What have we learned and what needs to be done?

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What have we learned and what needs to be done?

Niels G Mortensen, Morten Nielsen and Hans E Jørgensen

EWEA 2015
Paris, France
Comparison of Resource and Energy Yield Assessment Procedures

**EWEA CREYAP concept**
- Industry benchmarking
- In-house training and R&D
- Identification of R&D issues

**Issues for today**
- Review of the 4 CREYAP exercises
  - Methodologies
  - Magnitudes and uncertainties
  - Modelled vs observed yields
- Mostly conclusions presented here
  - Keep in mind the limited data set
  - Prioritised list of actions
  - Reference list in handout

**CREYAP history**
- Onshore Part 1, Bruxelles 2011
  - Scotland W, 14 × 2 MW (28 MW)
- Onshore Part 2, Dublin 2013
  - Scotland E, 22 × 1.3 MW (29 MW)
- Offshore Part 1, Frankfurt 2013
  - Gwynt y Môr, 160 × 3.6 (576 MW)
- Offshore Part 2, Helsinki 2015
  - Barrow, 30 × 3 MW (90 MW)

**Summary**
- 157 submissions from 27 countries
  - 97 for onshore
  - 60 for offshore
The CREYAP wind farms

Hilly/complex
Scotland W
14 turbines
28 MW

Hilly/complex
Scotland E
22 turbines
29 MW

Barrow
Irish Sea
30 turbines
90 MW

Gwynt y Môr
Irish Sea
160 turbines
576 MW

• Estimated wind turbine yields
  (local color scales from $P_{\text{min}}$ to $P_{\text{max}}$)
Methodology and limitations

- Open exercises, no team requirements
  - Results may not reflect industry
- Blind test with independent evaluation
  - Team identities unknown to evaluator
  - Peer review of evaluations
- Results based on group statistics
  - Limited data in forms and groups
  - Statistics sensitive to outliers
  - Non-parametric and normal stat’s

Definitions
- Bias ≡ difference between average of estimates and observations (mean)
- Uncertainty ≡ standard deviation (spread) of distribution of estimates.

N teams make predictions for one wind farm
Input data are identical; methods different
Mean and spread compared for each step
1 Long-term extrapolation

- LT extrapolation effects small and uncertain
  0 to 1.8% on average (onshore)
  -2.2 to 0.2% on average (offshore)
- Methodologies used
  - Not well defined at all
- Uncertainty
  80 to 280% (CV)
- Special issues
  5-13% outliers
- CREYAP results
  - Difficult analysis of ill-defined methods
  - Inconclusive results.
2 Vertical extrapolation

- Vertical extrapolations not so challenging
  - Mast height/hub height = 0.83-1.07
  - Profile effects less than 3% on $U$
- Methodologies used (onshore)
  - Shearing-up by ½ of the teams
  - Flow modelling by ½ of the teams
- Uncertainty (CV)
  - 10-22% on mean shear exponent
  - 0.7-3.6% on observed wind speed
- Special issues
  - 7-11% outliers on exponent value
- CREYAP results
  - Inconclusive, but a bit scary!
  - Challenging case study needed.
3 Horizontal extrapolation

- Model results not significantly different, e.g. linearized and CFD-type flow models
- Magnitude of effect (onshore only)
  - Extrapolation: +3.2 and −8.7% of yield
  - Topographical: 22 to 23% of yield
- Methodologies used
  - Flow modelling only; many different
  - Model name and specification important
- Uncertainty
  - Spread on extrapolation high: 59-132%
- Special issues
  - Few (0-2%) outliers
- Additional results
  - Model results ranges too narrow.
Wake modelling

- Wake models disagree inside wind farms: uncertainty (CV) $\propto$ WTG wake loss
- Wakes represent a significant wind farm loss
  - Onshore: 6-10%
  - Offshore: 8-14%
- Modelled with a separate wake model
  - Model name and specification important
  - Model configuration must be known too!
- WF wake modelling uncertainty (CV)
  - Onshore: 13-18%
  - Offshore: 16-22%
  - Uncertainty $\propto$ WF wake loss
- Classic models seem to provide realistic results for Barrow Offshore Wind Farm
5 Technical losses estimation

- Technical losses large and uncertain
  8-9.2% on average (onshore)
- Methodologies used
  - Not well defined at all
- Uncertainty
  - 32-34% coefficient of variation
- Special issues
  - 2-3% outliers
- Additional results
  - Calculation procedure sometimes wrong: losses added, not factored together.
## 6 Uncertainty estimation and calculation

<table>
<thead>
<tr>
<th>Wind farm</th>
<th>Estimated uncertainty</th>
<th>CV</th>
<th>$\sigma_{P50}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore W Hilly/complex</td>
<td>11%</td>
<td>34%</td>
<td>5%</td>
</tr>
<tr>
<td>Onshore E Hilly/complex</td>
<td>8%</td>
<td>28%</td>
<td>6%</td>
</tr>
<tr>
<td>Offshore Gwynt y Môr</td>
<td>10%</td>
<td>29%</td>
<td>7%</td>
</tr>
<tr>
<td>Offshore Barrow</td>
<td>10%</td>
<td>23%</td>
<td>3%</td>
</tr>
</tbody>
</table>

- Uncertainty estimates large and uncertain 8% to 11% on average
- Methodologies used
  - Not well defined at all
- Uncertainty 23% to 34% coefficient of variation
- Special issues
  - About ¼ of the teams make errors when calculating $P_{90}$ from $P_{50}$ and uncertainty
- Additional results
  - Spread of estimates < estimated spread.
Predicted vs observed AEP

- Only Barrow provided AEP comparison
  - Estimated = 104% of observed $P_{50}$
  - Spread ~ 3% for net yield
  - Measured yield has an uncertainty too
- Methodologies used
  - No simple relation between methodology and how well teams perform.
- Uncertainty
  - Nice bell-shaped distribution
  - Uncertainty (CV) ~ 3%
- Special issues
  - No or fewer outliers in Barrow study
- CREYAP results
  - Results seem to improve over time.
What needs to be done?

1. Calculation, documentation and reporting
   - Robust, unambiguous framework
2. Long-term extrapolation methods
   - Well-defined and proven (NWA)
3. Uncertainty estimation and calculation
   - Framework, methodology and tools
4. Wake modelling (especially offshore)
   - Best practice based on validation data
5. Systematic technical losses estimation
   - Methodology and tools
6. Flow modelling
   - Vertical + horizontal extrapolation = flow modelling
   - Best practice based on validation data

- Future CREYAP exercises 2016-2020
  - Very steep or forested terrain
  - Tall turbines, challenging climatology, ...
  - Wind conditions and site suitability

- So, the final word (as always) is...
  - High-quality wind farm data are in high demand for future studies and research!
Thank you for your attention!

Contributions by RES, Dong Energy, Iberdrola, Crown Estate, EWEA and all the teams are gratefully acknowledged!
CREYAP references

Land-based wind farms


Offshore wind farms


Dissemination

More than 1500 CREYAP publication downloads from DTU’s web site since 2011: more than $\times 10$ the number of submissions.
## Score for the different steps – low is more important

<table>
<thead>
<tr>
<th>Step</th>
<th>Scotland West</th>
<th>Scotland East</th>
<th>Onshore</th>
<th>Gwynt y Môr</th>
<th>Barrow OWF</th>
<th>Offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term extrapolation</td>
<td>11</td>
<td>9</td>
<td>10 (1)</td>
<td>16</td>
<td>8</td>
<td>12 (3)</td>
</tr>
<tr>
<td>Vertical extrapolation</td>
<td>18</td>
<td>20</td>
<td>19 (6)</td>
<td>n/a</td>
<td>12</td>
<td>12 (4)</td>
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<tr>
<td>Horizontal extrapolation</td>
<td>14</td>
<td>12</td>
<td>13 (3)</td>
<td>16</td>
<td>18</td>
<td>17 (6)</td>
</tr>
<tr>
<td>Wake modelling</td>
<td>18</td>
<td>13</td>
<td>16 (5)</td>
<td>5</td>
<td>11</td>
<td>8 (2)</td>
</tr>
<tr>
<td>Technical losses</td>
<td>12</td>
<td>14</td>
<td>13 (2)</td>
<td>12</td>
<td>19</td>
<td>16 (5)</td>
</tr>
<tr>
<td>Uncertainty estimation</td>
<td>11</td>
<td>16</td>
<td>14 (4)</td>
<td>10</td>
<td>6</td>
<td>8 (1)</td>
</tr>
</tbody>
</table>
What needs to be done?

**Land-based**

1. Long-term extrapolation methods
2. Systematic technical losses estimation
3. Horizontal extrapolation
4. Uncertainty estimation and calculation
5. Wake modelling
6. Vertical extrapolation

**Offshore**

1. Uncertainty estimation and calculation
2. Wake modelling
3. Long-term extrapolation methods
4. Systematic technical losses estimation
5. Vertical extrapolation
6. Horizontal extrapolation