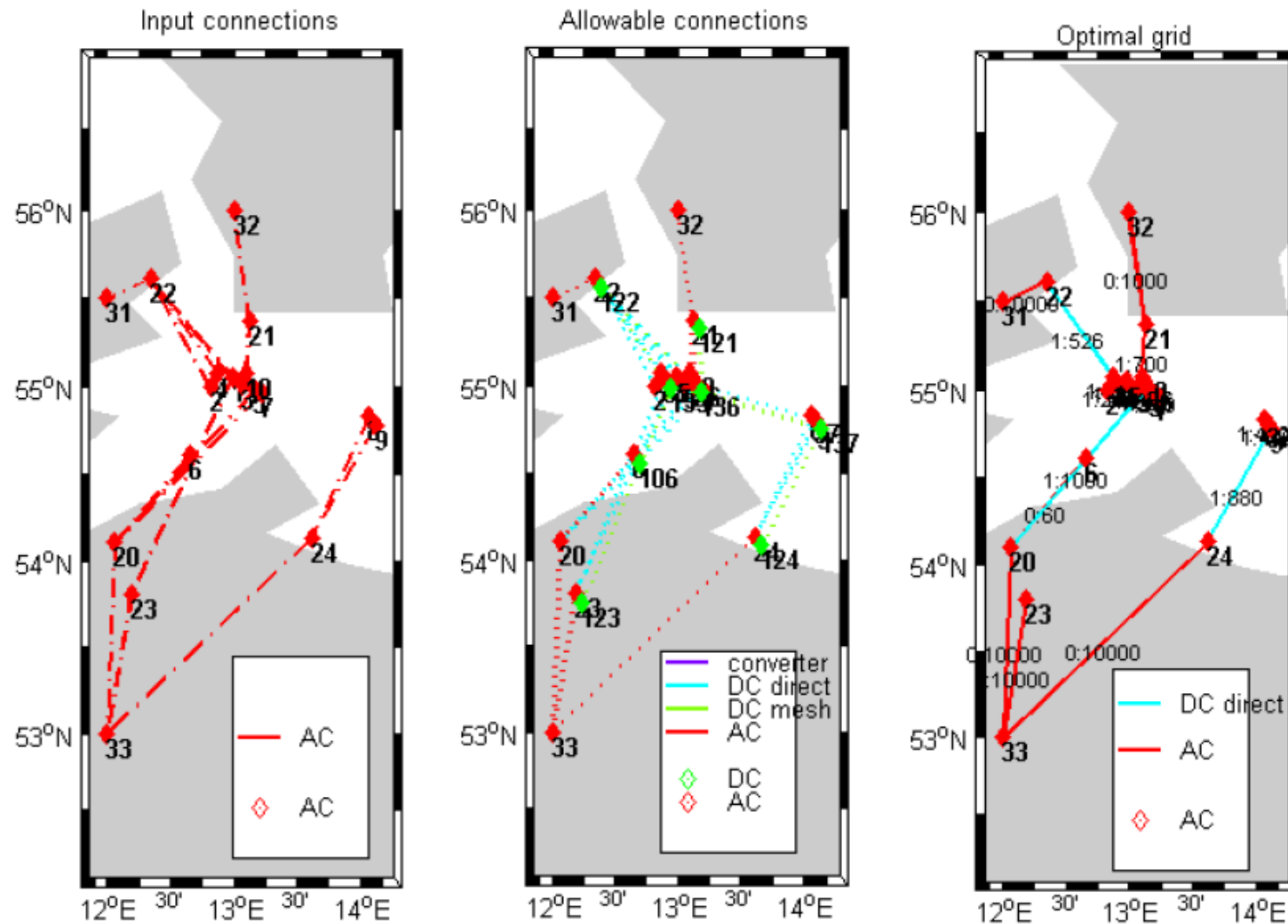
# Kriegers Flak case study



#	Country	Wind farm	Capacity
1	DK	Kriegers Flak A K2	200
2	DK	Kriegers Flak A K3	200
3	DK	Kriegers Flak A K4	200
4	DK	Kriegers Flak B K1	200
5	DE	EnBW Baltic 2	288
6	DE	EnBW Baltic 1	48
7	DE	Baltic Power	500
8	DE	Wikinger	400
9	DE	Arkona Becken Südost	480
10	SE	Kriegers Flak	640

Branch type	max distance	max power
AC	65 km	700 MW
DC-direct		1000 MW
DC-mesh		1000 MW
converter		1000 MW

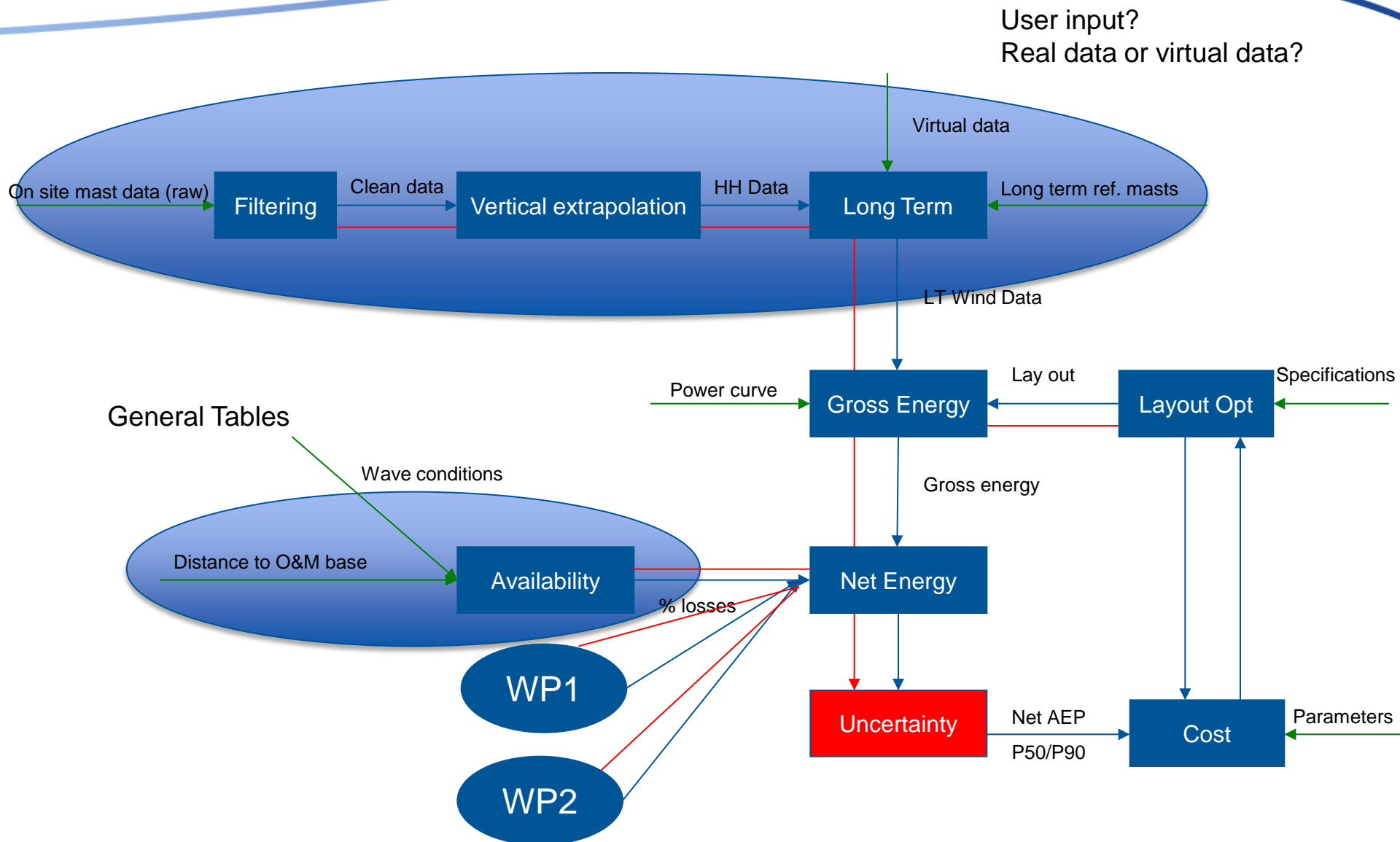
# Kriegers Flak case study results



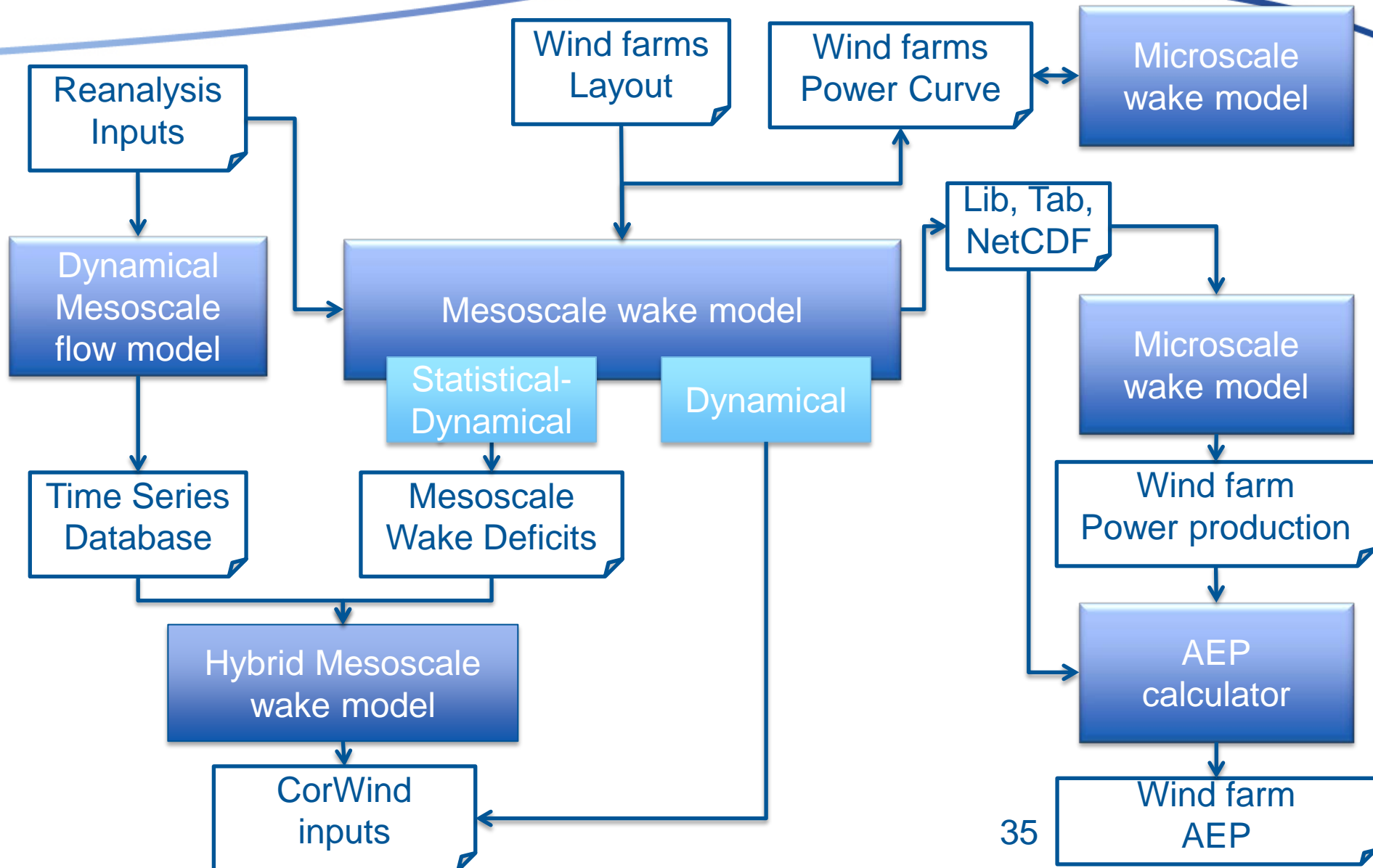


- Checking planned grid:
  - Fulfillment of full load flows → calculate component utilization factors.
  - Fulfillment of certain average load flows situations.
  - Checking congestions and voltages.
  - Control power:
    - Power reserve
    - Balancing power
  - Voltage control
  - Enabling market/ transport

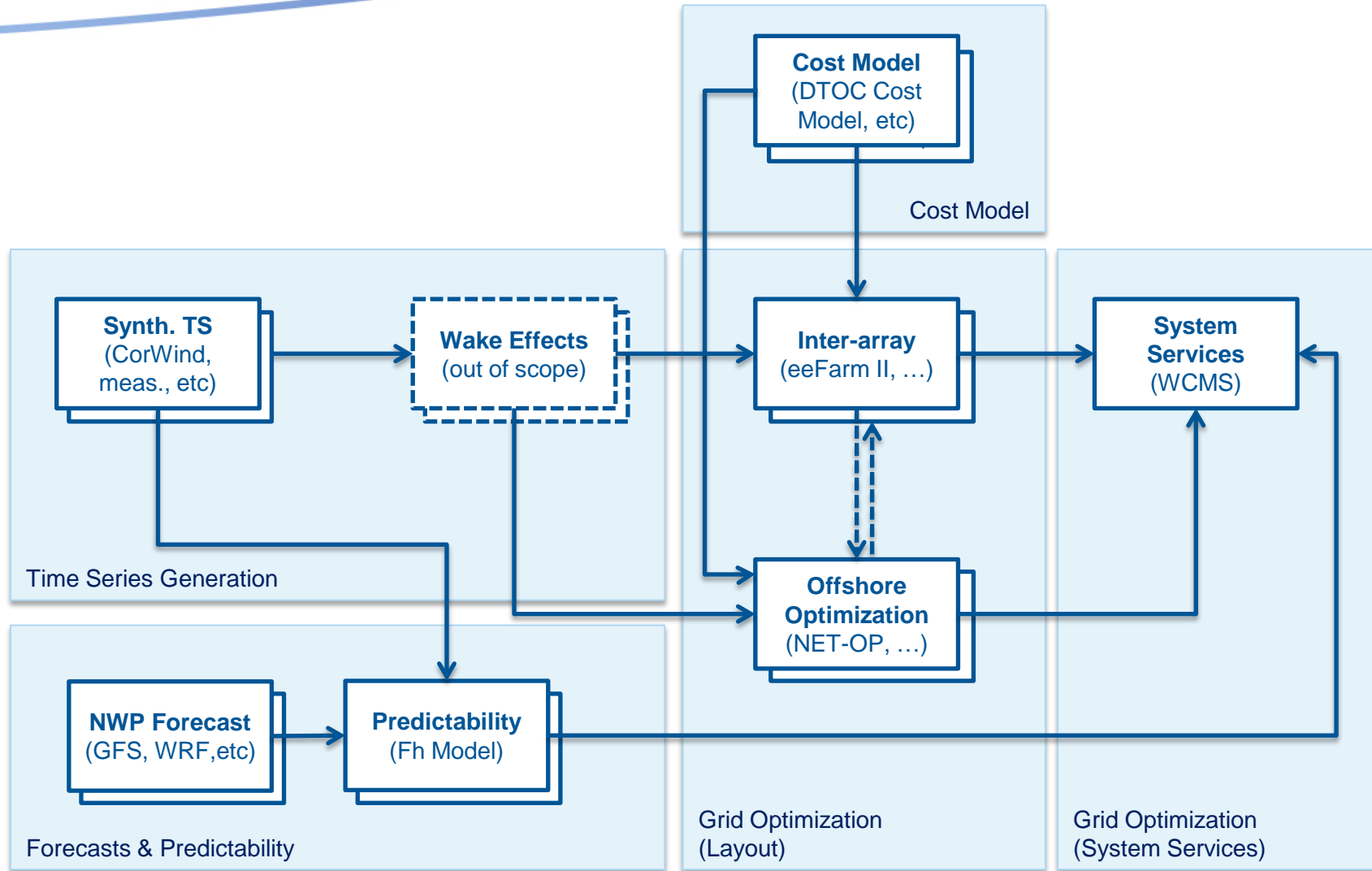
# Model workflow energy yield (WP3)



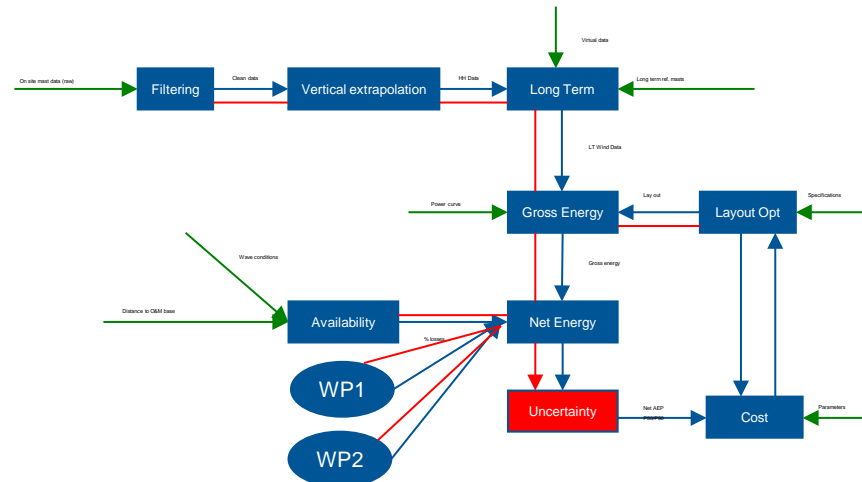
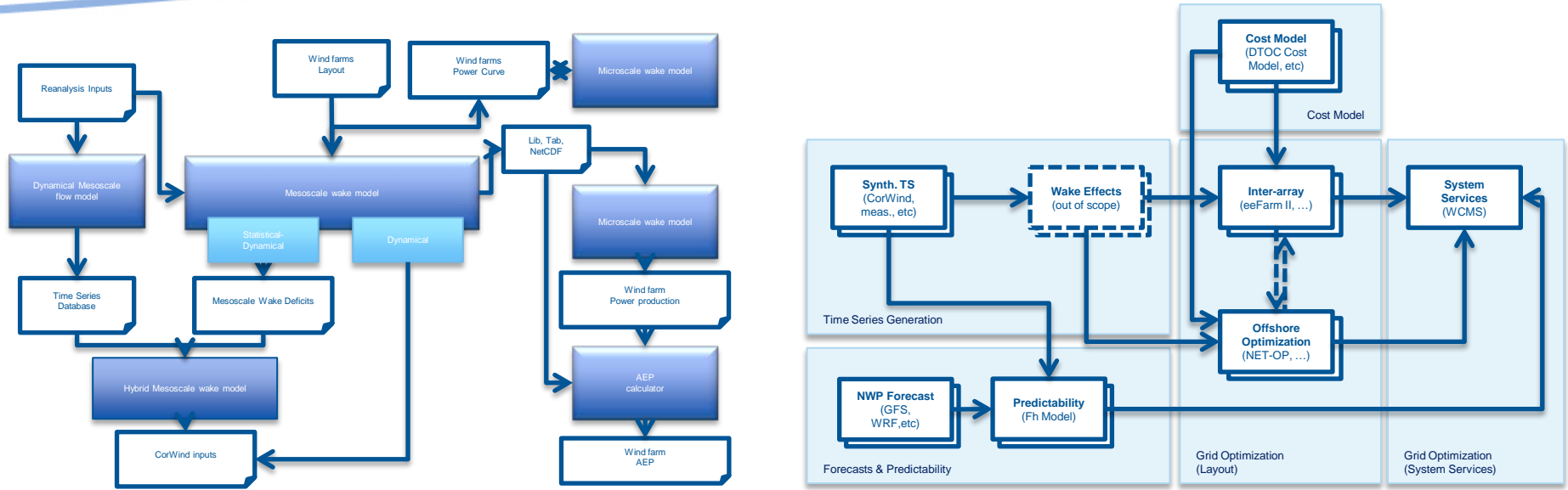
# Model workflow wake (WP1)



# Model workflow “Electrical” (WP2)



# Total tool overview – very complex!



- The sub-models are protected by IPR...
- ...but the interfaces in the model chain are going to be open
- File formats for data exchange are based on existing industry standard formats, e.g. the WAsP types based on XML and ESRI shape file standard

# DTOC software development timeline

*end user  
requirements*

*pre-design*

*design*

*test reports*

**2012**

**2013**

**2014**

existing  
models

dry runs

proof of  
concept

prototype

DTOC V0.5

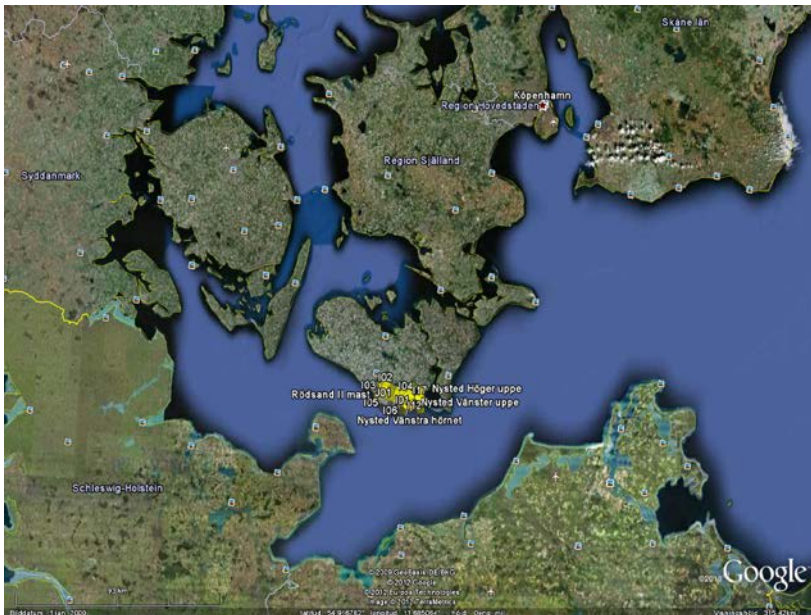
DTOC V1.0



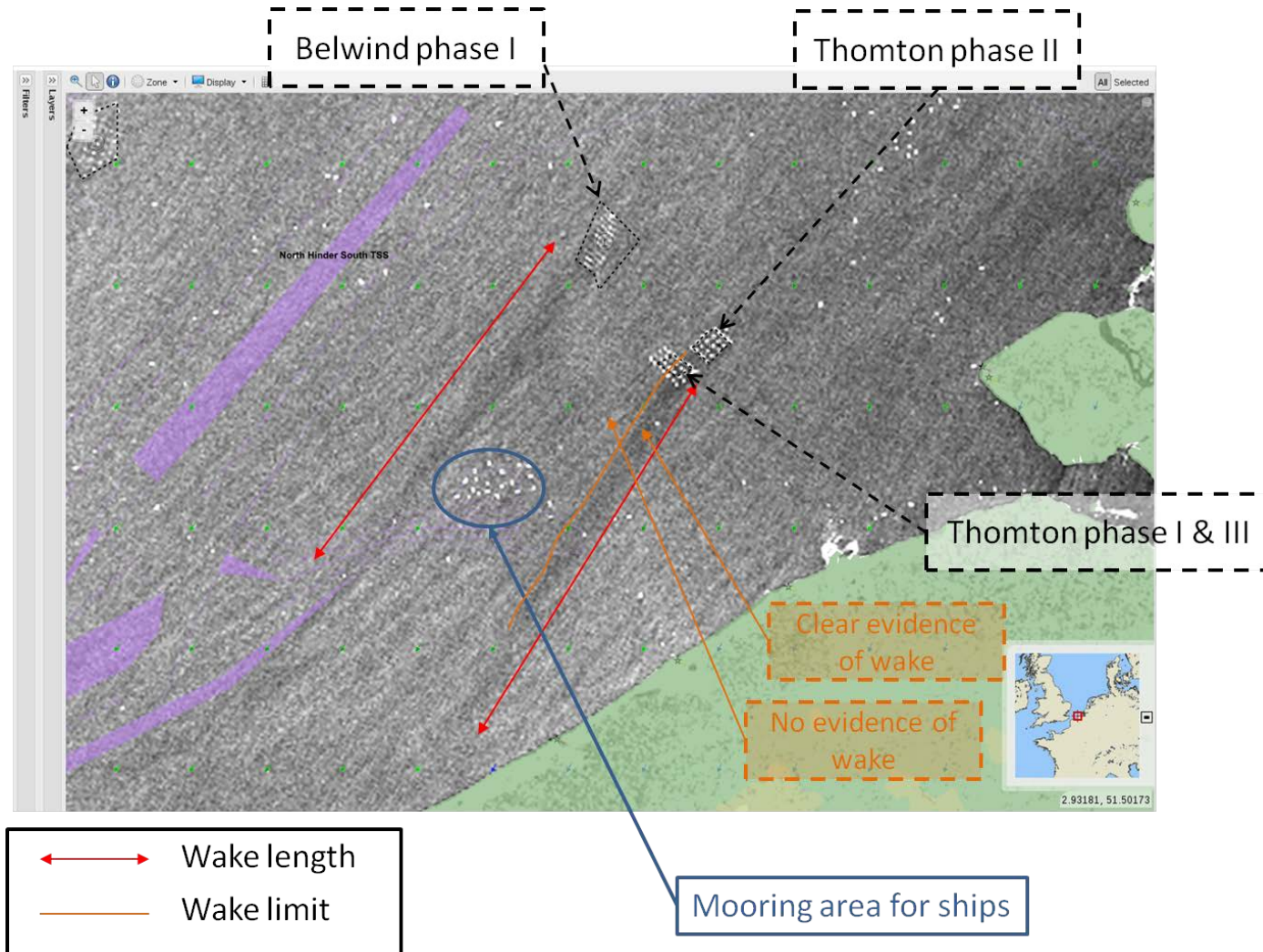
# Validation and demonstration

# Rødsand 2 data (E.On)

10 minute statistical data from meteorological mast and Rødsand 2 turbines  
(No data from neighbouring Nysted farm)

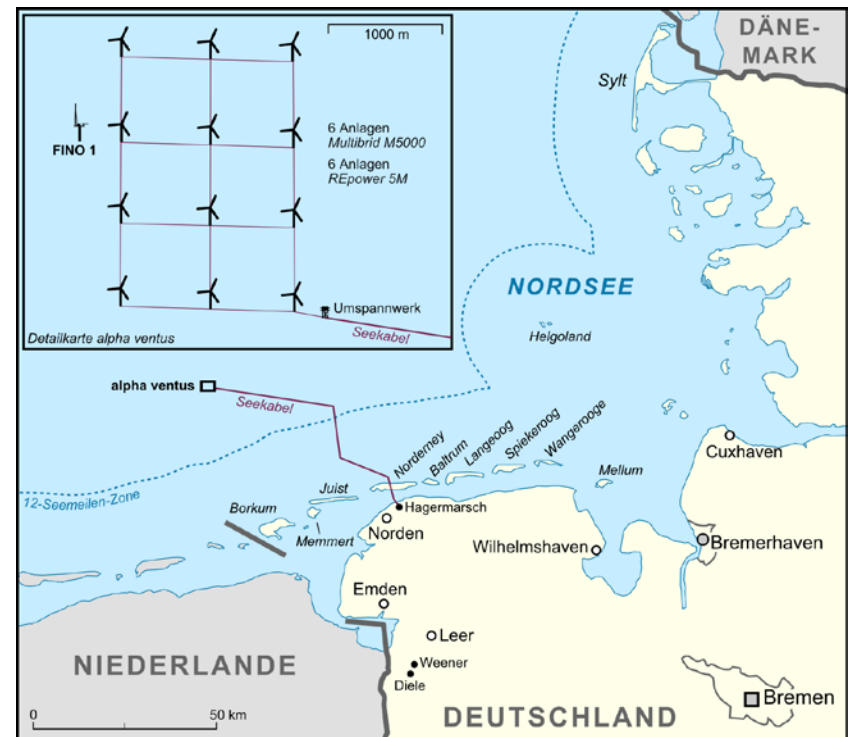


# SAR satellite images (CLS, DTU)



# Lidar measurements (ForWind & Fraunhofer IWES)

- Long range wind scanner measurements from fixed positions
- Ship based LIDAR measurements
- EERA DTOC partners requested
- Alpha Ventus SCADA data



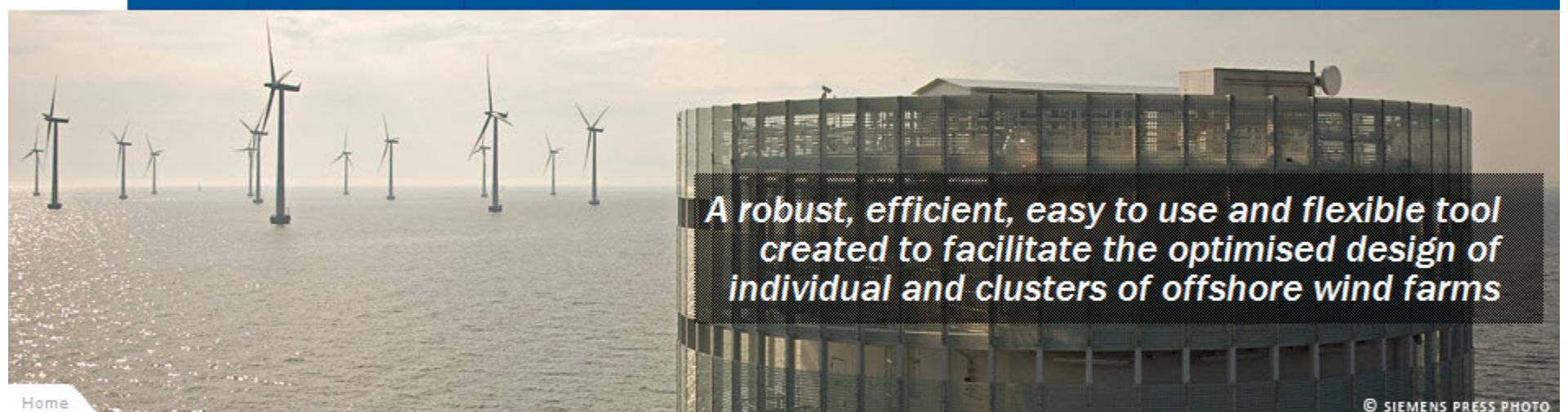
Industry partners are very important!

Iberdrola, Statoil, Carbon Trust,  
Hexicon, Statkraft, E.On, RES

# Purpose of the scenarios

- The tool should fulfill the previously defined user requirements:
  - The tool should be useful, easy to use, complete and robust
- Functionality of all modules in EERA DTOC should be proven → All parts of the tool should be activated during the scenarios
- Inventory of user experiences:
  - How steep is the learning curve?
  - Which tutorials should be added ?
- The results should LOOK realistic from an expert point of view



A wide-angle photograph of an offshore wind farm in the sea, with several wind turbines visible in the distance. In the foreground, a large, dark, cylindrical structure, likely an oil or gas platform, is partially visible.

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

© SIEMENS PRESS PHOTO

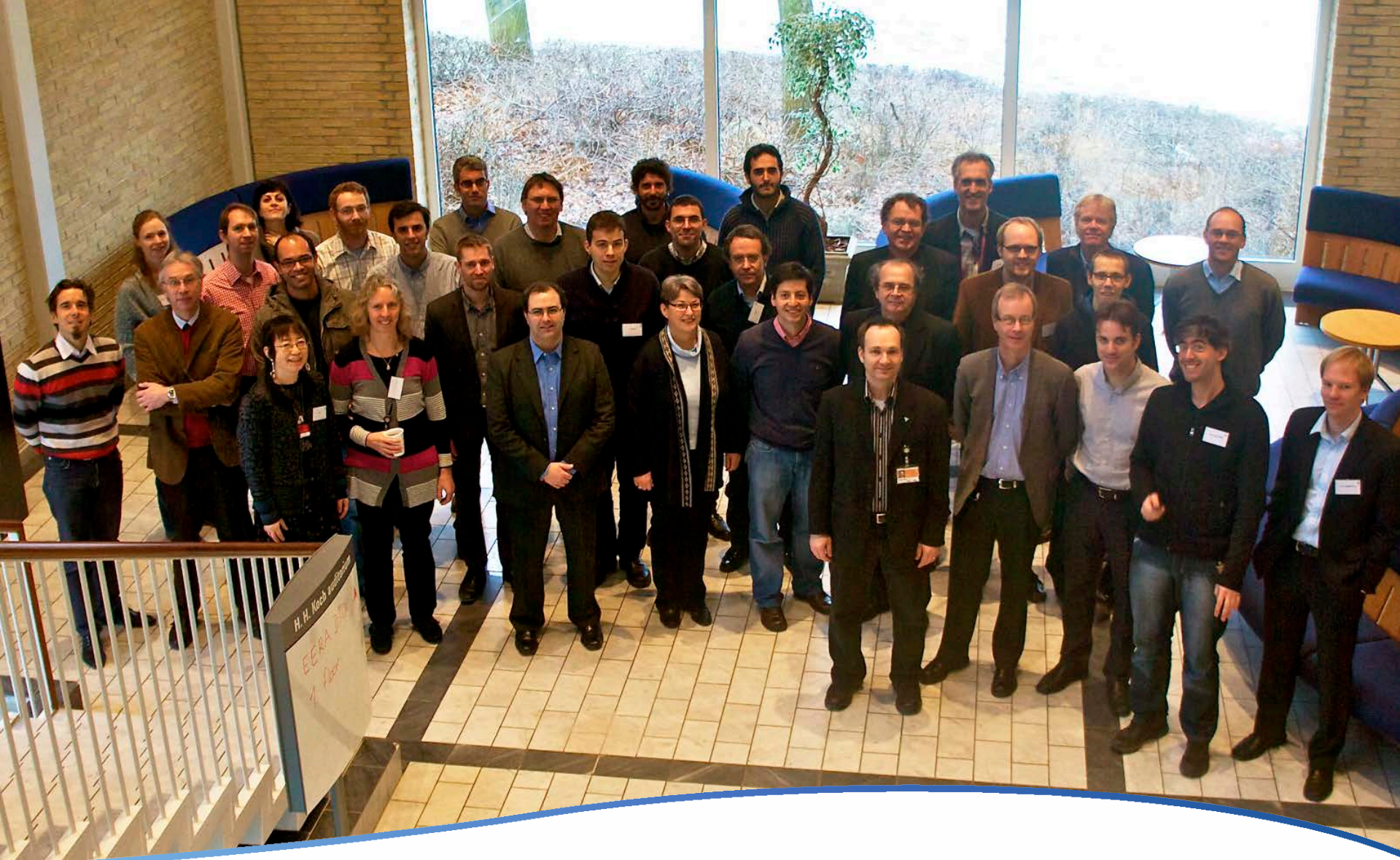
## What is EERA-DTOC?

EERA-DTOC stands for the European Energy Research Alliance - Design Tool for Offshore Wind Farm Cluster. The project is funded by the EU – [Seventh Framework Programme](#) – and runs from January 2012 to June 2015. It is coordinated by the [Technical University of Denmark](#) - DTU Wind Energy. The concept of the **EERA-DTOC** project is to combine this expertise in a common integrated software tool for the optimized design of offshore wind farms and wind farm clusters acting as wind power plants.

## Deliverables

- 7th Framework





Thank you very much for your attention



Support by

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EERA DTOC project  
FP7-ENERGY-2011-1/ n°282797