NORCOWE Reference Wind Farm

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Why NORCOWE Reference Wind Farm?

- In order to link the work in WP3 **- Design, installation and operation of offshore wind turbines**
- Better integration of the work in WP3 was a request from RCN after their mid-term evaluation of NORCOWE
- Idea: John Dalsgaard Sørensen, Aalborg University
- Development and use of NORCOWE RWF is integrated in NORCOWE's annual work plans
- NORCOWE RWF will be used in case studies in 2016 in NORCOWE
- NORCOWE RWF to be used in IEA Wind task 37 - **Wind Energy Systems Engineering: Integrated RD&D**

NORCOWE reference wind farm

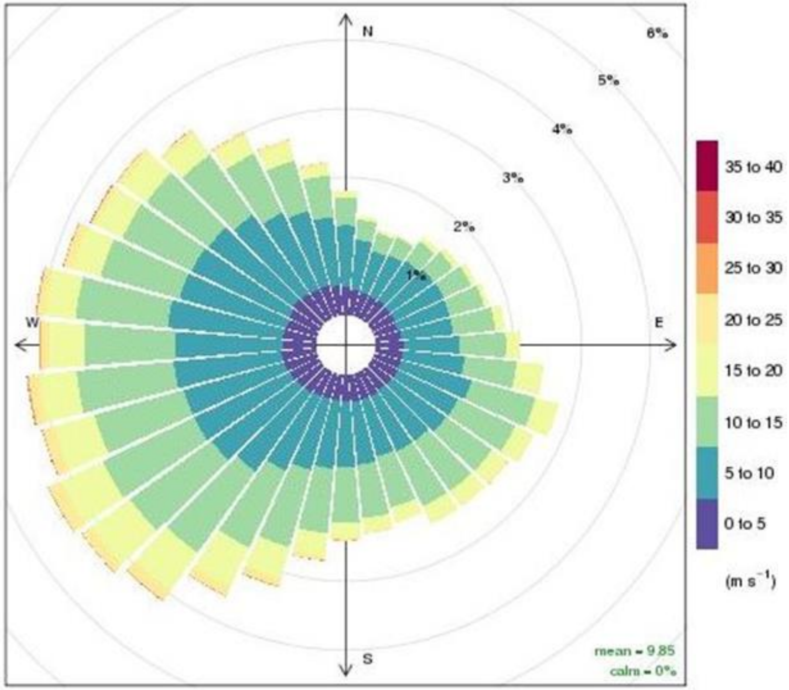
- Developmental work on NORCOWE’s reference wind farm (RWF) has taken place at Aalborg University and Uni Research.
- The RWF comprises a fictitious 800 MW wind farm at the location of the FINO3 met mast, 80 km west of the island of Sylt at the Danish-German border.
- The farm involves a set of 80 reference wind turbines and two substations.
- DTU’s 10 MW reference wind turbine is the chosen turbine type, a variable-speed rotor of diameter 178 m and hub height 119 m.
- Foundations are monopiles: mean water depth at FINO3 is 22.5 m, soil type comprises medium dense to very dense sand deposits with gravel and silt constituents.
- There is a real wind farm at FINO3, DanTysk, owned by Vattenfall.

Development drivers

- Output from consultation
  - **Open**ly available / **realistic** / **challenging** / **neutral**
  - **Spacing:**
    - Along wind, 8D
    - Cross wind, 6-7D
    - Perimeter: 5D
  - The availability of relevant measurement data
  - The use of publicly available **ambitious** turbine model to simplify the use and increase the impact
  - **Quick** rather than optimal
  - Rule based

Baseline turbine layouts of the NORCOWE reference wind farm

- The main wind and wave climatology at the FINO3 site for use in the reference wind farm will follow from met-ocean reanalysis over an 11 yr period 2000-2010, with the final year also serving as a year for calibrating to wind and wave measurements at the site.
- A wind rose has been established from a co-distribution of wind speed and direction, essentially at hub height.



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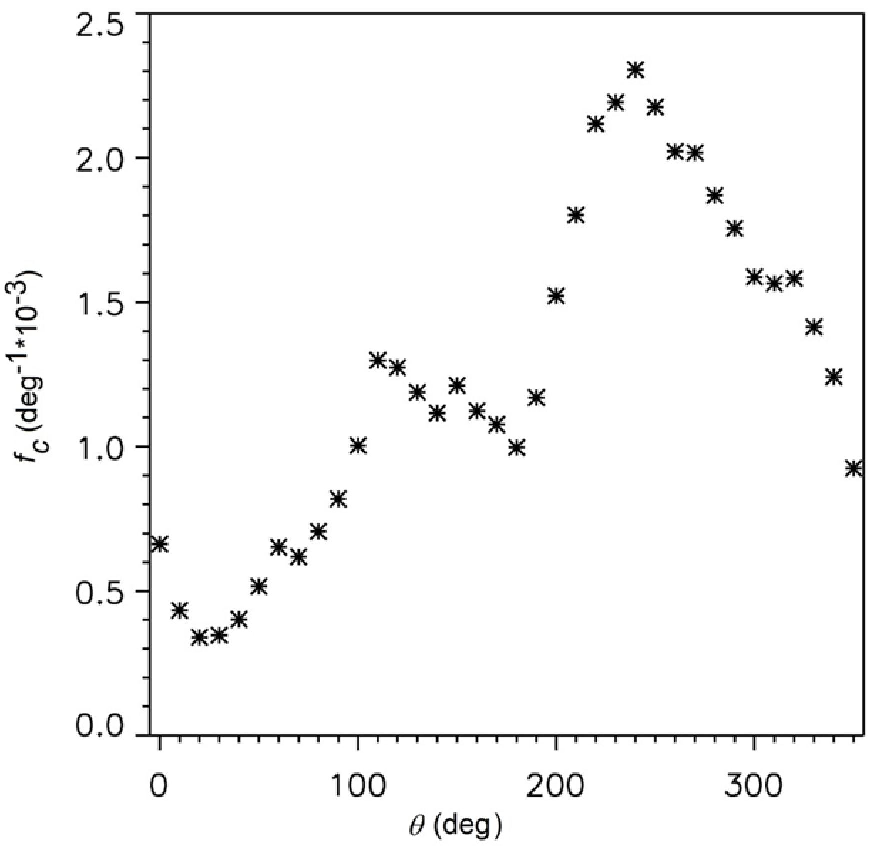
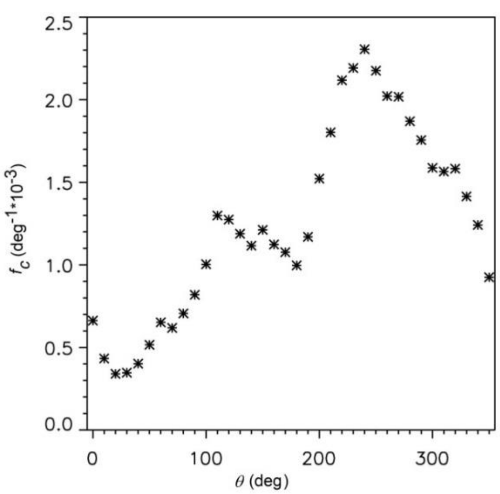
Baseline turbine layouts of the NORCOWE reference wind farm

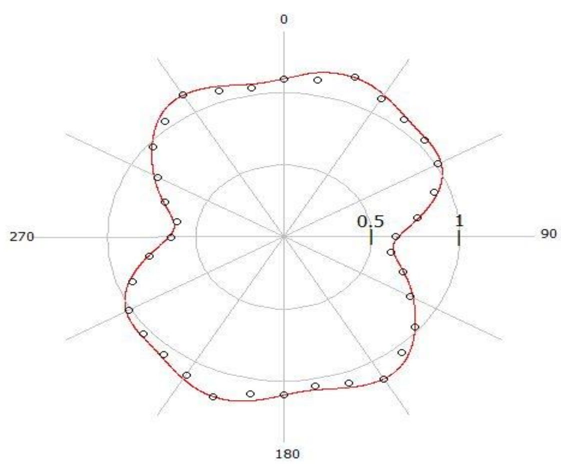
- The co-distribution has been used to calculate the directional capacity factor.
- This is the expected power at some arbitrarily-picked moment from winds from within a sector of unit angle, as a function of sector centre-line angle, and expressed as a fraction of rated power.
- Integration of the directional capacity factor over 360° yields an overall capacity factor at FINO3 for a DTU reference turbine of 0.45.



Baseline turbine layouts

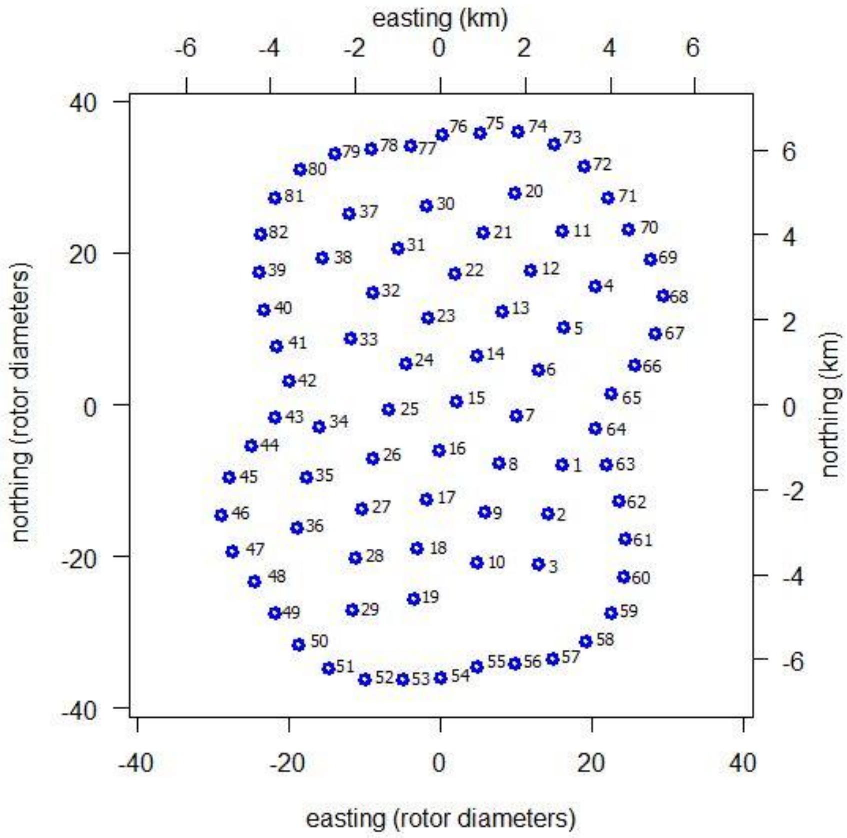
- As the reference wind farm is fictitious, it does not have a defining zone associated with the licensing and site concession.
- We have decided not to use real bathymetry in the vicinity of FINO3, but to take the seabed there as flat, so bathymetry will not play a role in determining the shape or area of the farm.
- Instead we have used the directional capacity factor to arrive at a shape for the reference wind farm.
- The width of the shape along a line through the centroid scales with the expected power from winds blowing normally to this.The shape is thus periodic over 180°.





Baseline turbine layouts

- The shape is then filled with turbines spaced 5-8 rotor diameters apart, and the smallest area containing 82 installations is obtained.
- Along the perimeter, turbines are spaced 5 rotor diameters apart – there is thus “perimeter weighting”.
- Within the shape, turbines lie on a spiral (the involute of a circle).
- The centre of the spiral is offset from the shape centre normally to the leading axis of the shape, by a distance which depends on the elongation of the shape.
- Successive spiral arms are spaced 8 rotor diameters apart.
- Along the spiral, turbines are separated by a distance which depends on the elongation of the shape, working out at FINO3 at 6.5 rotor diameters.



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Baseline turbine layouts

Advantages of the baseline layout scheme:

- It follows rationally with a minimum of ad-hoc parameters from rules.
- The methodology is generic: it can be applied with an arbitrary wind climatology to arrive at the corresponding layout at any location of interest.
- Wake effects are implicitly taken into account.

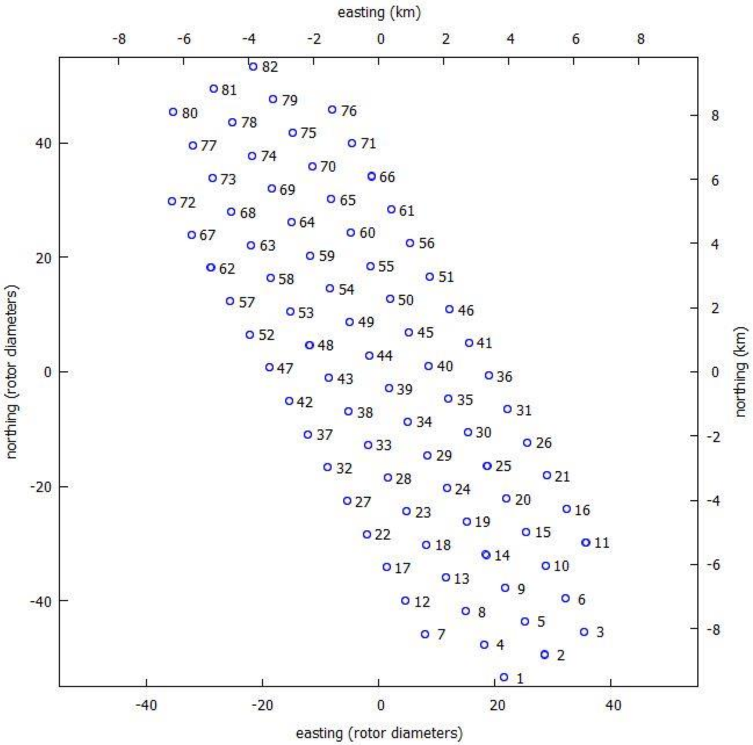
Disadvantages

- Real-world considerations reflecting zone limits established in the licencing process, and site bathymetry, are not taken into account.
- The shape does not resemble that of any current offshore wind farm.

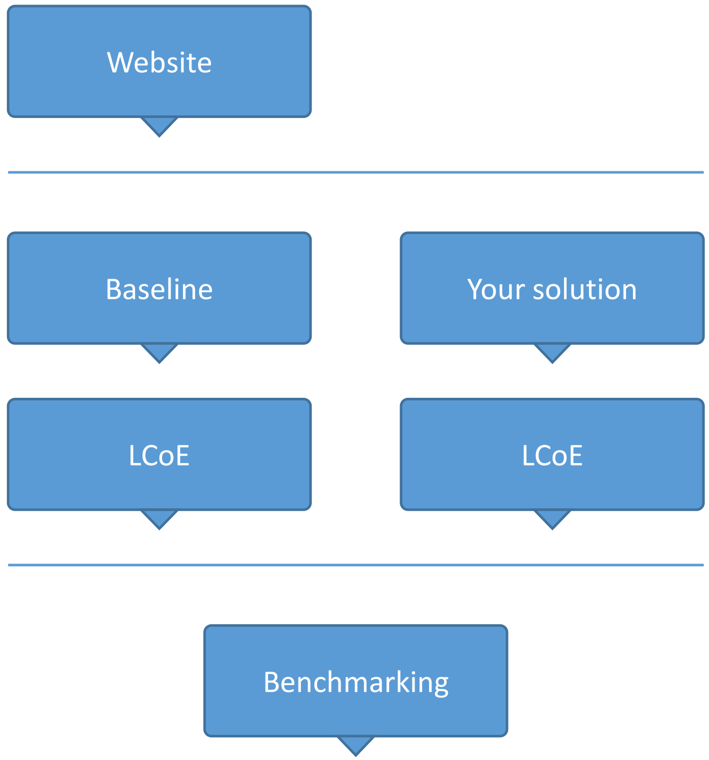
Baseline turbine layouts

It was decided to also determine a conventional, rectilinear, baseline layout.

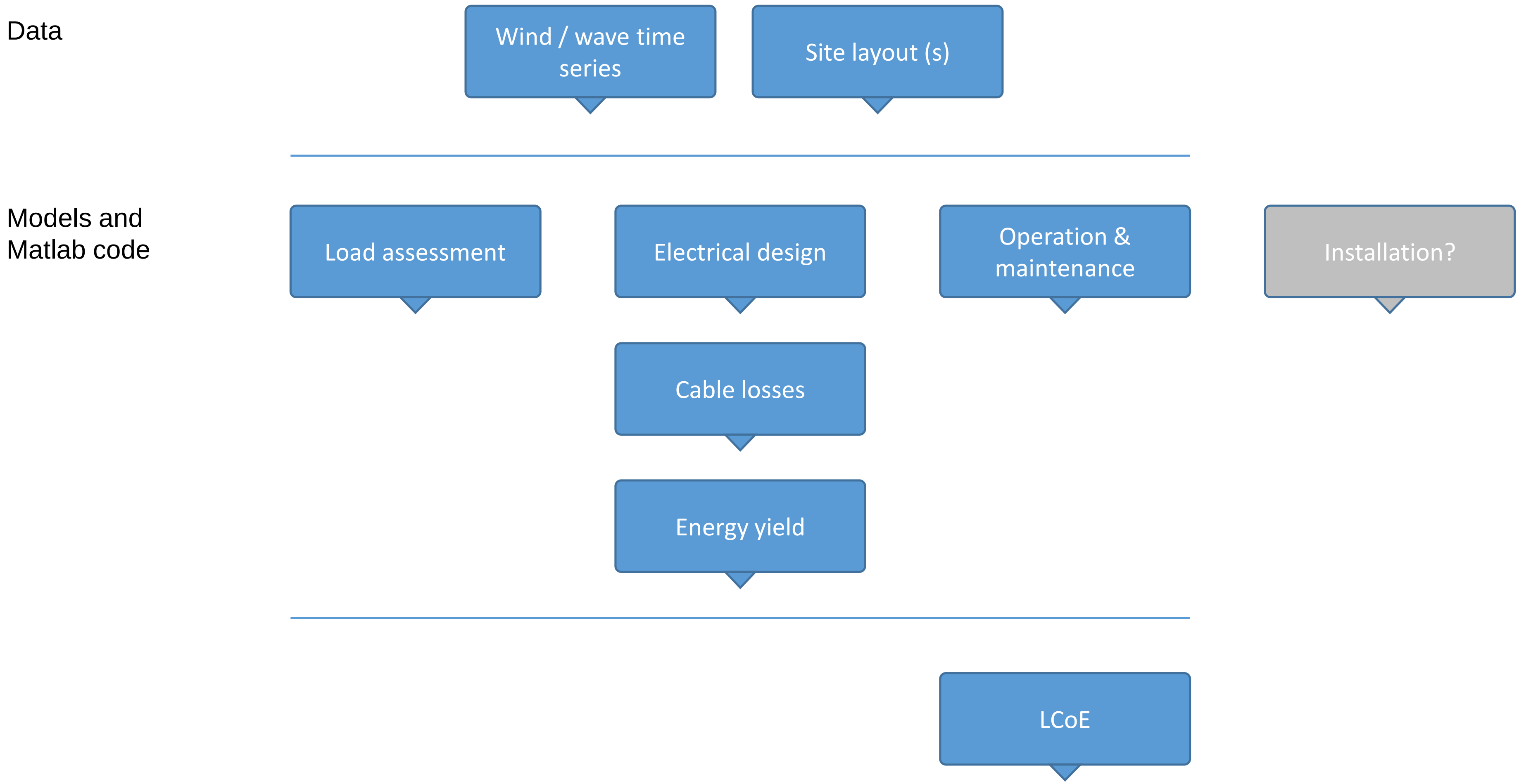
- It has the same number of installations (82), within the same square area (a factor, 4105, times the rotor area).
- It is a symmetric arrangement of installations about the centroid of its enclosed area, a set of five rows aligned normally to the direction from which most power is available (the direction of the prevailing wind).
- Installation spacing along the minor axis (in the prevailing wind direction) is 8 rotor diameters, spacing along the major axis 6.7 rotor diameters.
- Spacings are thus very close to the corresponding values in the curvilinear case.

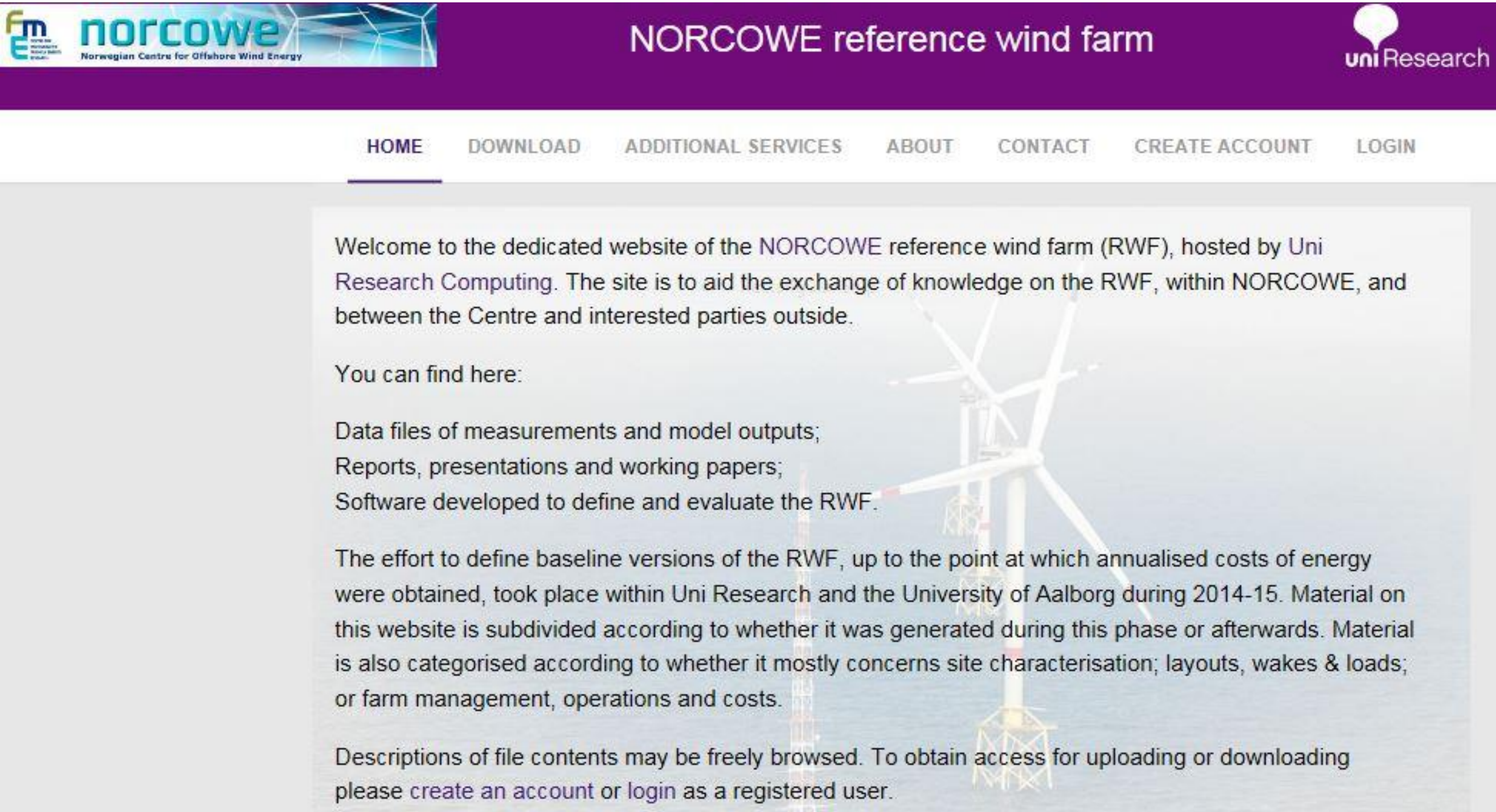


Use of the reference wind farm



Overview, models and data





Welcome to the dedicated website of the NORCOWE reference wind farm (RWF), hosted by Uni Research Computing. The site is to aid the exchange of knowledge on the RWF, within NORCOWE, and between the Centre and interested parties outside.

You can find here:

Data files of measurements and model outputs;
Reports, presentations and working papers;
Software developed to define and evaluate the RWF.

The effort to define baseline versions of the RWF, up to the point at which annualised costs of energy were obtained, took place within Uni Research and the University of Aalborg during 2014-15. Material on this website is subdivided according to whether it was generated during this phase or afterwards. Material is also categorised according to whether it mostly concerns site characterisation; layouts, wakes & loads; or farm management, operations and costs.

Descriptions of file contents may be freely browsed. To obtain access for uploading or downloading please create an account or login as a registered user.

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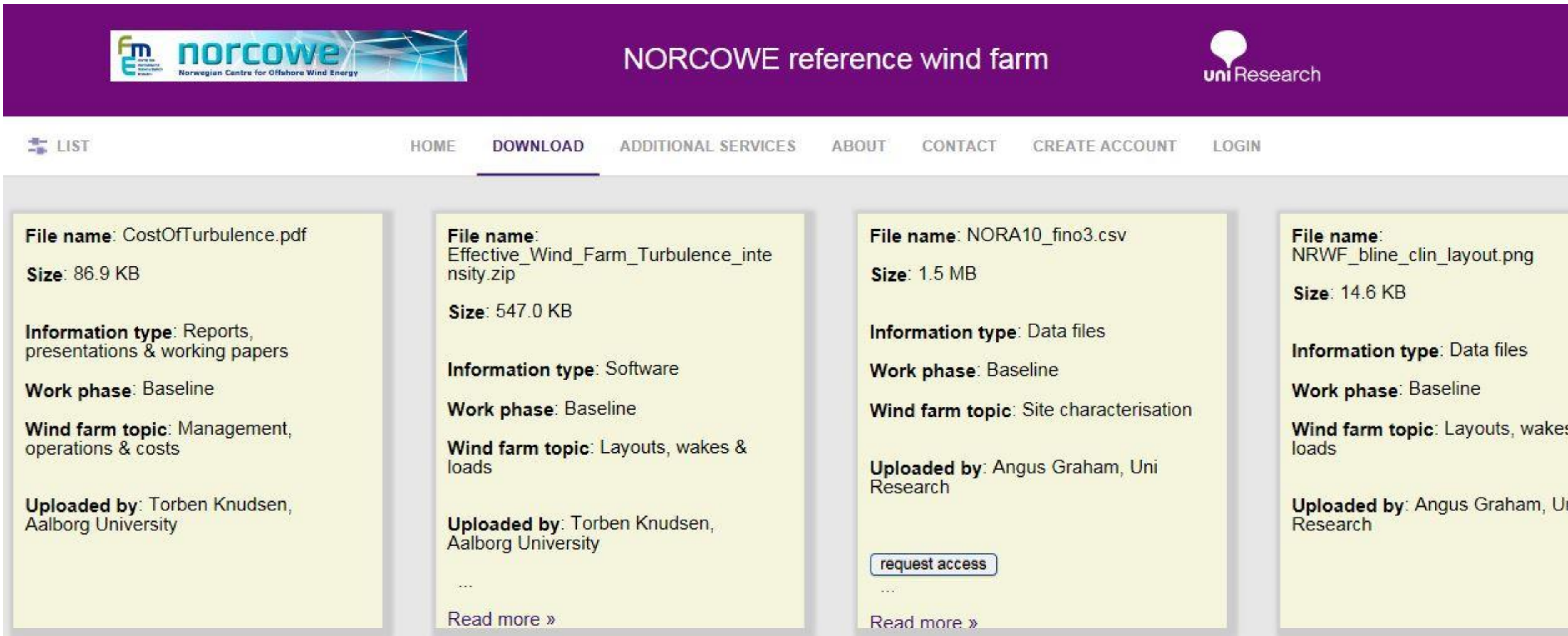
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LIST
HOME
DOWNLOAD
ADDITIONAL SERVICES
ABOUT
CONTACT
CREATE ACCOUNT
LOGIN
File name: CostOfTurbulence.pdf
Size: 86.9 KB
Information type: Reports, presentations & working papers
Work phase: Baseline
Wind farm topic: Management, operations & costs
Uploaded by: Torben Knudsen, Aalborg University
File name: Effective_Wind_Farm_Turbulence_intensity.zip
Size: 547.0 KB
Information type: Software
Work phase: Baseline
Wind farm topic: Layouts, wakes & loads
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File name: NORA10_fino3.csv
Size: 1.5 MB
Information type: Data files
Work phase: Baseline
Wind farm topic: Site characterisation
Uploaded by: Angus Graham, Uni Research
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Wind farm topic: Layouts, wakes
loads
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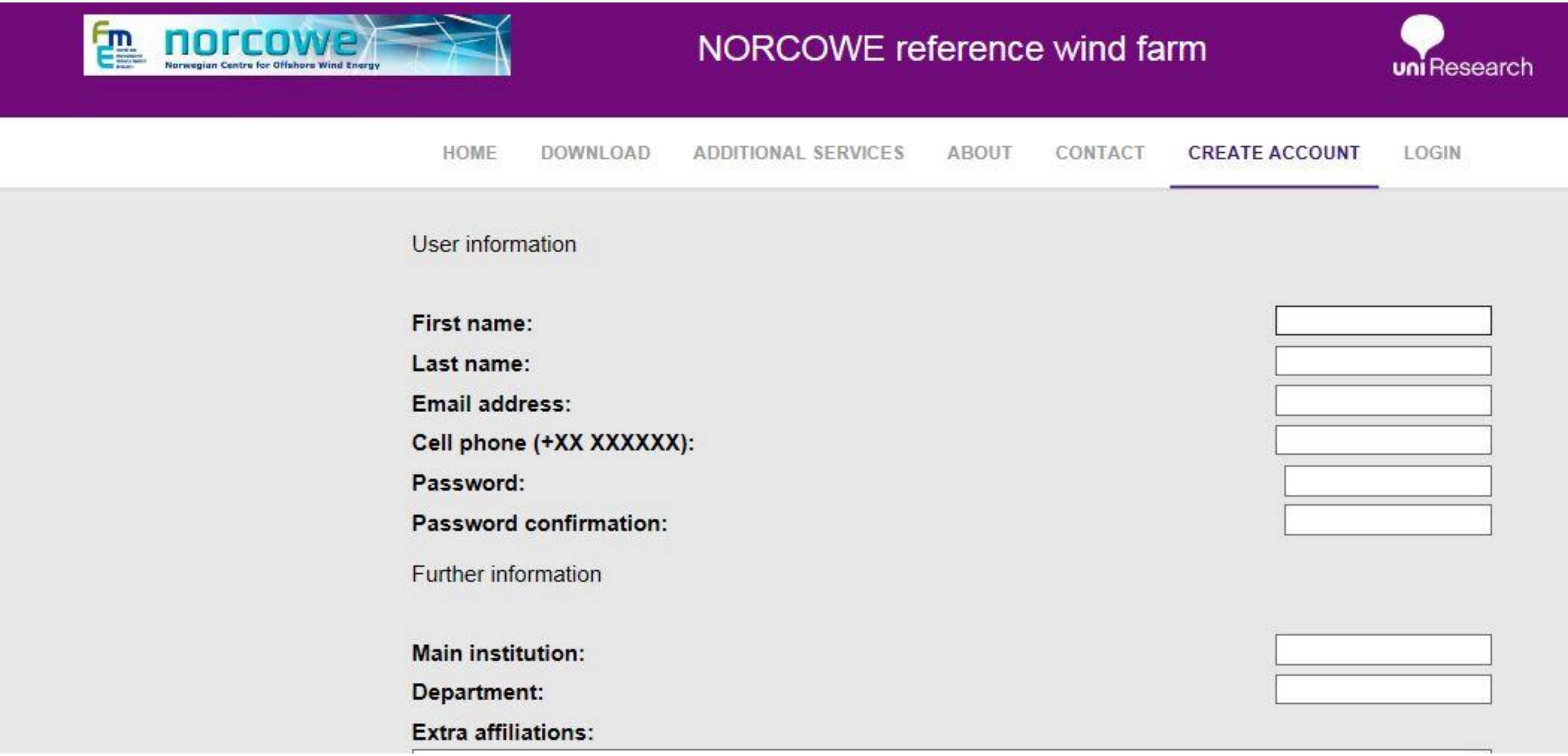
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HOME
DOWNLOAD
ADDITIONAL SERVICES
ABOUT
CONTACT
CREATE ACCOUNT
LOGIN
User information
First name:
Last name:
Email address:
Cell phone (+XX XXXXXX):
Password:
Password confirmation:
Further information
Main institution:
Department:
Extra affiliations:

Operation and Maintenance Strategies for NORCOWE Wind Farm

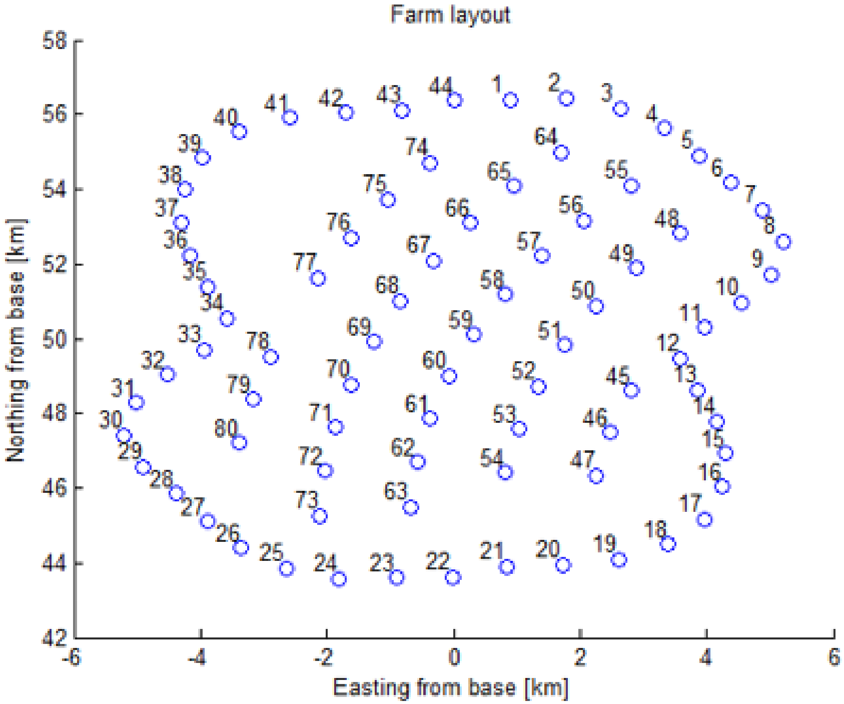
Mihai Florian, Masoud Asgarpour, John Dalsgaard Sørensen
Aalborg University, Denmark

Photo: wallconvert.com

NORCOWE RWF – Baseline O&M model

Weather:

- FINO3 - 3 h wind and wave time series
  - Limiting factor for farm access



Failures:

- Generated from exponential distributions

Simulations:

- 11 years simulation with 3h resolution – 20 year design lifetime

NORCOWE RWF – Baseline O&M model

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Corrective maintenance policy based partly on *

Failures in 3 categories and regular annual service :

	Minor Repair	Major Repair	Major Replacement	Annual Service
Frequency	6	1	0.1	1
Vessel	Crew transfer vessel	Crew transfer vessel	Heavy lift vessel	Heavy lift vessel
No. Technicians	3	3	6	3
Duration	6 [h]	18 [h]	48 [h]	35 [h]
Cost	61.200 [€]	530.000 [€]	3.000.000 [€]	140.000 [€]

- Spare parts available in stock
- 24 hired technicians working 12 h shifts a day
- Major replacements carried out in two 12 h shifts
- Failures lead to turbine shutdown
- Annual service carried out at start of each June

* Iain Dinwoodie, Ole-Erik V. Endrerud, Matthias Hofmann, Rebecca Martin, Iver Bakken Sperstad. 2014. ''Reference cases for verification of offshore operation and maintenance simulation models for offshore wind farms''.

NORCOWE RWF – Baseline O&M model

- 2 hired work boats (CTVs)
- HLV chartered for major replacements

	Crew Transfer Vessel (CTV)	Heavy-Lift Vessel (HLV)
Number	2	1
Limiting weather criteria	Wave	Wind / Wave
	1.5 [m]	20 [m/s] / 2[m]
Mobilisation time	0	40 [days]
Mobilisation cost	0	680.000 [€]
Speed	20 [knots]	11 [knots]
Technician capacity	12	100
Day rate	3200 [€]	320000 [€]
Maximum offshore time	1 shift	Unlimited

NORCOWE RWF – LCoE – preliminary results

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O&M cost	Availability
0.020 [€/kWh]	90.01[%]

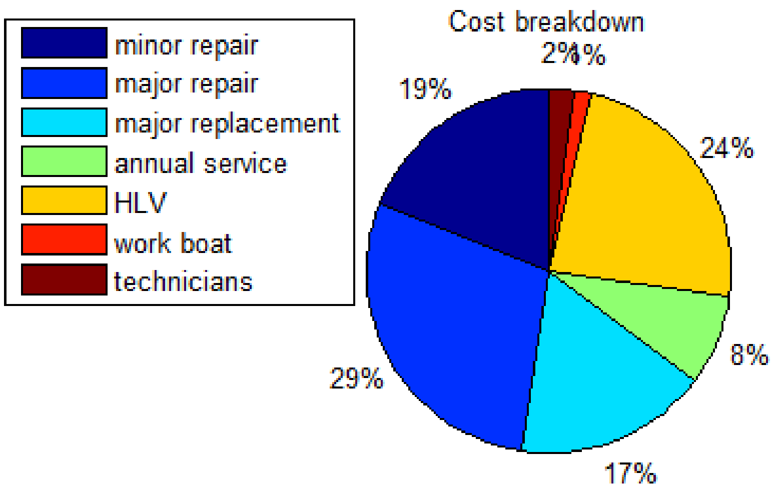
Table 2.4.1: O&M cost and availability

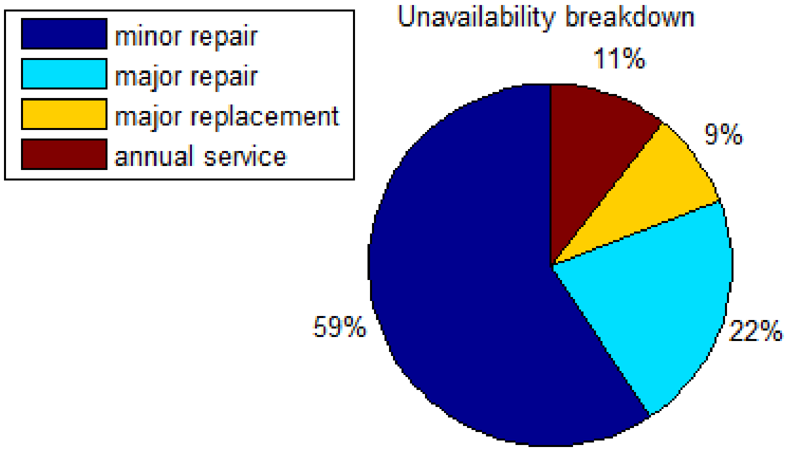
Cost of Energy:

Component	Value
Turnkey	3300 [€/kW]
OPEX	0.022 [€/kW]
AEP	3981.3 [GWh]
r_c	8 [%]
r_p	6 [%]
T	20 [years]

Table 3: LCoE input

LCoE = 0.098 [€/kWh]





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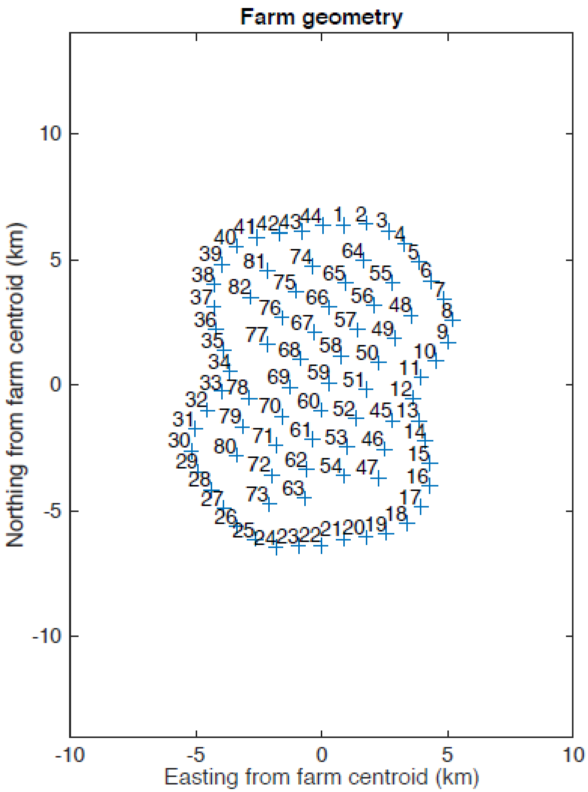
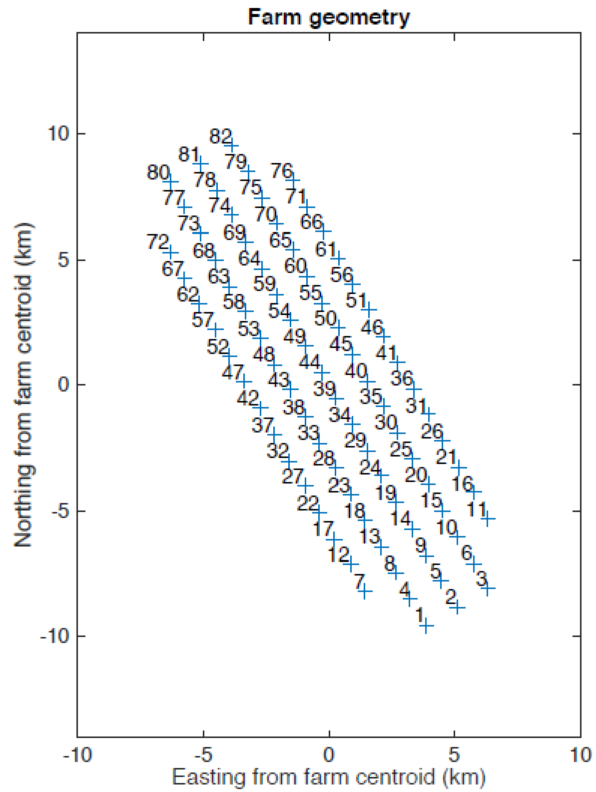
NORCOWE RWF – alternative Rectilinear layout





- slight difference in availability from vessel access – 0.2%

Results:

Layout	Annual O&M cost	Availability
Curvilinear	1.0564 10^8 [€]	90.01[%]
Rectilinear	1.0553 10^8 [€]	90.21[%]

Table 2.4.1: O&M cost and availability

NORCOWE RWF – Blade O&M

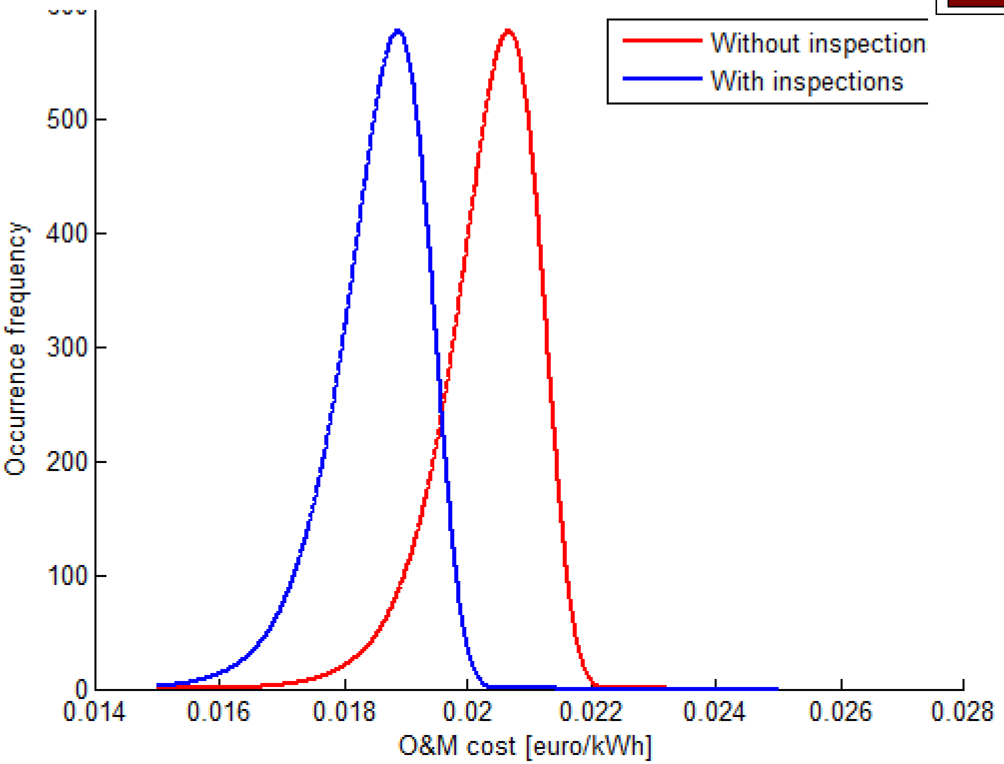
- Maintenance strategies:
  - Corrective maintenance
  - Preventive maintenance – incl. inspections

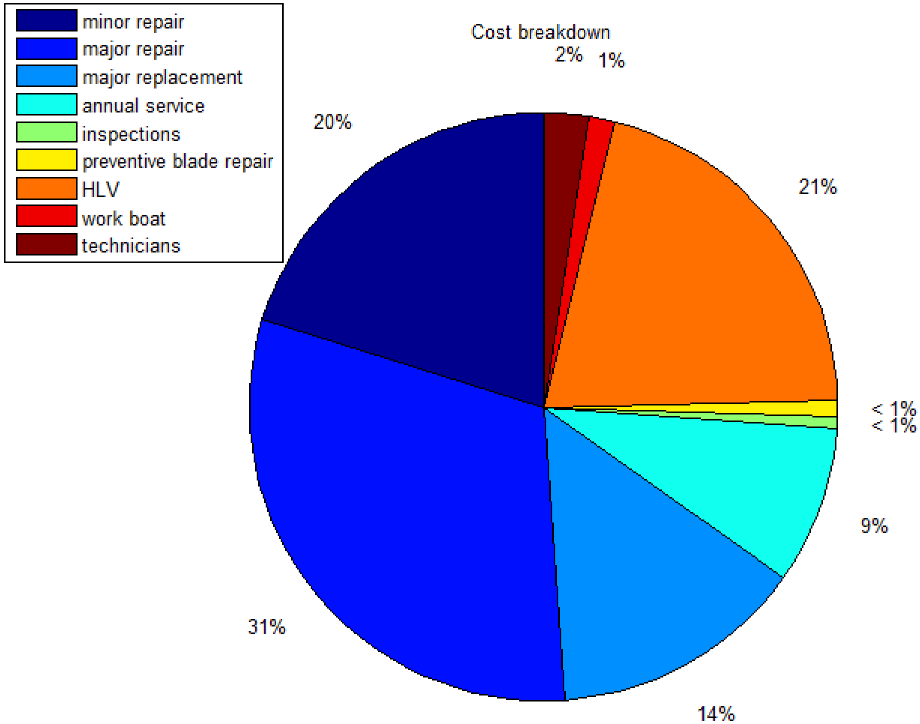
- Damage model
  - Example: bondline failures
  - Calibrated to observed failure rates
- Inspection reliability model

Blade O&M model for wind turbine blades
Results

	Without inspections	With inspections
O&M cost [€/kWh]	0.020	0.0188
Availability [%]	90.01	90.45

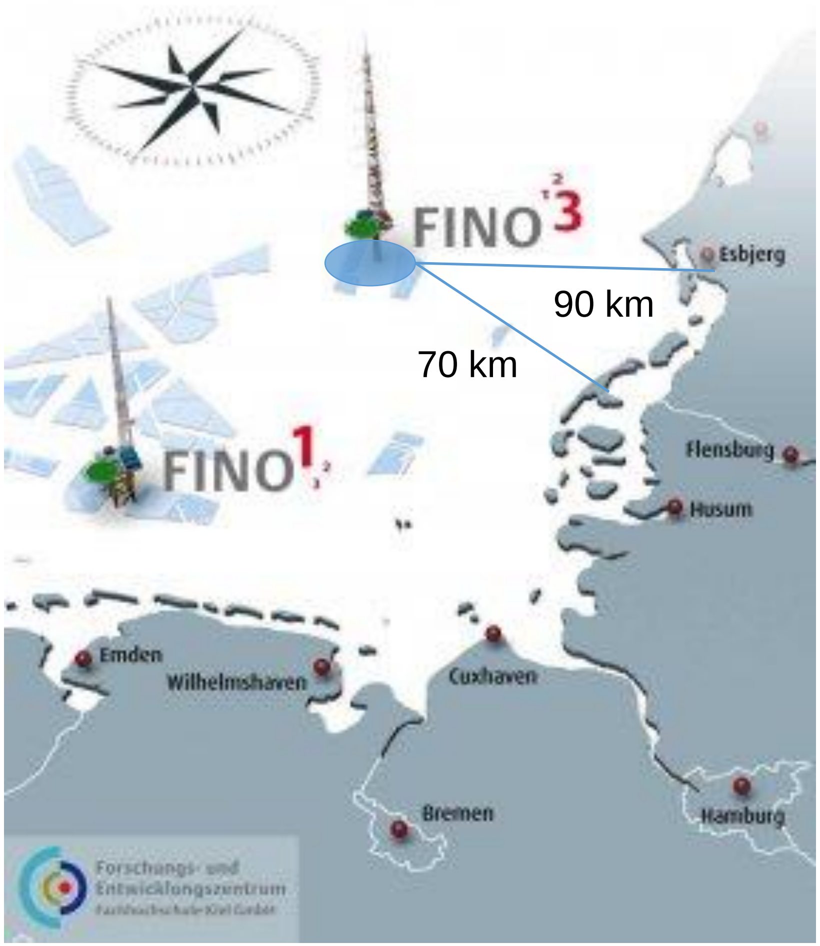
Table 4.1: O&M cost





Key parameters and more information

- Reference zone: FINO3
- Installed capacity: 800 MW
- Number of turbines: 80
- Turbine: DTU 10 MW turbine, rotor* 178m, hub height 119m
- Water depth / foundations is not in the initial focus – 22 meter, monopole
- More information
  - NORCOWE 2014 annual report
  - Science meets industry (SMI) Bergen 2015
  - https://rwf.computing.uni.no/



Upcoming NORCOWE events

- Science meets industry , Stavanger 6th April
  - At the conference the main focus areas will be turbulence and Hywind Scotland, with presentations from the University of Stavanger, Statkraft, Statoil and MacGregor. In addition we will have two presentations regarding decision support software, including the award winning Endrerud who started the company Shoreline in 2014. The conference is free of charge.
- NORCOWE 2016, Bergen 14-15 September
  - The conference will take place in Bergen on September 14-15, 2016. The first day of the conference aims to showcase the highlights of NORCOWE's research and to look at the impact of the FME centre. Day two will delve more into technical details, with two parallel sessions exploring themes like turbulence, wind farm layout and operation and maintenance. Poster sessions will take place on both days. The concluding conference is free of charge and open to the public.
  - On Friday September 16 NORCOWE organizes a trip to visit Midtfjellet wind farm and the ship yard Fjellstrand.