Hvordan kan forskningen bidra til å gjøre havvind konkurransedyktig på pris?

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Takk til
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Joachim Reuder, UiB
John Dalsgaard Sørensen, AAU
Masoud Asgarpour, AAU
for bidrag
What is the our key challenge?

- Levelized cost of electricity (LCOE):

\[
LCOE = \frac{\sum_{t=1}^{n} I_t + M_t}{\sum_{t=1}^{n} (1+r)^t} \frac{E_t}{\sum_{t=1}^{n} (1+r)^t}
\]

- Year number
- n: Lifetime of project (years)
- \(I_t\): Investments
- \(M_t\): O&M costs
- \(E_t\): Energy produced
- \(r\): Discount rate

What are the most important terms?
Illustration of sensitivities

- Base case:
  - $I_1 = 32\,000\,\text{kr/kW}$
  - $I_n = 3\,200\,\text{kr/kW}$
  - $M_t = 0.16\,\text{kr/kWh}$
  - $r = 8\%$
  - $N = 20$
  - Cap factor: 0.4
  - LCOE = 1.04 kr/kWh
Improve production. An effort across scales and disciplines.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Time</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesoscale</td>
<td>Days - Hours</td>
<td>10000 - 10 km</td>
</tr>
<tr>
<td>Park scale</td>
<td>20 min - 20 sec</td>
<td>10 - 1 km</td>
</tr>
<tr>
<td>Rotor scale</td>
<td>10 - 2 sec</td>
<td>200 - 50m</td>
</tr>
<tr>
<td>Blade scale</td>
<td>0.5 - 0.01 sec</td>
<td>5 - .5m</td>
</tr>
</tbody>
</table>

Factor $O(20 \times E06)$ on time and length scale
Met-ocean conditions important over wind farm life cycle

MABL (Marine Atmospheric Boundary Layer)
- planning phase: wind resource assessment; design criteria for structural loads (e.g. occurrence of extreme winds)
- construction phase: weather windows favorable for marine operations (e.g. heavy lift operations)
- operation phase:
  - actual flow conditions (wind speed, turbulence intensity)
  - accessibility for O&M

OML (Oceanic mixed layer)
- planning phase: design criteria for structural loads and excitation of movements (e.g. extreme waves)
- construction and operation phase: max. wave height for marine operations and WT accessibility; static and dynamic loads by currents, waves and wave breaking
NORCOWE campaign - WINTWEX-W wakes behind a turbine

Wind speed

Turbulence intensity

Instantaneous

10 min avg.

Geofysisk Institutt.

J. Reuder, Geophysical Institute, University of Bergen

NORCOWE campaigns – OBLEX-F1

FINO1, German Bight, May 2015 – September 2016 (atmospheric part); May 2015 – October 2015 (oceanic part)
OBLO infrastructure
OBLO (Offshore Boundary Layer Observatory) (http://oblo.uib.no/)
NFR infrastructure project, funded with ca. 4 M€
advanced mobile met ocean instrumentation for flexible deployments
The reference wind farm – a platform for testing tools

- Optimum Wind farm design and operation
- Rules for farm design and operation
- Site wind and wave climatologies
- Levelised cost of energy
Baseline O&M Model

Corrective maintenance policy based partly on *
Failures in 3 categories and regular annual service:

<table>
<thead>
<tr>
<th></th>
<th>Minor Repair</th>
<th>Major Repair</th>
<th>Major Replacement</th>
<th>Annual Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>6</td>
<td>1</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Vessel</td>
<td>Crew transfer</td>
<td>Crew transfer</td>
<td>Heavy lift vessel</td>
<td>Heavy lift vessel</td>
</tr>
<tr>
<td></td>
<td>vessel</td>
<td>vessel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. Technicians</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Duration</td>
<td>6 [h]</td>
<td>18 [h]</td>
<td>48 [h]</td>
<td>35 [h]</td>
</tr>
<tr>
<td>Cost</td>
<td>61,200 [€]</td>
<td>530,000 [€]</td>
<td>3,000,000 [€]</td>
<td>140,000 [€]</td>
</tr>
</tbody>
</table>

*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”.*

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

NOrRCOWE WP meeting, Stavenger, 6-8 May 2015
Baseline O&M Model

2 hired work boats
HLV chartered for major replacements

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

Table 2: Vessel input
Baseline O&M Results

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnkey</td>
<td>3300 [€/kW]</td>
</tr>
<tr>
<td>OPEX</td>
<td>0.022 [€/kW]</td>
</tr>
<tr>
<td>AEP</td>
<td>3981.3 [GWh]</td>
</tr>
<tr>
<td>(r_c)</td>
<td>8 [%]</td>
</tr>
<tr>
<td>(r_p)</td>
<td>6 [%]</td>
</tr>
<tr>
<td>(T)</td>
<td>20 [years]</td>
</tr>
</tbody>
</table>

Table 3: LCoE input

\[
LCoE = \frac{\text{Turnkey} + \frac{1 - (1 + r_c)^{-T}}{r_c} \cdot \text{OPEX}}{\frac{1 - (1 + r_p)^{-T}}{r_p} \cdot \text{AEP} \cdot \text{availability}}
\]

\[LCoE = 0.098 \, [\text{€/kWh}]\]
## Calendar

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.02.2017 12:00–13:00</td>
<td>Finn Gunnar Nielsen: Wave Energy - The basic principles</td>
<td>12:00–13:00</td>
<td>Auditorium 5, Realfagsbygget</td>
</tr>
<tr>
<td>21 FEB</td>
<td>Ignacio Herrera Anchustegui: Role of the state in implementing renewable energy in public procurement (Presentation)</td>
<td>12:00–12:30</td>
<td>Auditorium 5, Realfagsbygget</td>
</tr>
<tr>
<td>21 FEB</td>
<td>Finn Gunnar Nielsen: Electrification of Norwegian cars with offshore wind (Presentation)</td>
<td>12:30–13:00</td>
<td>Auditorium 5, Realfagsbygget</td>
</tr>
<tr>
<td>28 FEB</td>
<td>John Carter: Designing a course on Wave Energy (Presentation)</td>
<td>12:00–13:00</td>
<td></td>
</tr>
<tr>
<td>09 MAR</td>
<td>Emerging technologies and their impact on the society (Seminar)</td>
<td>09:15–14:00</td>
<td>Auditorium 2, Faculty of Law, Magnus Lagabøtes plass 1</td>
</tr>
</tbody>
</table>
SMI Stavanger
The yearly conference Science Meets Industry Stavanger will take place on March 29th
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