Design tool for offshore wind farm cluster planning

Hasager, Charlotte Bay; Giebel, Gregor; Hansen, Kurt Schaldemose; Madsen, Peter Hauge; Schepers, Gerard; Cantero, Elena; Waldl, Igor; Anaya-Lara, Olimpo

Publication date:
2015

Document Version
Peer reviewed version

Link back to DTU Orbit

Citation (APA):
Design tool for offshore wind farm cluster planning

Charlotte Hasager (1) Gregor Giebel (1) Kurt S. Hansen (1) Peter Hauge Madsen (1) Gerard Schepers (2) Elena Cantero (3) Igor Waldl (4) Olimpo Anaya-Lara (5) (1) DTU Roskilde Denmark (2) ECN Petten The Netherlands (3) CENER Pamplona Spain (4) Overspeed Oldenburg Germany (5) University of Strathclyde Glasgow United Kingdom
Our proceedings paper

Design tool for offshore wind farm cluster planning


(1) DTU Wind Energy, Roskilde, Denmark, cbha@dtu.dk, phone +45 21327328, (2) ECN, Petten, The Netherlands, (3) CENER, Sarriuguren Spain, (4) Overspeed, Oldenburg, Germany, (5) University of Strathclyde, Glasgow, UK (6) SINTEF Energy Research, Trondheim, Norway, (7) CIEMAT, Madrid, Spain, (8) University of Porto, Porto, Portugal, (9) IWES Fraunhofer, Bremerhaven, Germany, (10) FORWIND, University of Oldenburg, Oldenburg, Germany, (11) University of Cornell, Ithaca, NY, USA, (12) CRES, Athens, Greece, (13) CLS, Plouzane, France, (14) NTUA, Athens, Greece
Project partners
A robust, efficient, easy to use and flexible tool created to facilitate the optimised design of individual and clusters of offshore wind farms.
Streamlining project planning of offshore wind farms

Even though offshore wind farms are incredibly expensive—and a great deal of time is devoted to planning them—communication between project developers leaves a lot to be desired. Simply put: one expert often has little idea what another is doing, and this costs a lot of time and money. However, this situation may soon be history thanks to a new tool developed by DTU Wind Energy in Roskilde.

http://www.dtu.dk/english/News/2015/04/Offshore-wind-farms-to-be-developed-with-a-single-model?id=c3435bfd-ef12-42cf-8f39-fd5fa8e948c8
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
Concept and implementation

Meteorological data / Cluster layout / Turbine data

Grid data

Wake models

Grid models

Yield models

System services

Energy yield

Optimised Cluster Design

DTOC Tool

GIS

LCOE

uncertainty

FUGA

WAsP

WRF

WRF/ROMS

CorWind

DTOC Services

eefarm

FarmFlow

WCMS

Net-op

SKIRON

VENTOS
DTOC Design Tool Structure Overview

**DTOC Server**
- DTC core/server
- Parameter Management
  - WASP
    - Para 1: 0.5
    - Para 2: 0.434
  - FarmFlow
    - Para 1: 2.345
  - LCOE
    - Para 1: 9.5
    - Para 2: 3.1416

- Data Persistence
- CMD line interface/API

**Remote Servers**
- CorWind
- SOAP Connector
- WRF
- SOAP Connector
- etc

**Local Computer**

**Reporting**

**DTOC Wrapper**
- Connector
  - WASP/Park
  - FarmFlow
- Connector
  - LCOE Uncertainty
  - LCOE
- Connector
  - Electrical Iissues
  - etc

**GIS**

**Remote Connector**
Local computer: GIS and local web browser
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?
Validation of wake models

SCADA data at Horns Rev 1, Lillgrund and Rødsand 2 offshore wind farms have been compared to more than 10 wake models.

SCADA data and lidar data at Alpha ventus have been compared to three wake models.

Satellite data have been compared to four wake models.

The benchmark concludes that several models were able to handle the clustering of wind farms.
Lillgrund offshore wind farm (D=92.6m)
Rødsand-2

Offshore wind farm cluster: Rødsand II & Nysted

Reference diameter: D=92.6m

Rødsand II:
90 x SWT-2.3-92.6m

Nysted:
72 x Bonus-2.3-82.4m
## Participants and park models

<table>
<thead>
<tr>
<th>Models</th>
<th>Affiliation</th>
<th>Horns Rev WF</th>
<th>Lillgrund WF</th>
<th>Rødsand II WF</th>
<th>Rødsand II/Nysted WF</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCADA/BA</td>
<td>DTU Wind Energy/K.S.Hansen</td>
<td>X</td>
<td>X</td>
<td>X (x)</td>
<td></td>
</tr>
<tr>
<td>NOJ/BA</td>
<td>DTU Wind Energy/misc</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOJ/GU</td>
<td>DTU Wind Energy/misc</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOJ/BA</td>
<td>DTU Wind Energy/A. Pena</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>WASP/NOJ</td>
<td>Indiana Uni/RB</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCL/BA</td>
<td>DTU Wind Energy/misc</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCL/GU</td>
<td>DTU Wind Energy/misc</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCL(GU)</td>
<td>CENER/J.S.Rodrigo</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FUGA/NOJ</td>
<td>DTU Wind Energy/S. Ott</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>DMW</td>
<td>DTU Wind Energy/TJ.Larsen</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD/RANS</td>
<td>UPORTO/J.L. Palma</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>CRESflowNS</td>
<td>CRES/ J. Prospathopoulos</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>FarmFlow</td>
<td>ECN Wind Energy/J.G Scheepers</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>CFDWake</td>
<td>CENER/B.G. Hevia</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>RANS/f_pC</td>
<td>DTU Wind Energy/P.vd Laan</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ainslie</td>
<td>RES-LTD/T.Young</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WRF/UPM</td>
<td>Ciemat/A.Palomares</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Mesoscale</td>
<td>DTU Wind Energy/P.Volker</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

BA=Bin averaged & GU=Gaussian Uncertainty
Horns Rev park efficiency @ 0 - 360°

HornsRev-Efficiency; wdir=0-360 °; ws=8±0.5 m/s
• First EERA-DTOC benchmark included 11 models, which have been implemented successfully;
• The basic flow cases displayed some sector size dependent differences;
• The park efficiency case demonstrated that the participating models are able to handle a complete wind farm consisting of 80 turbines.
Lillgrund Wind farm - Annual Energy Production ΔAEP; U=9±0.5 m/s; 0 - 360°
Lillgrund benchmark - conclusion

- All models handles 3.3 and 4.3D spacing well;
- All models handles the speed recovery due to ”missing” turbines;
- All models were able to simulate the park efficiency for 0 - 360° inflow;
- The simulated ΔAEP demonstrates a variation of ±3% compared to the measured value;
Rødsand-2 wind farm cluster effect

Offshore wind farm cluster: Rødsand II & Nysted

Model inflow
$U_{\text{hub}}=8$ m/s
$\text{WDIR}=97^\circ$
Cluster effect for U=8 m/s; WD=97 °
Rødsand-2 park efficiency @ 77-118°
Rødsand cluster effect - conclusion

- Quantification of the cluster effect is not possible due to lack of measurements and park asymmetries.
- The benchmark has demonstrated that both size and location of the distinct deficit zone - caused by the Nysted wind farm has been predicted quite well by the models.
- The benchmark concludes that several models were able to handle the clustering of wind farms.
WRF V3.4
ERA Interim
Nests 18 km, 6 km, 2 km
12 m amsl
MYNN
**EWP scheme** applies a grid-cell averaged deceleration to the model's flow equation and additional turbulence is produced by the PBL scheme from the changed vertical shear in horizontal velocity.

Volker, P.J.H., Badger, J., Hahmann, A.N., Ott, S. *Geosci. Model Dev. Discuss.*, 8, 3481–3522, 2015

Velocity deficit with contours in ranges from -1.25 to -0.1 ms\(^{-1}\) over the sea surface only

Patrick Volker
Using Satellite SAR to Characterize the Wind Flow around Offshore Wind Farms

Charlotte Bay Hasager 1,*, Pauline Vincent 2,†, Jake Badger 1,†, Merete Badger 1,†, Alessandro Di Bella 1,†, Alfredo Peña 1,†, Romain Husson 2,† and Patrick J. H. Volker 1,†

1 Technical University of Denmark, Wind Energy Department, Frederiksborgvej 399, Roskilde 4000, Denmark; E-Mails: jaba@dtu.dk (J.B.); mebc@dtu.dk (M.B.); adia@dtu.dk (A.D.B.); aldi@dtu.dk (A.P.); pvol@dtu.dk (P.J.H.V.)
2 Collecte Localisation Satellites, Avenue La Pérouse, Bâtiment le Ponant, Plouzané 29280, France; E-Mails: pvvincent@cls.fr (P.V.); romain.husson@cls.fr (R.H.)
Welcome to Wind & Economy

One of the most challenging tasks for wind farm developers is the optimisation of offshore wind power plants. Our new software tool, Wind & Economy, supports your challenging work with the seamlessly integrated modelling of wind climate, large scale and localized wind farm effects, electrical loss calculations and derivation of economic key figures.

http://wind-and-economy.com/home/
Wind & Economoy: The tool for wind farm optimization

- wind climate
- turbine type selection
- turbine spacing and placing

- interaction between wind farms in clusters with respect to energy production

- LCOE and economic uncertainty

- Scenario approach
- GIS integration

Bringing leading edge modelling to your desktop
Conclusion

The main project output, the ‘Wind & Economy’ software, provides a new frame for planning offshore wind farm clusters.

By seamless integration of state-of-the-art models from the scientific development by the EERA members, which have been compared and validated by the research community and end-users, provides a significant potential for cost reductions.

The rapid development of offshore wind farms in the Northern European Seas with major clusters planned in many countries makes the release of this novel tool available with due diligence.
We aim at developing the tool for strategic planners

1) Add environmental aspects and restricted zones
2) Add sea bed and estimate foundation costs
3) Improved cost of energy and O&M module
4) Further detail wind farm cluster effects
5) Include social acceptance

DTU has submitted EUDP2015 proposal (Danish national activity).
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 (FP7) – and runs from January 2012 to June 2015. It is coordinated by the Technical University of Denmark - DTU Wind Energy.
Support by

This project has received funding from the European Union’s Seventh Programme for research, technological development and demonstration under grant agreement No FP7-ENERGY-2011-1/ n° 282797

Acknowledgements:
Funding: EERA DTOC FP7 and partners
SCADA data: DONG energy, Vattenfall, E.On, RAVE
Radarsat image: MacDonald, Dettwiler and Associates Ltd.
Wake modelling more than 20 participants at many partner institutes